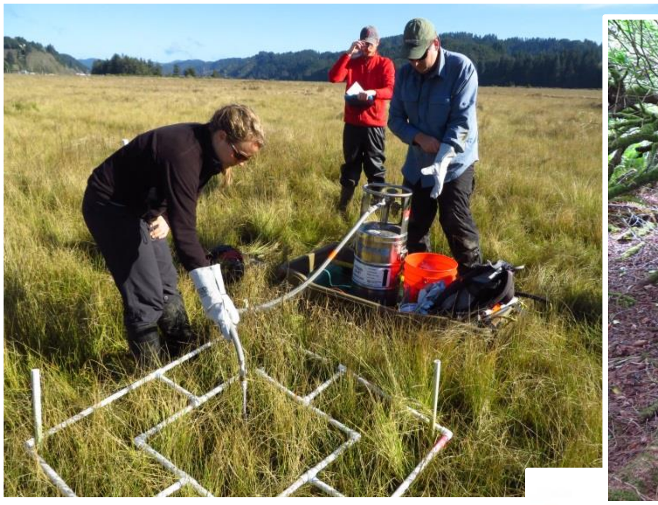
Waite Ranch Baseline Effectiveness Monitoring: 2014



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Prepared for:
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Data availability: Data from this project are available from the lead author listed above.

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- We thank the U.S. Environmental Protection Agency, Coastal Ecology Branch, Newport, Oregon for its major contribution to this project through the loan of RTK-GPS and cryocore equipment.
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Summary and key findings

During 2013-2014, the Estuary Technical Group (ETG) collected and analyzed baseline (pre-restoration) effectiveness monitoring data at Waite Ranch and two least-disturbed tidal wetland reference sites. The two reference sites were Cox Island (site S11 in Brophy 2005), and site S30 (a small undiked portion of Duncan Island due east of Waite Ranch, also described in Brophy 2005). The work was a continuation of earlier baseline monitoring conducted in 2010 (Brophy and Lemmer 2013). The overall monitoring plan was developed and implemented by ETG to support restoration design, interpretation of restoration effectiveness, and adaptive management at Waite Ranch. Field data collected in 2014 included the following:

Wetland vegetation monitoring metrics:

- Percent composition of herbaceous vegetation in emergent wetlands, using quadrat and transect methods (10 transects at Waite Ranch, 3 transects at Cox Island, and 2 transects at S30)
- Stem density of shrubs and trees, and DBH of trees, in forested tidal wetland ("tidal swamp") transects (1 at Cox Island, 1 at S30)
- Basal area of trees in tidal swamp transects (derived from DBH)
- High-accuracy (RTK-GPS) elevations of vegetation monitoring transects

Sediment accretion monitoring metrics:

- Depth of sediment accreted during one year (Nov. 2013 - Nov. 2014), using a feldspar marker horizon method, at 8 locations on reference sites, and 12 locations on Waite Ranch
- Sediment accretion/erosion during one year (Nov. 2013 – Nov. 2014), using a sediment stake method, with stakes located adjacent to each feldspar marker horizon plot
- High-accuracy (RTK-GPS) elevations of accretion plots

Reference channel morphology monitoring metrics (Cox Island and S30 sites):

- Channel profiles (including bank elevations, top of bank slope, channel bottom elevation, and flowpath elevation) at 27 cross-sections at the reference sites (20 at Cox Island, 7 at S30)
- Cross-sections and flowpath elevations at Waite Ranch were obtained from 17 channel cross-sections surveyed by Ward Northwest, Inc.
- Longitudinal gradient (flowpath elevation) for the full length of two channels at S30, and the upper 2/3 of one major channel at Cox Island (the portion that could be accessed on foot).

Key findings

To jump to further details about each key finding, click on the underlined hyperlink.

Key findings for elevation:

- Much of Waite Ranch has subsided about 3 ft (about 1 m) below the wetland's historic elevation; the lowest parts of the site have subsided over 5 ft (1.5 m).

- We used RTK-GPS to measure the wetland surface elevation at the S30 reference site, providing information on the likely pre-disturbance elevation at Waite Ranch. The S30 wetland surface elevation is about 7.5 ft (2.3 m), or about the elevation of Mean Higher High Water (MHHW).

Key findings for emergent wetland vegetation:

- Overall, native species cover, total plant cover and species richness were all significantly lower at Waite Ranch compared to the reference sites; conversely, non-native species cover was significantly higher at Waite Ranch compared to the reference sites.
- Native species were dominant in some of the lower transects at Waite Ranch; higher transects were dominated by non-native pasture grasses.
- Waite Ranch had extensive bare ground in 2014, probably caused by a 2013 tide gate failure that led to inundation by brackish water.
- The native species present at Waite Ranch are unlikely to persist at their current locations (due to the low elevation and future brackish salinity), but they will provide propagules for re-establishment at higher elevations on the site.
- Emergent tidal wetlands at the reference sites were dominated by native plant species typical of Oregon's outer coast tidal marsh.
- A rare plant, Henderson's checkermallow (*Sidalcea hendersonii*) was found at both Cox Island and the S30 reference site. The population at S30 was larger (hundreds of individuals).

Key findings for forested tidal wetland vegetation:

- Forested tidal wetlands at the reference sites were dominated mainly by the brackish-tolerant trees Sitka spruce and Pacific crabapple; other brackish-tolerant tree species were subdominant, including Pacific wax myrtle and cascara. The brackish-tolerant shrub black twinberry was dominant at the Duncan Island site (S30).
- The least-disturbed tidal swamp transect at S30 provided valuable quantitative data on the rare Pacific crabapple swamp that historically occupied Waite Ranch. No previous studies quantifying this tidal swamp association have been conducted on Oregon's outer coast.
- Red alder was dominant within one study plot at Cox Island, but only on the higher (north) side of the study transect, illustrating the strong internal gradient within this narrow band of forested wetland.
- Tree and shrub density and tree basal area at the reference sites fell within ranges observed at the very limited number of tidal swamp sites studied in Oregon and the Pacific Northwest.
- This study's tidal swamp data expand the number of tidal swamp study sites on Oregon's outer coast by about 33%, providing very important data for this and other projects. However, data on

soil characteristics and groundwater regime are needed for comparability to other Oregon tidal swamp datasets (see **Recommendations**).

Key findings for sediment accretion:

- Sediment accretion rates were significantly lower at Waite Ranch when compared to the reference sites.
- At nearby least-disturbed reference sites, sediment accretion rates decreased with increasing elevation.
- Sediment accretion rates at reference sites using the feldspar marker horizon method were comparable to other studies done in the PNW.

Key findings for channel morphology:

- The channel network at Waite Ranch had only about 1/10 the density and much lower sinuosity compared to least-disturbed high marsh.
- Channels at Waite Ranch were shallower and their banks were less steep compared to the reference sites. These effects are likely the result of livestock trampling, machinery operations, sedimentation, subsidence, and other effects of agricultural conversion.
- Channel bottom elevations at Waite Ranch were lower than at reference sites. These ditched channels had to be dug low in order to drain the site, which is low overall due to subsidence (described above).
- Channel gradients were similar at Cox Island and Waite Ranch, which have similar total area, but steeper in the smallest channels at Cox Island and S30.
- Differences in bank slope and width-to-depth ratio between Waite Ranch and reference sites were strongest in small to medium-sized channels.
- At reference sites, channel width, depth, and bank slope were strongly related to tidal elevation of the channel bottom.

Recommendations:

- Post-restoration effectiveness monitoring should use the same methods as the baseline monitoring, to allow comparisons and determination of project effectiveness.
- For comparability to other Oregon data, and to allow accurate interpretation of restoration trajectory, we recommend collecting data on groundwater and soil characteristics at the reference sites' forested tidal wetlands.
- Post-restoration monitoring should add vegetation and accretion plots within the lowest elevation zones at Waite Ranch.
- Because channel size (e.g. width) relates strongly to channel characteristics, it's important to monitor channel morphology at locations spanning the full length of the channel system. Monitoring only near channel mouths may provide very little information on conditions elsewhere in the channel network.

- Woody planting plans (species lists, elevation zones) should reflect likely post-restoration salinities at Waite Ranch. Plans should consider the possibility that post-restoration salinities may vary from adjacent water bodies and reference sites due to differences in channel development and flow patterns.
- New channels at Waite Ranch should be dug relative to a tidal datum (standard best practice for tidal wetland channel design).
- Excavated channel elevation may need to be low to connect to existing ditches. However, excavation of an extensive, deep channel network is not necessary because of the low, subsided wetland surface elevations at the site.

Study sites

We monitored the Waite Ranch site and two least-disturbed tidal wetland reference sites (Cox Island and S30). All are located in the Siuslaw River estuary (Figures 1-7). Site characteristics are summarized in Table 1 and described in detail below.

Table 1. Site descriptions for Waite Ranch and reference sites (Cox Island and S30)

Site	**Waite Ranch**	**Cox Island (S11)**	**S30 (Duncan Island)**
River mile	9 -10	7	9.5
Site type	pre-restoration	reference	reference
Historic wetland type (1850s)*	Pacific crabapple tidal swamp	tidal marsh and Sitka spruce tidal swamp	tidal marsh**
Alterations, impacts	diking, ditching, grazing	tree removal, likely grazing	none, other than possible grazing
Channel condition	ditched	natural, meandering	natural, meandering

* from Hawes *et al.* (2008)

** S30 also contains a small forested tidal wetland area not mapped in Hawes *et al*. 2008, but monitored in 2014

Restoration site

Waite Ranch

Prior to European settlement, Waite Ranch (Figures 2 and 3) was a tidal swamp dominated by Pacific crabapple, with scattered Sitka spruce (Hawes *et al*. 2008, Brophy 2005). In the early 20th century, the 217-acre site was diked and converted to a dairy farm (Brophy and Lemmer 2013). The current landowner, McKenzie River Trust, is working with the Siuslaw Watershed Council and other partners to plan restoration of this site. Restoration will be accomplished through dike and tide gate removal, ditch filling, channel excavation, and other activities (Brophy and Lemmer 2013). For a more detailed history, see the Waite Ranch Interim Management Plan (Brophy and Lemmer 2013).

Waite Ranch has not yet been restored, so all data presented in this report are pre-restoration (baseline) data.

Reference sites

Two least-disturbed reference sites provided examples of pre-disturbance conditions and goals for restoration trajectory at Waite Ranch. Reference sites were selected to represent historic conditions that were probably present at Waite Ranch prior to diking and conversion to agricultural use. Reference site selection was also based on proximity and similar geomorphic setting to Waite Ranch. These similarities will help interpret post-restoration changes at Waite Ranch by providing a "before-after-control-impact" (BACI) statistical framework – optimal for restoration effectiveness monitoring (Stewart-Oaten 1986, 1992).

Cox Island (S11)

Cox Island (Figures 4 and 5) is an undiked emergent tidal wetland owned by The Nature Conservancy and described as one of "Oregon's Greatest Wetlands" by The Wetlands Conservancy (http://www.wetlandconservancy.org/oregons_greatest.html). Vegetation on Cox Island is predominantly low and high marsh. The easternmost portion of the site's high marsh was originally Sitka spruce swamp in the 1850's (Hawes *et al*. 2008), but these trees were likely removed for lumber and to improve grazing (Brophy 2005, 2009). A remnant band of forested tidal wetland is found on the north edge of Cox Island, on the natural levee of the Siuslaw River. Our 2014 monitoring included both the marsh and swamp areas.

Cox Island has populations of the invasive species saltmeadow cordgrass (*Spartina patens*), which is native to the east coast. The Nature Conservancy has actively controlled this species for many years, and we did not observe this species in or near our plots.

In tables and graphs in this report, Cox Island is also referred to as S11, the site number assigned in the Tidal Wetland Prioritization for the Siuslaw River Estuary (Brophy 2005).

S30 (Duncan Island)

S30 (Figures 6 and 7) is a least-disturbed tidal wetland located directly east across the Siuslaw River from Waite Ranch, on the southernmost tip of Duncan Island. The site is primarily high tidal marsh, but also contains a small area of tidal swamp (forested tidal wetland). Our 2014 monitoring included both the marsh and swamp areas. This small portion of Duncan Island was never diked. By contrast, the majority of Duncan Island is a restoring tidal marsh: much of the island was formerly diked, and tidal flows were blocked by an earthen berm (Brophy 2005). The earthen berm was removed or breached and dikes were breached during the late 20th century (Brophy 2005). Around 300 acres of Duncan Island is permanently protected by a conservation easement held by the Natural Resources Conservation Service, and McKenzie River Trust recently secured a conservation easement for 88 more acres.

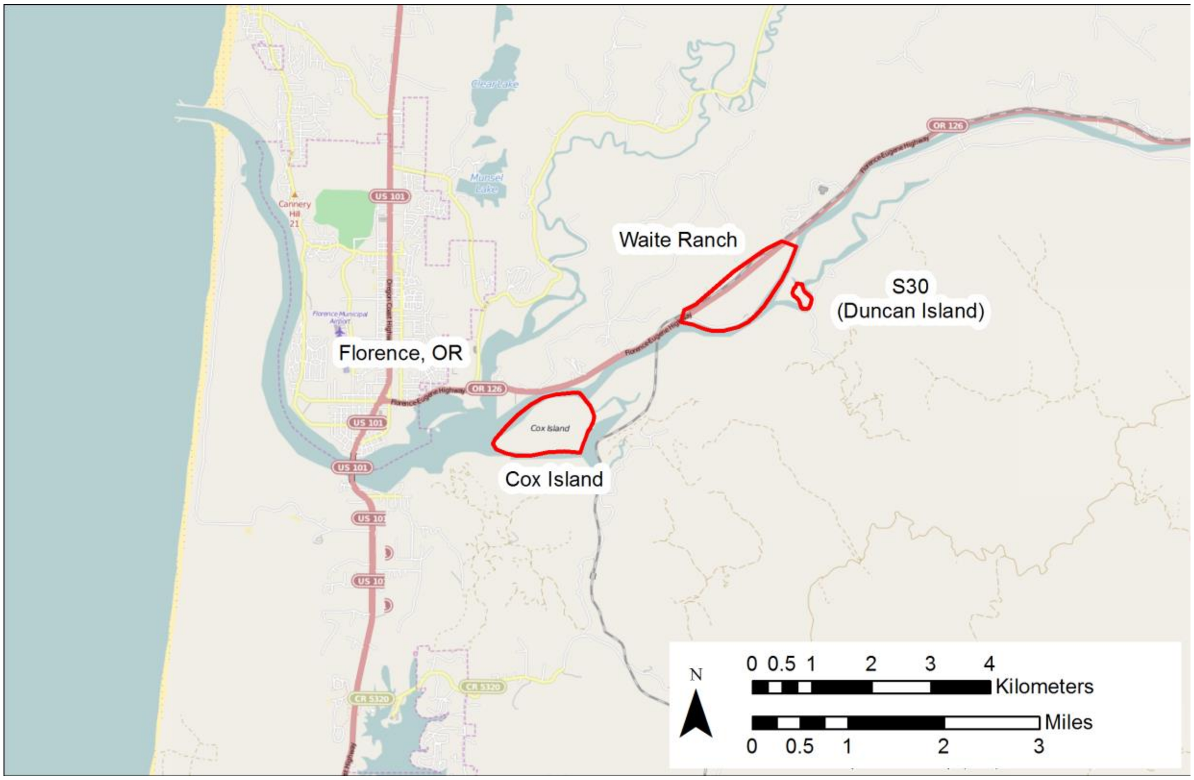


Figure 1. Overview of the study sites in the Siuslaw River Estuary, Oregon. Background: Open Street Map (http://openstreetmap.org).

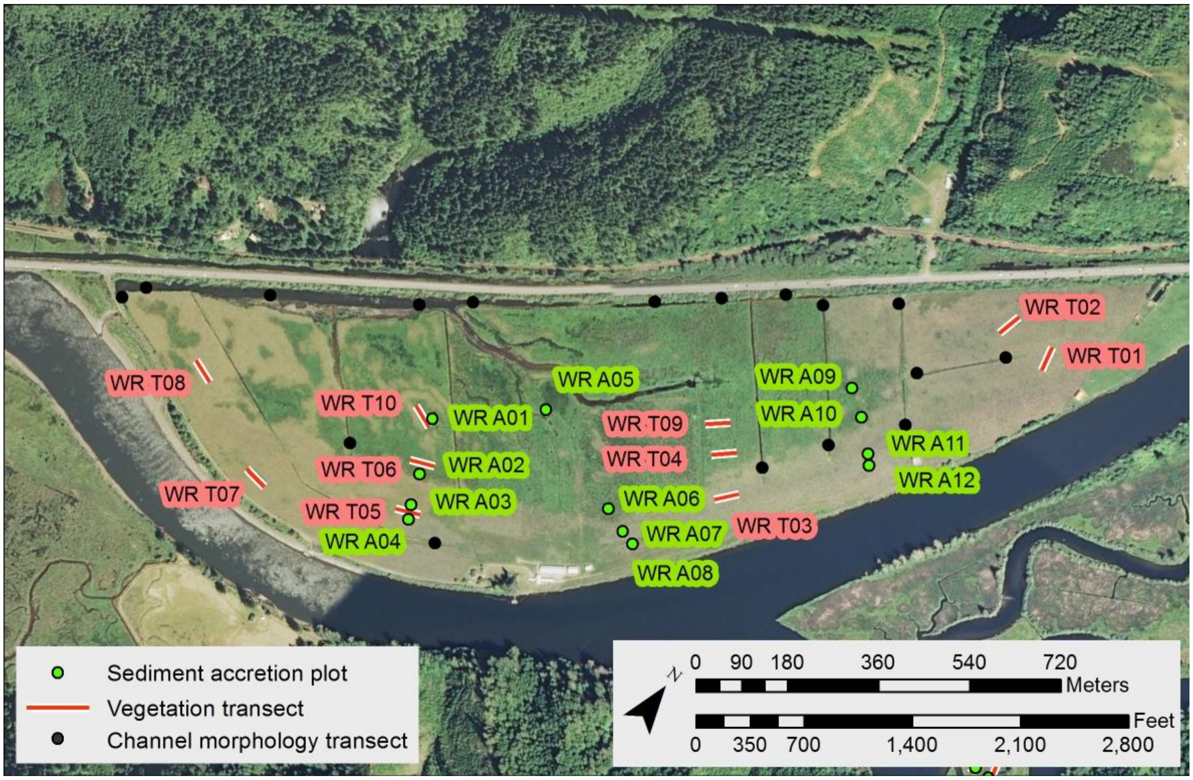


Figure 2. Monitoring infrastructure at Waite Ranch. The map has been rotated to fit the figure; the far right side is upstream. Red labels = vegetation transects, green = accretion plots. Background: 2011 NAIP.

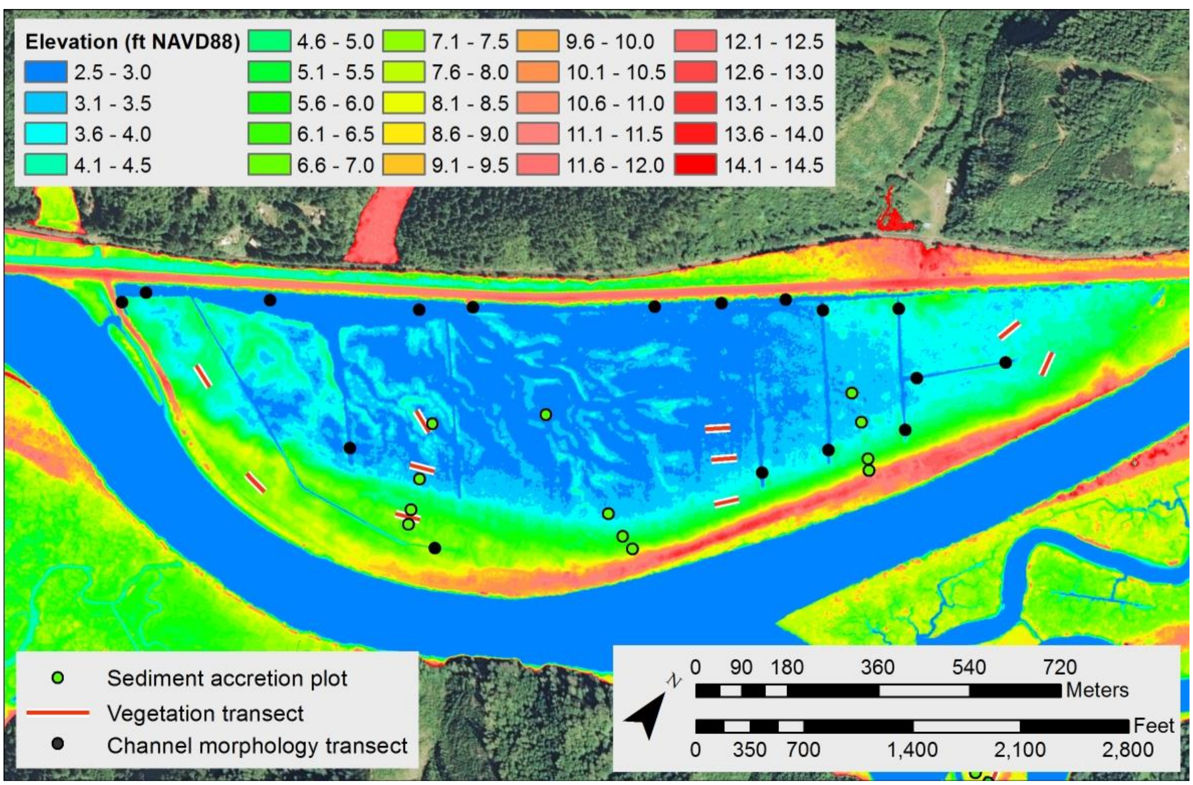


Figure 3. Elevations derived from 2009 bare earth LIDAR digital elevation model at Waite Ranch. The map has been rotated to fit the figure; the far right side is upstream.

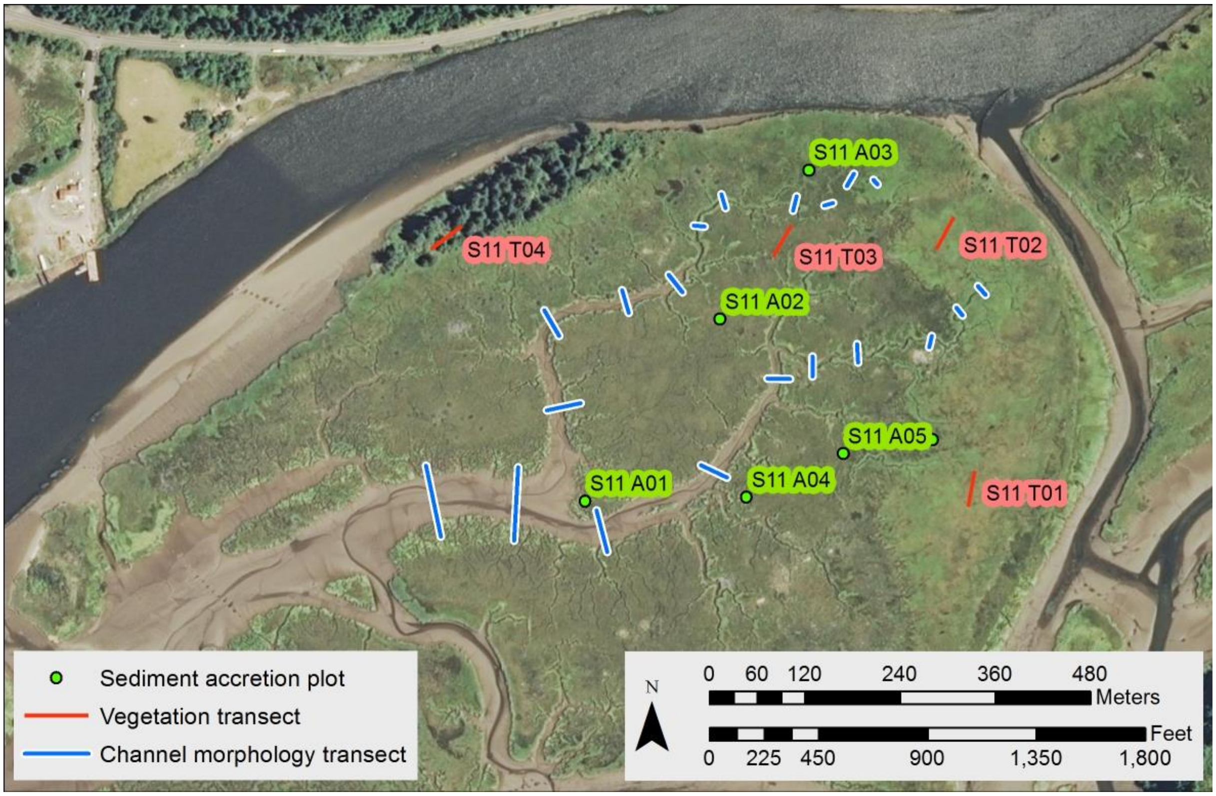


Figure 4. Monitoring locations at Cox Island (S11). Background: 2011 NAIP. Red labels = vegetation transects, green = accretion plots.

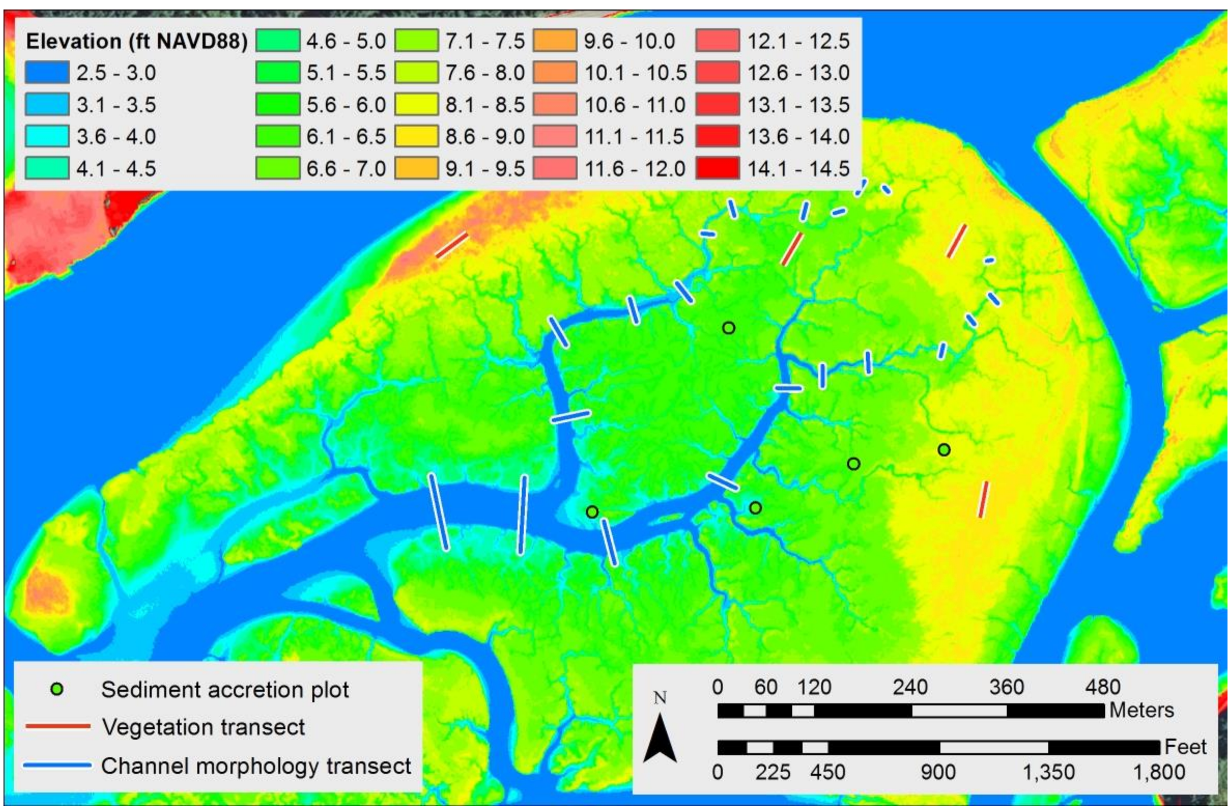


Figure 5. Elevations derived from 2009 bare earth LIDAR digital elevation model at Cox Island (S11).

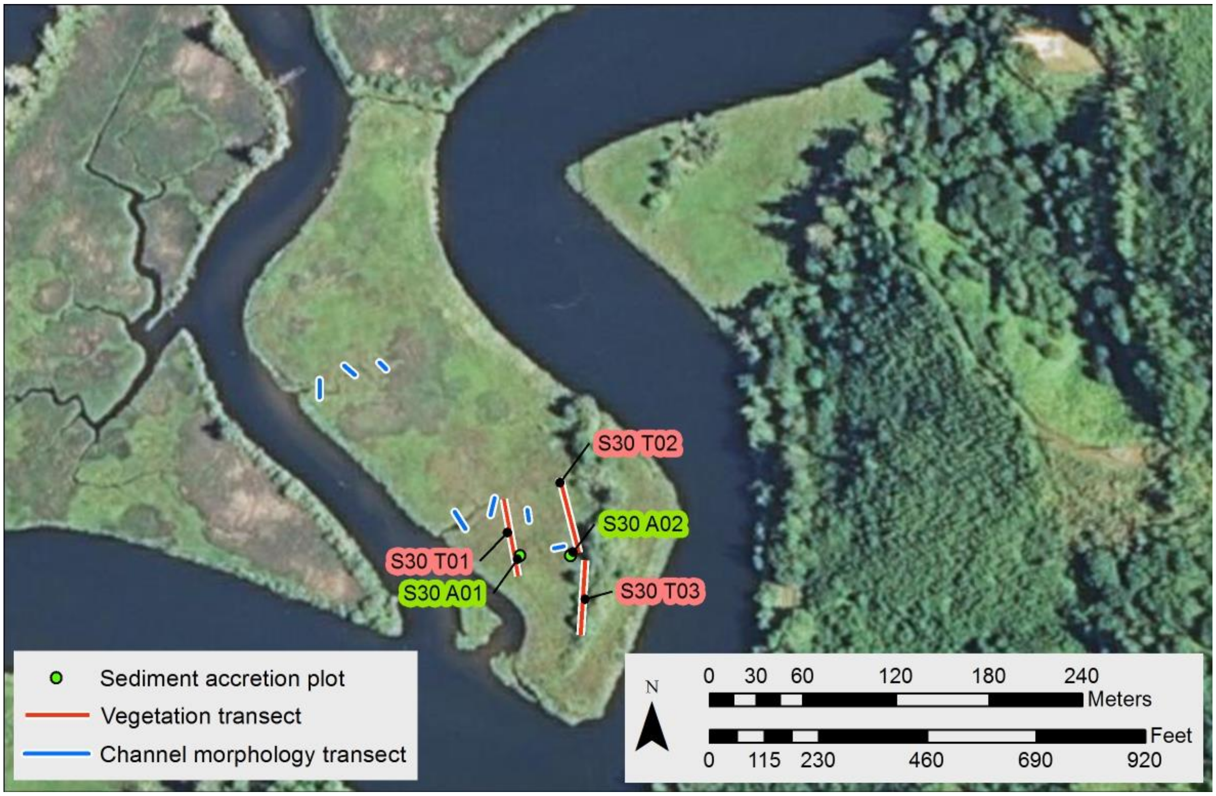


Figure 6. Monitoring locations at S30 (Duncan Island). Background: 2011 NAIP. Red labels = vegetation transects, green = accretion plots.

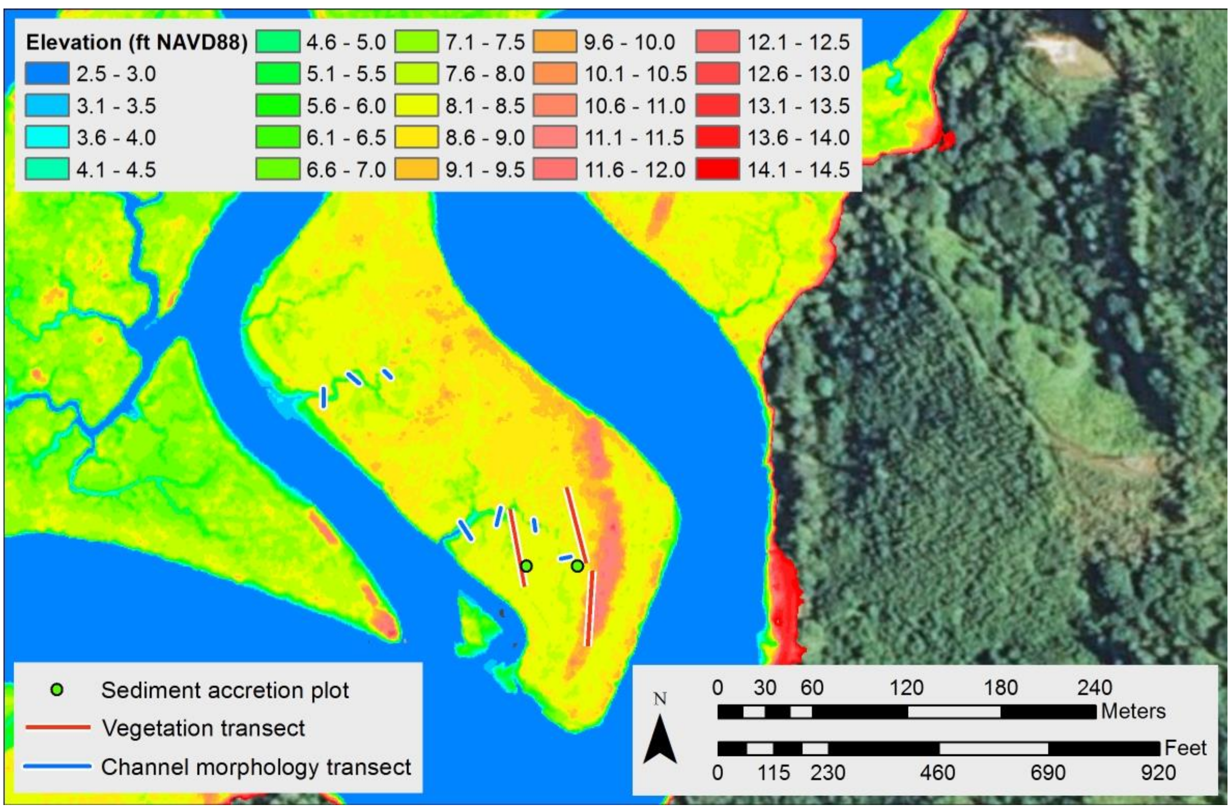


Figure 7. Elevations derived from 2009 bare earth LIDAR digital elevation model at S30 (Duncan Island).

Methods, results and discussion by parameter

In this report we summarize the rationale, methods, results and discussion for three parameters monitored during 2013-2014: vegetation, sediment accretion and channel morphology. These parameters were measured at Waite Ranch and two reference sites (Cox Island and S30). These parameters were selected because they are recognized high priorities for monitoring at tidal wetland restoration sites (Thayer *et al*. 2005, Rice *et al*. 2005, Brophy 2007); because they clearly show the ecological effects of human alterations at Waite Ranch (through comparison to the reference sites); and because they provide goals and targets for post-restoration conditions at Waite Ranch.

We also report on elevation measurements made at the sites using high-accuracy RTK-GPS. Although elevation was not listed among our monitoring parameters, elevation data are used throughout the report to relate monitoring parameters to tidal inundation frequency and other ecosystem drivers (controlling factors). The elevation data we collected at the reference sites are especially important to understanding the degree of subsidence at Waite Ranch – an important consideration in restoration site design and post-restoration effectiveness monitoring.

The Waite Ranch Interim Management Report (Brophy and Lemmer 2013) contains results of baseline monitoring for several other parameters: soils, groundwater, and plant community extent (mapping). A summary of the full recommended effectiveness monitoring program for Waite Ranch is also included in the Interim Management Report.

Elevation

We collected high-accuracy elevation measurements at Waite Ranch and both reference sites using RTK-GPS equipment (Appendix 1). At the forested transect on Cox Island, the canopy was too dense to receive the GPS signal, so we used a laser level to obtain elevation information.

One key dataset we gathered was the wetland surface elevation at the S30 reference site. For the high marsh at S30, elevation was consistently around 7.5 ft (2.3 m). This is approximately the elevation of Mean Higher High Water (MHHW), calculated as 7.6 ft (2.32 m) ESA (ESA PWA 2011). Most high marsh sites we have studied occur slightly above MHHW (Brophy 2009, Brophy *et al*. 2011), so this site is slightly lower than expected for high marsh. We recommend rechecking the elevation at this site. Nonetheless, these data provide our best estimate of the historic elevation of tidal wetlands at Waite Ranch prior to diking.

Comparing the elevation at S30 to our RTK-GPS measurements and the LIDAR digital elevation model for Waite Ranch (ESA PWA 2015), we determined that most of Waite Ranch has subsided about 3 ft (about 1 m) below the wetland's historic elevation, and the lowest parts of Waite Ranch have subsided around 6 ft (2 m), with elevations as low as 1 ft (0.3 m). This is a high degree of subsidence compared to most other diked former tidal wetlands we have investigated (e.g. Brophy 2007, 2009; Brophy *et al.* 2014). The high degree of subsidence is likely due to the historic vegetation type: we have found that outer coast tidal swamps have very high levels of soil organic matter, which may in turn lead to greater elevation loss after diking and drainage (Turner 2004; Frenkel and Morlan 1991). Although the pre-settlement organic matter content of the soils at Waite Ranch is unknown, the organic matter content of soils at the adjacent least-disturbed reference site (S30) is likely to be similar, and is high (17 to 22% organic matter, corresponding to 11 to 15% organic carbon, Brophy and Lemmer 2013). In fact, the pre-settlement organic content of the soil at Waite Ranch was probably even higher, since the pasture soil currently had an average organic matter content of 18.5% (12.6% organic carbon) in 2010 (Brophy and Lemmer 2013), even after decades of oxidation and organic matter loss.

Historic aerial photographs show that Waite Ranch was already diked in 1939, so subsidence occurred over a period of at least 76 years. The rates of subsidence that occurred during the first few decades after diking, versus more recent periods, are unknown.

This information does not change our earlier estimates of the likely restoration trajectory for Waite Ranch. Our previous project documents (Brophy and Lemmer 2013) estimated that the lower areas of Waite Ranch would initially restore to mud flat, while the majority of the site would initially restore to low marsh. This remains true, although the proportion of mud flat versus tidal marsh may vary from earlier estimates. The earlier estimates were calculated from the 2009 LIDAR (Watershed Sciences 2009), but the LIDAR DEM for Waite Ranch has recently been adjusted for better accuracy (ESA PWA 2015).

Tidal datums

Information on tidal datums is needed to interpret monitoring data at tidal wetland sites. In our field studies (Brophy 2009, Brophy *et al*. 2011, 2014) we have found Mean Higher High Water (MHHW) to be the most important datum for interpreting vegetation development. We obtained information on MHHW for Waite Ranch and nearby NOAA gauge stations from ESA PWA's 2011 engineering report (ESA PWA 2011). MHHW is 7.60 ft NAVD88 at Waite Ranch (ESA PWA 2011), and that value also applies to S30, which is immediately adjacent to Waite Ranch. For Cox Island, we interpolated between the MHHW values provided by ESA PWA (2011) for Waite Ranch (7.60 ft NAVD88) and Florence (7.25 ft NAVD88). Assuming a steady gradient in the water surface, we calculated that MHHW is about 7.43 ft NAVD88 for Cox Island.

Emergent wetland plant communities

Vegetation monitoring at Waite Ranch and the reference sites allows us to document current plant communities and track changes to plant communities after restoration. Measurements of total plant cover, native species cover, nonnative species cover, species richness, and community composition at each site provide a baseline for determining vegetation shifts over time after the re-introduction of tidal flows, allowing determination of the project's effectiveness and generating data to support adaptive management.

Scientific and common names of plants in this report are referenced to the Oregon Flora Project's checklist (Cook *et al*. 2013).

Methods

Baseline monitoring of emergent wetland plant communities was conducted in summer 2014 at Waite Ranch and the S30 reference site, and in summer 2006 at the Cox Island reference site (Brophy 2009). The 2006 data are considered appropriate for comparison to Waite Ranch because plant community composition is not expected to vary drastically among years at least-disturbed reference sites like Cox Island.

Data on emergent wetland plant community composition were collected using a standard transect-quadrat method (Roegner *et al*. 2008). Transect lengths were 150 ft (45.7 m) at Cox Island and 165 ft (50.3 m) at Waite Ranch and S30; transect placement was stratified by elevation. Ten emergent wetland transects were sampled at Waite Ranch, two emergent transects were sampled at S30, and three emergent transects were sampled at Cox Island (Figures 1-7; Tables 2 and 3). Eight of the transects at Waite Ranch (WR T01 through WR T08) were at the same locations where groundwater, soils were monitored during 2010 (Brophy and Lemmer 2013), improving our ability to interpret results. We also added two new transects at lower elevations; these were intended to provide further data on the lower parts of the site. We did not add more transects in the area of Waite Ranch closer to Highway 126 for two reasons: 1) this area will be difficult to access after restoration due to its low elevation (it will be flooded during all but the lowest tides); and 2) there are several construction activities planned for this area during restoration (ESA PWA, personal communication), so access will be difficult during restoration work and the area will potentially be subject to disturbance during that period.

Visual estimates of species percent cover were made within 10 randomly placed 10.76 ft^2 (1 m^2) quadrats along each transect. Quadrats were placed 3.28 ft (1 m) to the left or right side of the transect's central axis (randomly determined), and at randomly selected distances from the transect end. Each quadrat was at least 9.8 ft (3 m) away from the other and 9.8 ft (3 m) from the transect end post. Visual cover estimates followed the Oregon Department of State Land's Routine Monitoring Protocol (Oregon DSL 2009). Percent cover represents the area of the plot that is covered by the species in question (vertical projection of foliage and stems). Cover estimates generally sum to 100% within each plot (including bare ground and other unvegetated surfaces), but cover may exceed 100% if the vegetation has distinct layers, such as tall plants extending above a layer of low-growing plants.

Emergent wetland plant community metrics (species richness, total plant cover, native plant cover and non-native plant cover) were compared between Waite Ranch and reference sites using the Student's t-test. When distributions did not meet the normality assumption, data were transformed accordingly. When data could not be transformed to meet normality assumptions, a non-parametric Wilcox test was used. A multivariate technique, non-metric multidimensional scaling (NMDS), was used to summarize and visualize differences in plant community composition between Waite Ranch and the reference sites. All analyses were completed in R (Version 3.1.1) using average percent cover per transect. The NMDS analysis was run using the R package *vegan* (Version 2.2-1).

In the sections below, the term "dominant" is used for species that have the highest percent cover values or the highest number of stems within the study transect. Species with more than 20% cover are generally considered dominant, although species with less than 20% cover may be considered dominant when total cover is low (i.e. when bare ground is prevalent).

Table 2. Endpoint coordinates for transects at Waite Ranch, Cox Island, and S30. The horizontal coordinate system is NAD83(2011) (epoch 2010.00) UTM Zone 10N (m). See Appendix 1 for detailed spatial reference and datum information.

Site	Transect	Wetland class	Endpoint position	Easting (m)	Northing (m)
Waite Ranch	T01	emergent	south	0418282	4872031
Waite Ranch	T01	emergent	north	0418272	4872082
Waite Ranch	T02	emergent	south	0418170	4872040
Waite Ranch	T02	emergent	north	0418183	4872091
Waite Ranch	T03	emergent	west	0417916	4871440
Waite Ranch	T03	emergent	east	0417948	4871479
Waite Ranch	T04	emergent	west	0417859	4871508
Waite Ranch	T04	emergent	east	0417896	4871542
Waite Ranch	T05	emergent	west	0417425	4871046
Waite Ranch	T05	emergent	east	0417471	4871066
Waite Ranch	T06	emergent	west	0417390	4871140
Waite Ranch	T06	emergent	east	0417436	4871159
Waite Ranch	T07	emergent	west	0417140	4870932
Waite Ranch	T07	emergent	east	0417191	4870925
Waite Ranch	T08	emergent	west	0416933	4871044
Waite Ranch	T08	emergent	east	0416980	4871028
Waite Ranch	T09	emergent	west	0417813	4871549
Waite Ranch	T09	emergent	east	0417581	4871582
Waite Ranch	T10	emergent	west	0417334	4871235
Waite Ranch	T10	emergent	east	0417380	4871214
Cox Island (S11)	T01	emergent	south	0414910	4869234
Cox Island (S11)	T01	emergent	north	0414918	4869279
Cox Island (S11)	T02	emergent	south	0414870	4869558
Cox Island (S11)	T02	emergent	north	0414892	4869598
Cox Island (S11)	T03	emergent	south	0414665	4869548
Cox Island (S11)	T03	emergent	north	0414687	4869588
Cox Island (S11)	T04	forested	east	0414273	4869587
Cox Island (S11)	T04	forested	west	0414234	4869558
S30	T01	emergent	south	0418646	4871316
S30	T01	emergent	north	0418638	4871366
S30	T02	emergent	south	0418686	4871332
S30	T02	emergent	north	0418675	4871380
S30	T03	forested	south	0418691	4871280
S30	T03	forested	north	0418692	4871327

Table 3. Average elevation and dominant plant species of transects at Waite Ranch, Cox Island, and S30 The vertical datum is NAVD88 (Geoid 12A).

Site	Transect	Year monitored	Elevation (ft)	Elevation (m)	Dominant species or cover
Waite Ranch	T01	2014	4.20	1.28	greater birdsfoot trefoil
Waite Ranch	T02	2014	3.38	1.03	slough sedge
Waite Ranch	T03	2014	3.71	1.13	common velvetgrass
Waite Ranch	T04	2014	2.62	0.80	slough sedge
Waite Ranch	T05	2014	6.69	2.04	creeping bentgrass
Waite Ranch	T06	2014	2.59	0.79	bare ground
Waite Ranch	T07	2014	6.69	2.04	creeping bentgrass, greater birdsfoot trefoil, Pacific silverweed
Waite Ranch	T08	2014	4.00	1.22	common velvetgrass
Waite Ranch	T09	2014	2.36	0.72	bare ground
Waite Ranch	T10	2014	2.62	0.80	Pacific silverweed
Cox Island (S11)	T01	2006	7.84	2.39	Baltic rush, saltgrass
Cox Island (S11)	T02	2006	7.87	2.40	Baltic rush, Pacific silverweed
Cox Island (S11)	T03	2006	6.14	1.87	seaside arrowgrass, saltgrass, tufted hairgrass
Cox Island (S11)	T04a	2014	7.58	2.81	red alder, Pacific crabapple
Cox Island (S11)	T04b	2014	7.58	2.81	Sitka spruce
S30	T01	2014	7.58	2.31	tufted hairgrass
S30	T02	2014	7.78	2.37	Baltic rush, Pacific silverweed
S30	T03	2014	8.33	2.54	Pacific crabapple

Results and discussion

Pooling data across all transects, all emergent wetland plant community metrics were significantly different between Waite Ranch and the reference sites. Total plant cover, native plant cover and species richness were all significantly higher at reference transects compared to Waite Ranch transects, and conversely, Waite Ranch transects had significantly higher non-native plant cover (Table 4; Figure 8). Emergent wetlands at reference sites averaged 114% total plant cover (nearly all of which was native), while Waite Ranch had only 57% total plant cover and only 23% native plant cover. Emergent wetlands at the reference sites averaged less than 1% non-native plant cover, compared to 34% non-native cover at Waite Ranch. The remaining cover at Waite Ranch was bare ground (43%). Average species richness per transect at the reference sites was 9.6, compared to 4.9 at Waite Ranch.

Looking at individual transects at Waite Ranch, the higher-elevation transects (WR T01, WR T05, WR T07, WR T08) were dominated by non-native pasture grasses, whereas native species dominated the lower transects (WR T02, WR T04, WR T06, WR T09, WR T10) (Table 5; Figure 9). This is probably due to the wetter conditions at the lower transects, which made them less suitable for the non-native pasture grasses. After restoration, the native species present at these lower transects -- mainly Pacific silverweed (*Potentilla anserina*) and slough sedge (*Carex obnupta*) -- are unlikely to persist at their current locations due to the low elevation, but they may provide propagules for establishment at higher elevations on the site.

The higher-elevation transects at the reference marshes (S11 T01 and S11 T02 at Cox Island; S30 T01 and S30 T02) were dominated by native high marsh species, including tufted hairgrass (*Deschampsia cespitosa*), Baltic rush (*Juncus balticus*) and Pacific silverweed (Tables 3 and 6; Figure 10). The elevation of these transects was about 0.4 ft (0.12 m) above MHHW (Table 3), in agreement with past studies showing high marsh generally occurs above MHHW on Oregon's outer coast (Brophy *et al.* 2011). The lowest transect at Cox Island (S11 T03) was dominated by the low marsh species seaside arrowgrass (*Triglochin maritima*) and saltgrass (*Distichlis spicata*), and but also had a substantial component of tufted hairgrass, a species that can be found in both high and low marsh (Brophy *et al*. 2011). The elevation of S11 T03 was 1.3 ft (0.4 m) below MHHW (Table 3), in agreement with past studies showing that low marsh generally occurs below MHHW on Oregon's outer coast (Brophy *et al.* 2011).

As mentioned in Brophy and Lemmer (2013), a rare plant, Henderson's checkermallow (*Sidalcea hendersonii*) is found at both Cox Island and the S30 reference site. The population is large at S30, containing hundreds of individuals. Protection of these sites is especially important due to the presence of this species, which is listed by the Oregon Natural Heritage Information Center as a Species of Concern and ranked at the highest level of rarity in the state.

Cover of bare (unvegetated) ground was high at Waite Ranch in 2014. During our team's vegetation mapping at Waite Ranch in 2010 (Brophy and Lemmer 2013), there was very little bare ground. The bare ground observed in 2014 appeared to be related to a tide gate failure in 2013 which allowed brackish water into the site, killing much of the existing vegetation on low parts of the site. In summer 2014, Pacific silverweed was rapidly colonizing these bare ground areas; this species is tolerant of brackish water and is also dominant at the reference sites. Winter inundation due to low elevation, precipitation, and likely subsurface flow from the tidal slough north of Highway 126 (GeoScience Inc., 2013) also probably contributes to the high amount of bare ground at Waite Ranch.

Table 7 contains a complete list of plant species found at reference and restoration transects.

Table 4. Results of statistical tests for differences in plant community metrics, Waite Ranch *versus* reference sites, 2014. Bold text indicates significant differences ($p < 0.05$).

	T- value (or W rank)	p-value	Transformation/test
Species richness	4.65	**0.001**	log
Total plant cover	4.76	**0.0003**	none
Native cover	6.44	**< 0.0001**	square-root
Non-native cover	1.00	**0.001**	Wilcox test

The NMDS analysis suggested that there is a difference in plant community composition between reference sites and Waite Ranch, with reference transects grouping together, and Waite Ranch transects grouping together (Figure 11). The plants driving the groupings are mainly native plants for reference transects, and pasture grasses for Waite Ranch. Post-restoration monitoring is expected to show the species composition at Waite Ranch converging with that of the reference sites. However, this process will take time. We expect that there will be an initial decrease in total plant cover at Waite Ranch after brackish tides are restored due to die-off of salt-intolerant species, but over several years salt-tolerant native species will become dominant. Similar trajectories have been observed at other restored tidal marshes, such as the Ni-les'tun Unit of the Bandon National Wildlife Refuge and sites at South Slough National Estuarine Research Reserve (Cornu and Sadro 2002). Given the low elevations that predominate across much of Waite Ranch, species with broad salinity and inundation tolerances such as creeping bentgrass and Lyngbye's sedge are likely to dominate in early post-restoration period (Cornu and Sadro 2002; Brophy 2007). In the medium-term (decades), plant community composition at Waite Ranch is likely to become similar to the lower elevation transects at Cox Island. Only after substantial accretion is Waite Ranch likely to once again support the Pacific crabapple tidal swamp community that was historically present at the site. Plant communities change slowly, and accretion is an even slower process, so long-term monitoring is critical to determining the effectiveness of a restoration project (Frenkel and Morlan 1991; Brophy *et al*. 2014).

Figure 8. Average plant species richness, total cover, native cover and non-native cover for reference sites and Waite Ranch. Error bars show one standard error; columns with no letters in common are significantly different (t-test, $p<0.05$).

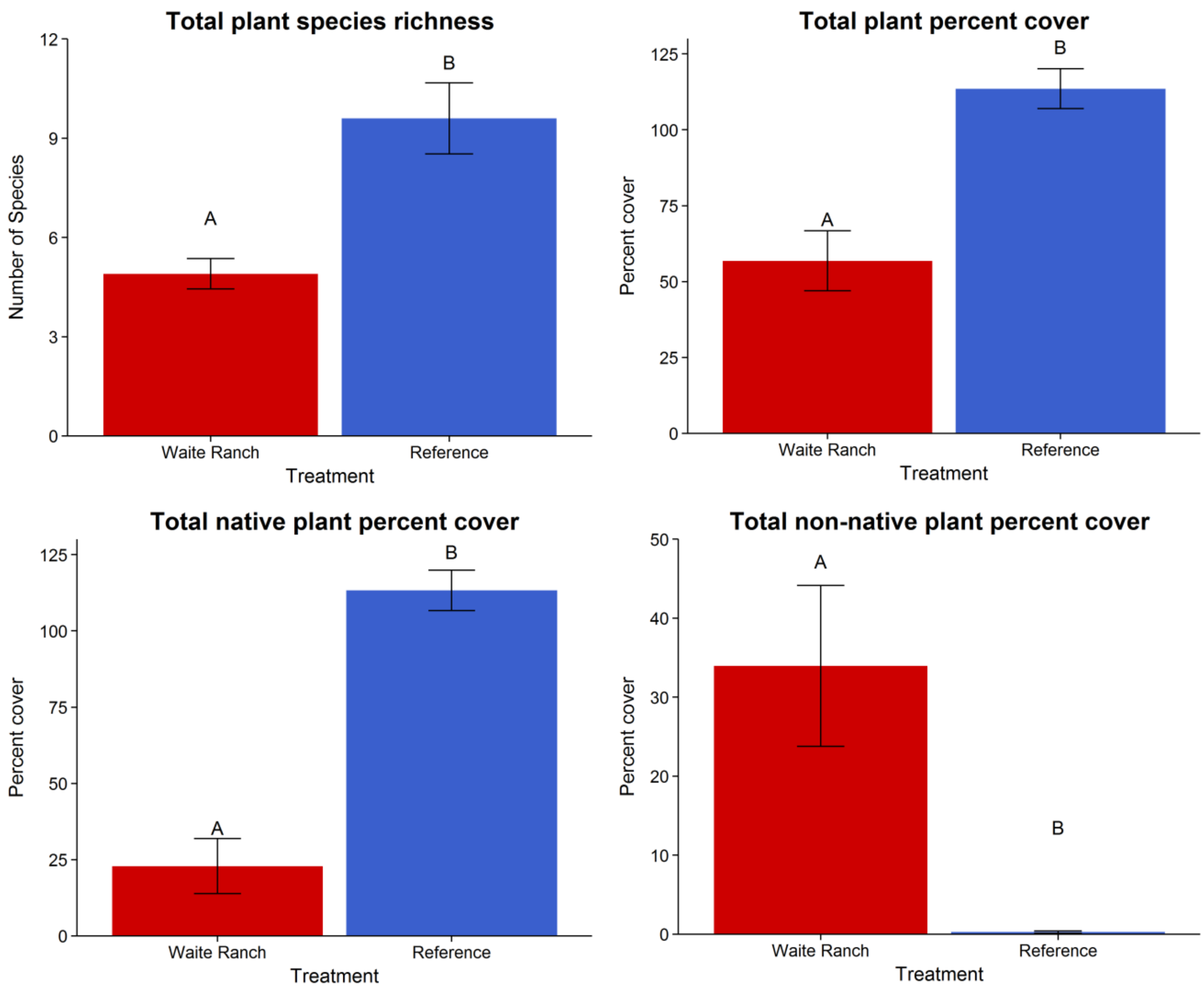


Table 5. Percent cover by species in Waite Ranch emergent wetland transects. Species with >5% average cover are individually listed. Green indicates native species, orange indicates non-native species.

		Average percent cover									
Species	**Common name**	**WR T01**	**WR T02**	**WR T03**	**WR T04**	**WR T05**	**WR T06**	**WR T07**	**WR T08**	**WR T09**	**WR T10**
Agrostis stolonifera	creeping bentgrass	0	0	19.7	1.0	64.6	6.5	21.1	1.6	0.5	1.0
Carex obnupta	slough sedge	0.3	76.5	0	35.7	0	0	0	0	2.3	1.0
Eleocharis palustris	common spikerush	0	0	0	13.0	0	0.1	5.0	0	0	0
Holcus lanatus	common velvetgrass	1.6	15.0	35.2	0	13.2	0	2.3	34.0	0	1.8
Juncus effusus	soft rush	0	0	0	9.9	0	0	0	0	3.6	0.1
Lotus uliginosus	greater birdsfoot trefoil	45.6	1.5	0	0	6.9	0	29.4	6.0	0	0
Potentilla anserina	Pacific silverweed	0	0	0	8.4	0	16.6	29.5	0	3.3	22.4
Ranunculus repens	double flowered creeping buttercup	0	0	0	0	0	0	10.0	0	0	0
Schedonorus arundinaceus	tall fescue	11.7	0	0	0	0	0	0	0.5	0	0
Total plant cover		59.2	94.0	55.5	68.5	89.7	23.2	98.5	42.1	9.7	27.1
Bare ground		40.8	6.0	44.5	31.5	10.3	76.8	1.5	57.9	90.3	72.9

Figure 9. Percent cover by species at each transect at Waite Ranch during 2014. Blue colors indicate native species; red colors indicate non-native species.

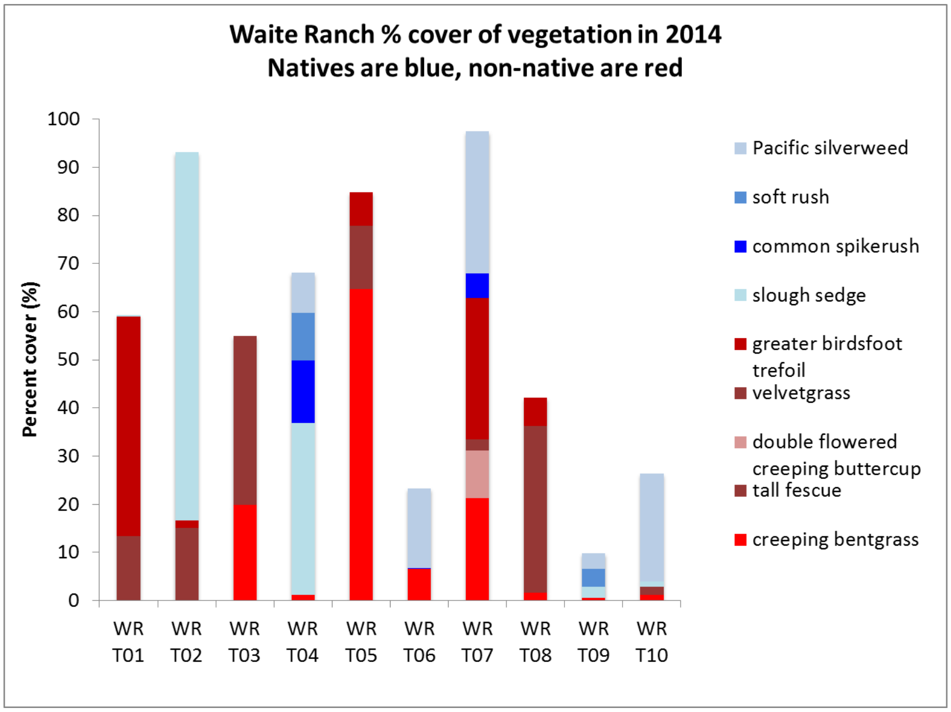


Table 6. Percent cover by species for emergent tidal marsh transects at reference sites. Species with more than 5% average cover are individually listed. Cox Island transects are indicated by S11. All species shown are native. For year monitored, see Table 3.

		Average percent cover				
Plant species	**Common name**	**S11 T01**	**S11 T02**	**S11 T03**	**S30 T01**	**S30 T02**
Carex lyngbyei	Lyngbye's sedge	0.19	10.0	16.6	0	0.8
Claytonia sibirica	candyflower	0	0	0	9.9	3.4
Deschampsia cespitosa	tufted hairgrass	0	0.4	24.8	48.5	12.0
Distichlis spicata	saltgrass	27.9	10.1	28.1	0	0
Juncus balticus	Baltic rush	77.8	58.3	0.6	13.5	47.4
Lilaeopsis occidentalis	lilaeopsis	0	0	17.5	0	0
Potentilla anserina	Pacific silverweed	0.1	49.8	0	19.7	35.2
Triglochin maritima	seaside arrowgrass	0	0	29.4	0	0
Total plant cover		100.0	100.0	100.0	100.0	100.0

Figure 10. Percent cover by species and transect at the reference sites during 2006 and 2014, for species with more than 5% average cover. Cox Island transects are indicated by S11. Blue colors indicate native species (all species shown are native).

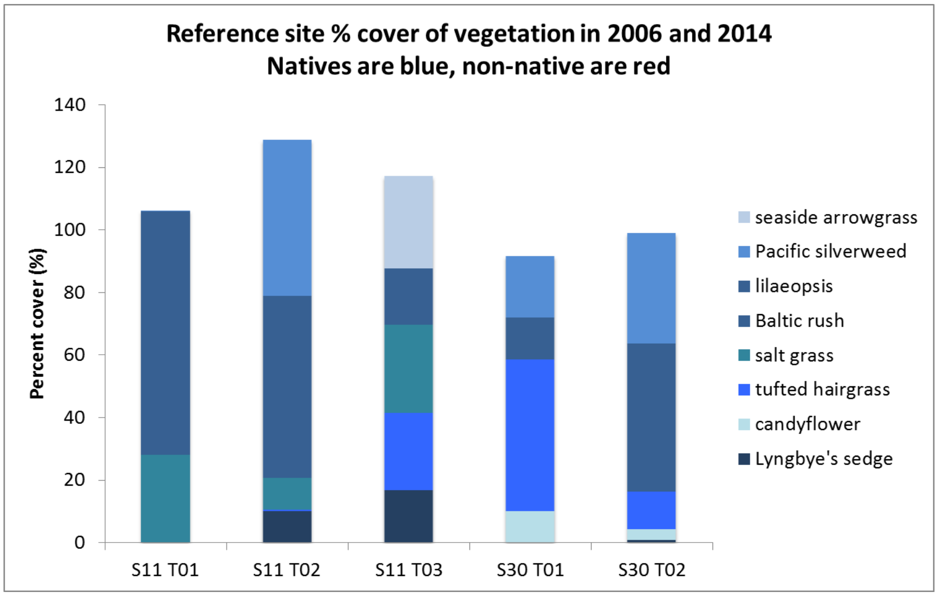
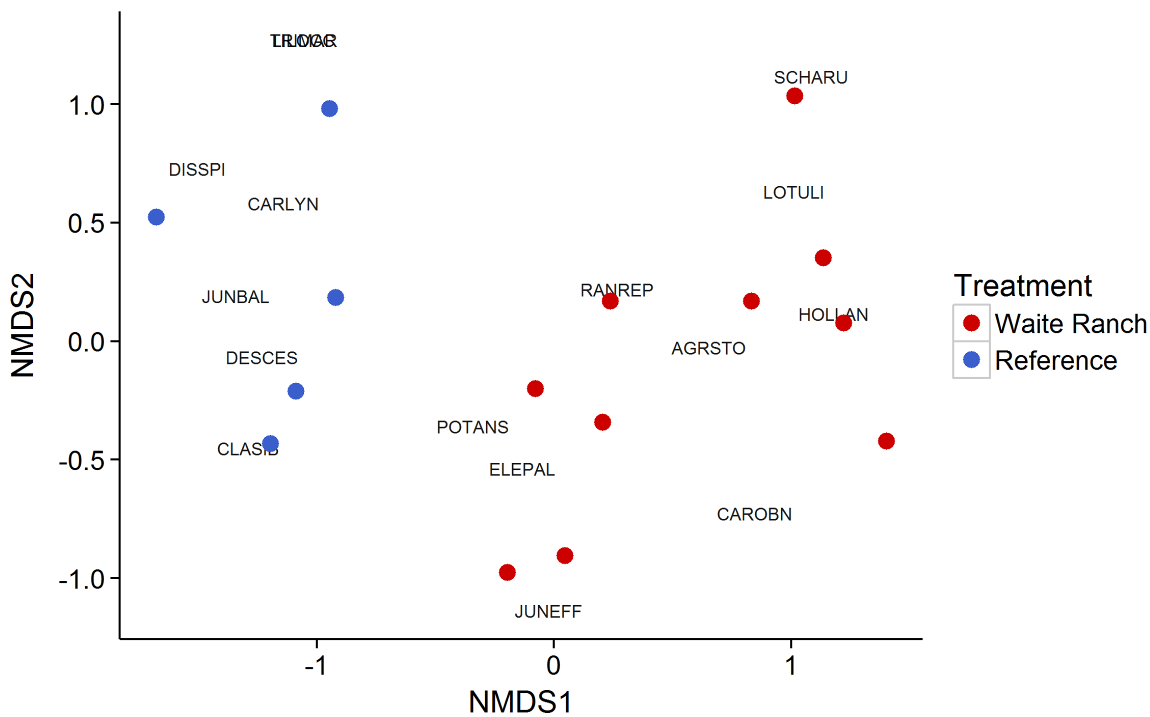


Table 7. Complete list of species found within emergent wetland transects at Waite Ranch and nearby reference marshes, and their common names.

Plant species	**Common name**
Achillea millefolium	yarrow
Agrostis stolonifera	creeping bentgrass
Alopecurus pratensis	meadow foxtail
Anthoxanthum odoratum	sweet vernalgrass
Atriplex patula	common orache
Carex lyngbyei	Lyngbye's sedge
Carex obnupta	slough sedge
Claytonia sibirica	candyflower
Deschampsia cespitosa	tufted hairgrass
Distichlis spicata	saltgrass
Eleocharis palustris	common spikerush
Eleocharis parvula	small spikerush
Epilobium ciliatum	purple leaved willowherb
Erechtites minima	toothed coast fireweed
Galium aparine	stickywilly
Holcus lanatus	common velvetgrass
Hordeum brachyantherum	meadow barley
Juncus balticus	Baltic rush
Juncus effusus	soft rush
Lilaeopsis occidentalis	lilaeopsis
Lotus uliginosus	greater birdsfoot trefoil
Phalaris arundinacea	reed canarygrass
Poa palustris	fowl bluegrass
Potentilla anserina	Pacific silverweed
Ranunculus repens	double flowered creeping buttercup
Rumex acetosella	sheep sorrel
Rumex conglomeratus	clustered dock
Rumex crispus	curly dock
Rumex occidentalis	Rocky Mountain western dock
Schedonorus arundinaceus	tall fescue
Schoenoplectus tabernaemontani	softstem bulrush
Scirpus microcarpus	small-fruited bulrush
Sidalcea hendersonii	Henderson’s checkermallow
Sonchus sp.	sowthistle
Triglochin maritima	seaside arrowgrass
Vicia nigricans	giant vetch

Figure 11. Non-metric multidimensional scaling (NMDS) plot for reference and Waite Ranch transect plant communities. Blue dots indicate reference transects and red dots indicate Waite Ranch transects. Each dot represents a single transect. Dots closer together are more compositionally similar. The centroid points of plant species used in the analysis are indicated by six letter species codes on the plot. Only species that had a presence of greater than 5% were included in the analysis.



Tidal swamp (forested tidal wetland) plant communities

The terms “tidal swamp” and “forested tidal wetland” are used interchangeably in this report. The term “tidal swamp” is broader; it includes tidal wetlands dominated by either shrubs or trees. By contrast, the term “tidal marsh” refers to tidal wetlands dominated by emergent vegetation (herbaceous species such as grasses, sedges, and rushes)

Prior to diking and conversion to agricultural use, Waite Ranch was a tidal swamp dominated by Pacific crabapple (*Malus fusca*) (Hawes *et al.* 2008). Therefore, data from tidal swamp reference sites is important for understanding impacts of human alterations and for planning restoration at Waite Ranch. According to Hawes *et al.* (2008), crabapple swamp was very rare in the Siuslaw River estuary and on the entire Oregon coast, but Pacific crabapple is often a component of Sitka spruce tidal swamp. Sitka spruce tidal swamp was and still is the most common type of tidal swamp in Oregon’s outer coast estuaries (Jefferson 1975, Brophy *et al*. 2011).

Prior to European settlement, about 70% of the tidal wetlands in the Siuslaw River estuary were tidal swamps, but 97% of the Siuslaw’s historic tidal swamp has been lost, primarily through conversion to diked agricultural land (Brophy 2005). Therefore, it was challenging to find least-disturbed reference sites for tidal swamp for this study and others (e.g. Brophy 2009). The two reference sites for this project (Cox Island and S30) were selected in part because they still contain remnants of tidal swamp. Fortunately, the remnant tidal swamp at S30 is the same type that was historically present at Waite Ranch (Pacific crabapple swamp).

Methods

Field measurements were made within permanent plots along transects; one transect was sampled at Cox Island (S11 T04, with two associated plots as described below) and one transect was sampled at S30 (S30 T03). Transect length varied depending on vegetation density; S30 T03 was 150 ft (45.7 m) long, and S11 T04 (which included S11 T04a and S11 T04b) was 165 ft long.

Along each transect, sample units for different vegetation strata were nested within plots of varying size following methods described in Peet *et al*. (1998). Herbaceous cover was measured in the smallest nested plots (1 m^2 quadrats), with 14 quadrats sampled at Cox Island and 12 quadrats sampled at S30. Plot size for shrubs and trees varied depending on woody species density. Shrubs were measured in 7 plots each 15 by 15 ft (4.6 by 4.6 m) at Cox Island, and in 6 plots each 10 by 10 ft (3 by 3 m) at S30. Trees were measured in the largest plots, described below.

At both reference sites, adjustments to the sample design were made because only a narrow band of forested wetland was available for sampling. At Cox Island, trees were measured in two adjacent plots. The first, S11 T04a, was established in June 2014, and was 30 by 120 ft (9.1 by 36.6 m), occupying the easternmost 120 ft of the 165 ft transect and sampling 15 ft on each side of the transect. The second, S11 T04b, was established in September 2014; it was 60 by 165 ft (18.3 by 50.3 m) and sampled only the south side of the transect. Despite their proximity, the two plots sampled different associations. S11 T04a was dominated by deciduous trees, and lacked the Sitka spruce that are dominant in much of the forested wetland at Cox Island. T04b was added as an extension onto T04a in order to sample the adjacent spruce-dominated area. S11 T04a and T04b shared the same transect endposts (Tables 2 and 3). Herbaceous and shrub plots were sampled only in plot T04a and were placed at random distances along the transect.

At S30, only one side of the transect was used (the east side), to keep the sampled area narrow. This was necessary because the forested wetland at S30 has a fairly rapid elevation gradient, and we specifically wanted to sample its lower edge, which was most strongly dominated by Pacific crabapple – the historic vegetation type at Waite Ranch (Hawes *et al*. 2008). Herbaceous and shrub plots were placed at random distances along the transect.

For shrubs – woody plants < 20 ft (6 m) tall (Cowardin *et al*. (1979) -- all stems branching below knee high were counted; stem diameters were not measured. For trees (woody plants >20 ft tall), stems were counted and diameter at breast height (DBH) was measured; these data were converted into tree (stem) density and basal area. Tree saplings were counted as shrubs. Cover of herbaceous species within forested wetlands was estimated using the same methods as for emergent wetlands.

No forested wetland data were collected at Waite Ranch, as the site lacks forested habitat. Therefore, no statistical tests were run on forested wetland data, since no comparisons were possible between Waite Ranch and the reference sites.

Results and discussion

Tree species composition, basal area, and density

The forested wetland at S30 provided a valuable reference for the Pacific crabapple tidal swamp that once occupied the Waite Ranch site (Hawes *et al*. 2008) – in fact, this area provides the only data currently available for this tidal swamp association on Oregon's outer coast. Pacific crabapple was the only dominant tree species at S30 T03 (Table 8), with basal area of 128.2 ft^2/acre (Table 8). As described in Shrub density below, the brackish-tolerant shrub black twinberry (*Lonicera involucrata*) was also dominant in this transect. Both of these species will be appropriate for plantings at appropriate elevations (just above MHHW) at Waite Ranch, assuming salinities inside Waite Ranch after restoration are similar to salinities at S30 (see **Salinity and planting plans** in **Recommendations** below).

As described in **Methods** above, the forested tidal wetland (tidal swamp) at Cox Island was monitored in two separate plots, S11 T04a and S11 T04b; the former represents a deciduous association, and the latter documents the Sitka spruce that are dominant throughout much of the Cox Island forested wetland. Dominant tree species at plot S11 T04a (based on basal area) were red alder (*Alnus rubra*) and Pacific crabapple, with subdominant Pacific wax myrtle (*Myrica californica*) and cascara (*Rhamnus purshiana*) (Table 8). We have studied two other tidal swamp sites in Oregon that were dominated by these species: the recently restored tidal swamp at the Ni-les'tun restoration site, and the nearby least-disturbed tidal swamp reference site at Bandon Marsh National Wildlife Refuge (Brophy *et al.* 2014). Red alder basal area was 43.5 ft^2/acre in S11 T04a, slightly greater than its range of 18 to 35 ft^2/acre at the Bandon Marsh NWR. Pacific crabapple basal area in S11 T04a was 31.3 ft^2/acre, slightly higher than this species' range of 4 to 21 ft^2/acre at Bandon Marsh NWR.

Sitka spruce (*Picea sitchensis*) dominated plot S11 T04b, with basal area of 107.1 ft^2/acre, similar to the Bandon Marsh NWR sites (33 to 147 ft^2/acre; Brophy *et al*. 2014) and other least-disturbed Oregon tidal swamps (52 to 184 ft^2/acre; Brophy 2009, Brophy *et al.* 2011). Density of Sitka spruce at S11 T04b (238 stems/acre, Table 9) was higher than the density documented at other least-disturbed tidal swamps on Oregon's outer coast (17 to 136 stems/acre; Brophy 2009, Brophy *et al.* 2011), but lower than the density at one site in the Columbia River estuary (1253 stems/acre; Brophy *et al*. 2011). Sitka spruce often grows at very high densities along tidal river banks such as the forested edge of Cox Island. Other examples of dense Sitka spruce along tidal river banks include the east end of Duncan Island (Brophy and Christy 2009), site S63 on the North Fork Siuslaw (Brophy 2009); and Hoquarten Slough in the Tillamook River estuary (Paul Levesque, personal communication).

When considering the overall composition of tidal swamp at Cox Island, plots S11 T04a and T04b can be combined. From this perspective, Sitka spruce and/or Pacific crabapple were dominant in both of the tidal swamp reference sites for this study. These two species have been documented as dominants in least-disturbed brackish forested tidal wetlands across Oregon's outer coast (Franklin and Dyrness 1998, Christy and Brophy 2007, Brophy 2009, Brophy *et al*. 2011). Red alder (*Alnus rubra*) was also dominant at S11 T04a, but only on the north side of the transect, which is slightly higher and slightly farther from the tidal channels carrying brackish water. This is consistent with our past field observations, which suggest that red alder is less tolerant of brackish salinity compared to Sitka spruce and Pacific crabapple.

Pacific wax myrtle was also relatively common at S11 T04a (Tables 8 and 9), but it was not dominant. This species was also found in least-disturbed tidal swamp at Bandon Marsh National Wildlife Refuge

(Brophy *et al.* 2014), but it has not been documented as dominant or common at any other brackish tidal swamps on Oregon's outer coast (Brophy *et al.* 2011).

As described in methods above, the forested tidal wetlands at both Cox Island and S30 contained fairly strong internal elevation gradients – primarily because of their small size and their landscape setting, on river banks and areas of fluvial deposition. Ideally, reference sites are larger and more homogeneous. However, due to the 97% loss of tidal swamps within the Siuslaw River estuary (Brophy 2005), no large, least-disturbed, homogeneous tidal spruce swamps remain as reference sites. For this reason, we emphasize comparison to other least-disturbed tidal swamp reference sites on Oregon's outer coast, and we recommend continuing this practice during final restoration design and post-project effectiveness monitoring for Waite Ranch continue.

Table 12 contains a complete list of species found in forested transects.

Table 8. Forested wetlands: 2014 basal area for tree species (ft^2/acre), by transect. Cox Island transects are indicated by S11 in the transect name. All trees in plots were native species. See Table 12 for common names.

		Basal area (ft^2/acre)		
Species	**Common name**	**S11 T04 a**	**S11 T04 b**	**S30 T03**
Alnus rubra	red alder	43.5	0	0
Malus fusca	Pacific crabapple	31.3	4.4	128.2
Myrica californica	Pacific wax myrtle	20.6	0	0
Picea sitchensis	Sitka spruce	0	107.1	0
Rhamnus purshiana	cascara	13.8	4.4	31.1
Total		**109.2**	**115.9**	**159.3**

Table 9. Forested wetlands: 2014 tree density by species (trees/acre), by transect. Cox Island transects are indicated by S11 in the transect name. All trees in plots were native species.

		Tree density (stems/A)		
Species	**Common name**	**S11 T04 a**	**S11 T04 b**	**S30 T03**
Alnus rubra	red alder	24	0	0
Malus fusca	Pacific crabapple	254	22	1337
Myrica californica	Pacific wax myrtle	206	0	0
Picea sitchensis	Sitka spruce	12	238	0
Rhamnus purshiana	cascara	109	26	29
Total		**605**	**286**	**1366**

Shrub species composition and density

Total shrub density was very low at Cox Island (S11 T04a; 415 stems/acre); the understory was very sparse in both S11 T04a and S11 T04b. Shrub density was higher at S30 T03 (4940 stems/acre) (Table 10), where the dominant shrubs included black twinberry (*Lonicera involucrata*) and little wild rose (*Rosa gymnocarpa*). Black twinberry is a common dominant in least-disturbed brackish tidal swamps; its density at S30 T03 was in the midrange of densities observed at other least-disturbed Oregon tidal swamps (193 to 8,261 stems/acre; Brophy 2009, Brophy *et al.* 2011). The Cox Island shrub layer was too sparse for dominance to be meaningful.

Table 10. Forested wetlands: 2014 shrub stem and sapling density (stems/acre), by transect. Cox Island transects are indicated by S11 in the transect name. Shrubs were not counted within S11 T04b.

		Stem density (stems/A)	
Species	**Common name**	**S11 T04 a**	**S30 T03**
Corylus cornuta	California hazelnut	0	73
Ilex aquifolium	English holly	28	0
Lonicera involucrata	black twinberry	0	3196
Malus fusca	Pacific crabapple	28	0
Myrica californica	Pacific wax myrtle	277	0
Ribes sp.	gooseberry	55	0
Rosa gymnocarpa	little wild rose	0	1453
Rubus spectabilis	salmonberry	0	218
Vaccinium ovatum	evergreen blueberry	28	0
Total		**416**	**4940**

Herbaceous vegetation in forest transects

The dominant herbaceous species at the S30 reference site was the invasive reed canarygrass (*Phalaris arundinacea*), which averaged 40% cover (Table 11). This species is often found at the landward margins of brackish tidal marsh, where fresher salinities and slightly higher elevations allow its persistence, as it is not tolerant of strongly brackish water (Brophy 2009, Brophy and Janousek 2013, Brophy *et al*. 2011). At Cox Island, total herbaceous cover was low (under 50%), and the species with the highest percent cover (13.5%) was sword fern (*Polystichum munitum*). Sword fern is a common moist forest understory species, and was often found growing on fallen logs in the tidal swamp at Cox Island.

Table 11. Forested wetlands: 2014 percent cover of herbaceous (understory) species, by transect, for species with more than 2% average cover. Cox Island transects are indicated by S11 in the transect name. Herbaceous cover was not measured in Cox Island transect S11 T04b.

	Average percent cover	
Species	**S11 T04 a**	**S30 T03**
Bromus vulgaris	6.4	0
Carex obnupta	3.2	19.6
Heracleum maximum	1.5	2.3
Holcus lanatus	2.9	0
Lonicera involucrata	5.3	10.3
Malus fusca	0	5.3
Oenanthe sarmentosa	4.1	0
Phalaris arundinacea	0	39.6
Polystichum munitum	13.5	4.2
Vicia nigricans	2.7	0
Total	**39.6**	**81.3**

Table 12. Complete list of species found within forested tidal wetland transects at reference sites, and their common names. There were no forested wetlands at Waite Ranch.

Species	Common name
Agrostis stolonifera	creeping bentgrass
Alnus rubra	red alder
Angelica lucida	sea watch
Atriplex patula	common orache
Bromus vulgaris	common brome
Carex leptopoda	slender-foot sedge
Carex obnupta	slough sedge
Cerastium sp.	chickweed
Corylus cornuta	California hazelnut
Galium aparine	stickywilly
Hedera helix	English ivy
Heracleum maximum	cow parsnip
Holcus lanatus	velvetgrass
Ilex aquifolium	English holly
Lonicera involucrata	black twinberry
Malus fusca	Pacific crabapple
Myrica californica	Pacific wax myrtle
Oenanthe sarmentosa	water parsley
Phalaris arundinacea	reed canarygrass
Picea sitchensis	Sitka spruce
Polystichum munitum	sword fern
Rhamnus purshiana	cascara
Ribes sp.	gooseberry
Rosa gymnocarpa	little wild rose
Rubus laciniatus	cut leaved blackberry
Rubus spectabilis	salmonberry
Rubus ursinus	Pacific blackberry
Rumex sp.	dock
Stellaria sp.	starwort
Streptopus sp.	twisted stalk
Vaccinium ovatum	evergreen blueberry
Vaccinium parvifolium	red huckleberry
Vicia nigricans	giant vetch

Sediment accretion and erosion

Sediment accretion and erosion were monitored at Waite Ranch and reference sites to establish baseline rates that can be used to determine post-restoration changes at Waite Ranch, as well as determine accretion rates at two least-disturbed marshes in the Siuslaw River Estuary. Establishing these rates will assist us in assessing the post-restoration rate of recovery from subsidence due to diking, which has a cascading effect on which plant communities establish and what fish utilize the sites.

Quantifying rates of accretion also allows us to determine whether or not these marshes will be able to keep up with projected rates of relative sea level rise for the area, information which is critical in understanding and planning future restoration projects.

Methods

To measure changes in sediment accretion or erosion, we used feldspar marker horizon plots and cryocore methods (Cahoon *et al*. 1996, 2000), plus sediment stakes (Roegner *et al.* 2009). Feldspar plots and sediment stakes were installed side by side, enabling direct comparison. Plot/stake placement was randomized within elevation strata to allow determination of accretion rate differences among elevations. However, plot/stake placement was not completely random within elevation strata; instead, plots and stakes were placed only in areas that would allow access within the cost and time limitations of the study. For example, at Cox Island, plots/stakes were placed in the single largest sub-basin accessible by boat at low tide; and at Waite Ranch, plots/stakes were placed in zones that will not be disturbed during restoration activities, to avoid damage by earthmoving equipment.

Twelve plots were sampled at Waite Ranch, 6 at Cox Island and 2 plots at S30. Plots and stakes were installed in fall 2013 and sampled a year later (November 2014), yielding an accretion rate per year. All sampling was prior to restoration, so these rates represent pre-restoration accretion rates for Waite Ranch. The elevation of each plot/stake setup was measured in October 2013 using a high-precision Trimble R8 GNSS receiver; data were differentially corrected using real-time kinematic (RTK) techniques against the Oregon Real-Time GPS Network (ORGN, http://theorgn.net).

Existing literature often relates accretion rates to wetland type (low marsh *versus* high marsh), so we categorized plot/stake setup locations as low or high marsh by relating plot elevations to the Mean Higher High Water (MHHW) tidal datum. Based on information in ESA-PWA (2011), MHHW was determined to be 7.43 ft (2.26 m) for Cox Island and 7.60 ft (2.32 m) for Waite Ranch and S30. Based on reference conditions data from Brophy *et al*. (2011) and onsite observations, plots at elevations below MHHW were considered low marsh and those above MHHW were considered high marsh (Table 13).

Table 13. Average elevation, locations, and habitat type of accretion plots at Waite Ranch, Cox Island and S30 (NAVD88 Geoid 12A). The horizontal coordinate system is NAD83(2011) (epoch 2010.00) UTM Zone 10N (m). See Appendix 1 for detailed spatial reference system and datum information.

Site	Plot	Year monitored	Habitat type	Elevation (ft)	Elevation (m)	Easting	Northing
Waite Ranch	WR.001	2014	low marsh	1.95	0.60	417378	4871233
Waite Ranch	WR.002	2014	low marsh	2.66	0.81	417423	4871130
Waite Ranch	WR.003	2014	low marsh	5.18	1.58	417446	4871072
Waite Ranch	WR.004	2014	low marsh	6.57	2.00	417459	4871046
Waite Ranch	WR.005	2014	low marsh	2.26	0.69	417546	4871383
Waite Ranch	WR.006	2014	low marsh	2.99	0.91	417762	4871300
Waite Ranch	WR.007	2014	low marsh	4.45	1.36	417812	4871282
Waite Ranch	WR.008	2014	low marsh	6.43	1.96	417842	4871273
Waite Ranch	WR.009	2014	low marsh	2.27	0.69	418003	4871779
Waite Ranch	WR.010	2014	low marsh	2.91	0.89	418053	4871745
Waite Ranch	WR.011	2014	low marsh	4.80	1.46	418106	4871695
Waite Ranch	WR.012	2014	high marsh	7.71	2.35	418122	4871678
Cox Island (S11)	CX.001	2014	low marsh	5.94	1.81	414428	4869242
Cox Island (S11)	CX.002	2014	low marsh	5.98	1.82	414598	4869470
Cox Island (S11)	CX.003	2014	low marsh	6.85	2.09	414710	4869660
Cox Island (S11)	CX.004	2014	low marsh	6.14	1.87	414632	4869247
Cox Island (S11)	CX.005	2014	low marsh	6.17	1.88	414753	4869301
Cox Island (S11)	CX.006	2014	high marsh	7.54	2.30	414866	4869319
S30	S30.001	2014	high marsh	7.77	2.37	418649	4871328
S30	S30.002	2014	high marsh	7.82	2.39	418681	4871328

Feldspar marker horizon method

Feldspar is a white-colored mineral that is recommended as a marker horizon, as it is usually easy to distinguish the white material from dark soils (Cahoon *et al*. 2000). In November 2013, a layer of feldspar was spread over a 0.25 m^2 area in the center of a larger demarcated plot (1 m^2). The feldspar layer thickness was about 5 to 15 mm. The corners of the 1 m^2 plot were marked with PVC poles to reduce human trampling of plots. A year later, in 2014, we returned to the plots with a pressurized canister (“Dewar”) filled with liquid nitrogen. The liquid nitrogen was used to sample two cores at each plot using the “cryo-coring” method (Cahoon *et al*. 1996). Four replicate measurements of the amount of material accreted (distance from top of soil to top of feldspar layer) were taken for each core (Photo 1). The core was then placed back into the ground. Core locations within the quadrat were recorded to ensure those areas would not be re-sampled in future years of monitoring.

Photo 1. Photo of feldspar marker horizon method. Sediment to the left of the white feldspar marker horizon has been deposited over the past year.

Sediment stake method

In November 2013, directly adjacent to each feldspar marker horizon plot, two sediment stakes (PVC pipe 1 in diameter, 1 m length, schedule 40) were placed 1 m apart, driven deeply into the ground and leveled. A meter stick was laid horizontally across both stake tops, and a vertical measurement was taken to the ground surface every 10 cm along the stick. Measurements were then averaged to get one measurement per plot and an estimate of standard error. A year later, in November 2014, the measurements were repeated, averaged, and the difference between the two measurements was calculated, yielding an accretion/erosion rate (mm/year). Erosion was indicated where the difference between the measurements was negative, and sediment accretion was indicated where the difference between the measurements was positive. Sediment stakes are not intended to provide precise measurement of small changes in sediment accretion or erosion, but were used as a back-up for the feldspar marker horizon plots. For example, if the feldspar layer is washed away, or if there is significant erosion at a site, sediment stakes can be used to document major elevation changes.

Statistical analysis

Marker horizon and sediment stake data were analyzed using two-way ANOVA to compare accretion/erosion rates between Waite Ranch and reference sites, and between high marsh and low marsh habitats. The LSMeans procedure was used as a post-hoc test to determine differences among levels. Marker horizon and sediment stake data were also analyzed by simple linear regression to investigate the relationship between sediment accretion rates and elevation. All analyses were completed in R (Version 3.1.1). Data were transformed if they did not meet the assumption of normality.

Results and discussion

Using the feldspar marker horizon method, we saw a significant difference between rates of sediment accretion at the reference sites versus Waite Ranch (p=0.002), with reference sites having higher rates of sediment accretion (5.13 mm/yr compared to 0.55 mm/yr at Waite Ranch) (Figure 12; Tables 14 and 15). Our range of accretion rates is comparable to other studies done in the PNW, which range from 1.8 to 5.8 mm/yr at reference sites (Rybczyk *et al.* 2011), and 2.4 to 4.8 mm/yr across the entire PNW (Thom 1992). Waite Ranch is currently diked off from the estuary, without any tidal influence; therefore only very limited amounts of sediment are introduced to the site during rare dike-overtopping events. After the restoration event occurs, we would expect to see higher rates of sediment accretion at Waite Ranch with the reintroduction of tidal forces. Studies along the Columbia River Estuary have shown that post-restoration, sediment accretion rates at restored sites often exceed those at the reference sites, likely due to the lower elevation of the restored sites due to pre-existing (pre-restoration) subsidence and compaction (Borde *et al*. 2011).

When evaluated across all sites (Waite Ranch and reference sites), accretion was lower in high marsh and higher in low marsh; however, the difference was not significant (Table 14 and 15). Restoration of the natural sediment regime at Waite Ranch will allow sediment to enter the site during daily tides and during river flood events. Newly recruited native plants species will trap sediment drifting through the water column, allowing more sediment to be retained (Borde *et al*. 2011). After restoration, we expect low marsh at Waite Ranch to have higher rates of sediment accretion compared to the high marsh. This is due to the higher inundation frequency and consequently higher sediment inputs for low marsh, compared to high marsh (Borde *et al.* 2011).

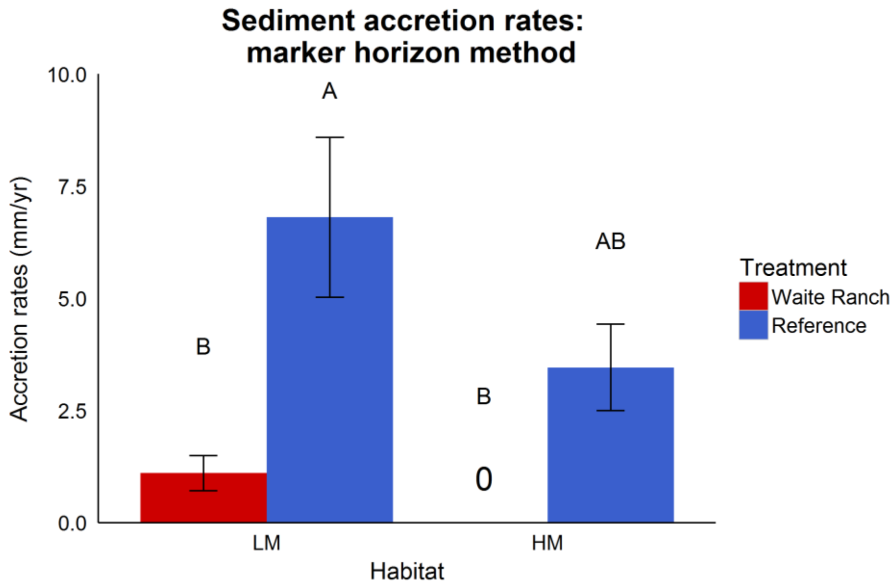


Figure 12. Sediment accretion rates at Waite Ranch and reference sites (Cox Island and S30), within low marsh (LM) and high marsh (HM) elevation categories (below and above MHHW respectively), using the marker horizon method. Only one plot at Waite Ranch fell in the high marsh category; it had no measured accretion. Columns with no letters in common are significantly different (two-way ANOVA, $p < 0.05$). Error bars represent one standard error.

Table 14. Summary of two-way ANOVA results for sediment accretion rates in two habitat types (low and high marsh) at Waite Ranch and reference sites (Cox Island and S30), using two different measurement methods. Bold text indicates significant differences ($p < 0.05$).

		F-value	**p-value**
Marker horizon	site	4.54	**0.05**
	habitat	1.66	0.22
	site x habitat	0.00	0.95
Sediment stakes	site	0.53	0.48
	habitat	0.63	0.44
	site x habitat	0.25	0.63

Table 15. Average yearly rates of sediment accretion in two habitat types (low and high marsh) at Waite Ranch and reference sites (Cox Island and S30), using two different measurement methods.

	Site	Habitat	Average accretion/erosion rate (mm/yr)	Standard error (N)
Marker horizon	Waite Ranch	low marsh	1.11	0.39 (11)
		high marsh	0.00	N/A (1)
	reference	low marsh	6.80	1.78 (5)
		high marsh	3.46	0.96 (3)
Sediment stakes	Waite Ranch	low marsh	5.24	3.11 (11)
		high marsh	4.71	N/A (1)
	reference	low marsh	7.17	3.36 (5)
		high marsh	12.62	4.67 (3)

Consistent with the general pattern of higher rates of accretion in low marsh and lower rates in high marsh, linear regression showed a significant relationship between elevation and sediment accretion rates at the reference sites (Figure 13; Table 16). That is, the accretion rate was higher at lower elevations than at higher elevation. This relationship is consistent with tidal wetland development models (Allen 1990) and observations by others on the West Coast (e.g. Thom 1992, Simenstad and Thom 1996, Borde *et al.* 2011). The relationship between accretion rate and elevation was much less clear at Waite Ranch (Figure 14; Table 16). Figure 15 shows the amount of sediment accretion in each plot, ordered by elevation, showing the lack of relationship between elevation and accretion rates at Waite Ranch. This lack of relationship is due to the fact that Waite Ranch is currently disconnected from tidal and fluvial sediment sources by its dike and tide gate. Because of this disconnection, natural elevational gradients in sediment deposition rates are disrupted. Once Waite Ranch is restored, we expect to see accretion rates follow a pattern similar to the reference sites, with higher accretion at lower elevations.

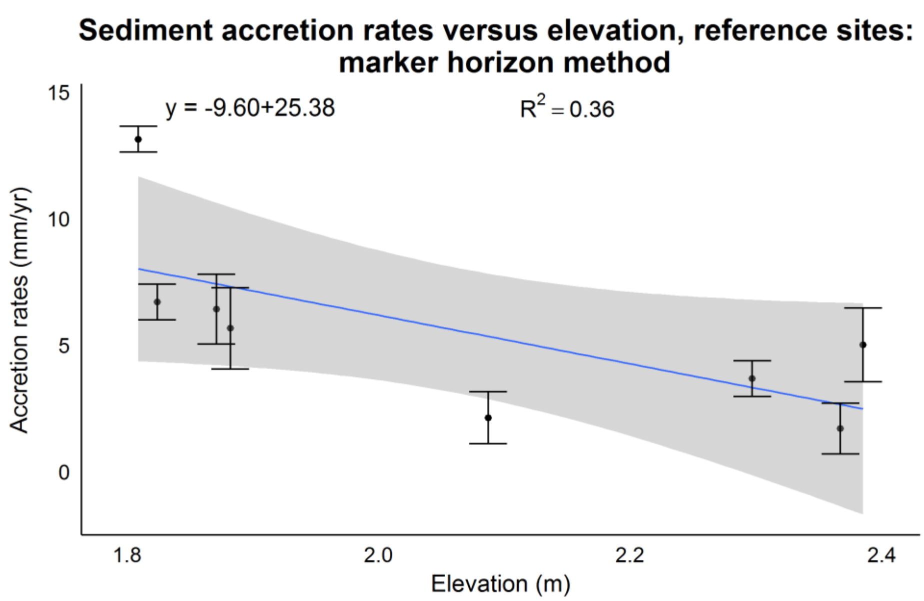


Figure 13. Accretion rates along an elevation gradient for all plots at reference sites on Cox Island and S30 using the marker horizon method. The gray region is one standard error from the predicted line. Error bars represent one standard error for each point.

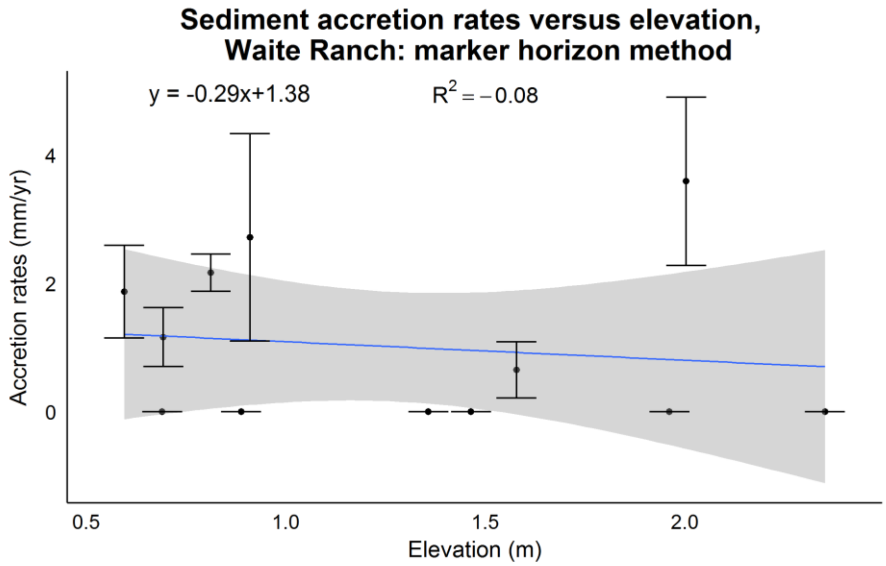


Figure 14. Accretion rates along an elevation gradient for all plots at Waite Ranch using the marker horizon method. The gray region is one standard error from the predicted line. Error bars represent one standard error for each point.

Table 16. Summary of simple linear regression results for sediment accretion rates at Waite Ranch and reference sites (Cox Island and S30) using two different measurement methods.

		p-value	R^2
Marker horizon	Waite Ranch	0.68	-0.07
	reference	0.06	0.36
Sediment stakes	Waite Ranch	0.49	-0.05
	reference	0.63	-0.11

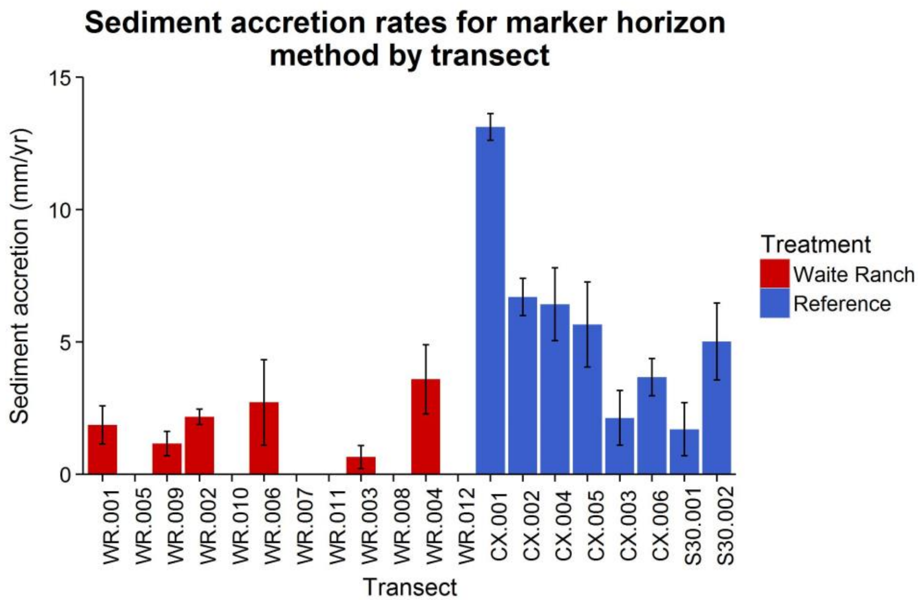


Figure 15. Sediment accretion using the marker horizon method at Waite Ranch (WR), Cox Island (CX) and S30. Transects are ordered by ascending elevation from left to right within each site, with WR.001 and CX.001 having the lowest elevation, WR.012 and S30.002 the highest. Error bars represent one standard error.

In contrast to the marker horizon method, sediment stake results showed no significant differences between sites, nor did they show clear relationships between elevation and accretion rate. These data are presented in Appendix 2.

Sediment accretion is a very useful metric that can indicate how marshes recover after subsidence caused by human alterations (Frenkel and Morlan 1991). Sediment accretion is also a major factor in whether our coastal wetlands will adapt to sea level rise, or be inundated by rising waters. We expect that after the restoration event occurs, sediment accretion rates will increase at Waite Ranch. Provided accretion exceeds sea level rise, the site should gradually approach its historic elevation (near MHHW). At that point, accretion rates are likely to approach those in high marsh at the reference sites.

Channel morphology

Channel morphology monitoring allows us to quantify in-stream habitats and compare restoration site channel development to reference conditions. As tidal forces are introduced to a restoration site, we expect to see channel morphology to shift towards equilibrium with amount of tidal flow introduced, providing an increasingly high quality and quantity of fish habitat and ultimately coming to resemble reference site channel morphology.

Methods

We used several methods to document the morphological differences between the restoration site channel network and the least-disturbed reference channel network. First, we compared channel network metrics (length, density, and sinuosity) at Waite Ranch to a complete field survey of channels at a least-disturbed tidal marsh in the Siletz River estuary (So *et al.* 2009). The Siletz survey (So *et al.* 2009) constitutes the most complete dataset available for tidal channel morphology at any Oregon tidal wetland. (Although comparison to the channel network at Cox Island would have been ideal, a complete survey of channels would be necessary for this purpose, which was well beyond the scope and budget of this project.) Second, we analyzed Waite Ranch channel morphology data collected in spring 2011 by Ward NorthWest, Inc. Ward Northwest surveyed 17 transects of the existing channel and ditch network within Waite Ranch using a total station and other high precision survey equipment. Third, our team measured channel morphology cross-sectional transects at Cox Island (S11) and S30 (Duncan Island) reference sites in spring 2014 using high-precision methods. Although the methods for the Waite Ranch and nearby reference sites differed, the datasets were successfully merged, and the metrics generated from the merged data are directly comparable across sites.

Waite Ranch channel cross-section survey

The Waite Ranch channel cross-section survey data were provided by Ward NorthWest Inc. in a geospatial point dataset coded with transect number, easting, northing, and elevation projected to the Oregon State Plane South horizontal coordinate system and referenced to the North American Vertical Datum (NAVD88). To match existing data, the dataset was reprojected to Universal Transverse Mercator (UTM) Zone 10 North using ArcGIS (version 10.2.1, ESRI, http://esri.com).

We created line features for each transect in the GIS by connecting the first measurement (left bank) to the last measurement (right bank) in the point dataset. Point measurements along each transect were snapped to the line feature to remove small (< 1 ft, < 30 cm) field measurement inaccuracies. Next, the distance from the start of each transect to each measurement point along the transect was calculated. For each transect, we calculated flowpath distance to the intersection of the channel and the main river from NAIP 2009 Imagery. As described in the following sections, various metrics that describe the channels were calculated from the dataset and compared to reference channels.

Reference sites channel cross-section survey

We surveyed channel morphology at Cox Island and S30 reference sites in March 2014. We installed 20 cross-sectional transects (called “transects” hereafter) at Cox Island and seven transects at S30. Within each site, transects were placed at elevations ranging from low in the tide-frame (where channels are likely to be widest) to small headwater channels (Figures 1-7). Semi-permanent monuments were installed at both ends of each transect. Monuments were constructed by driving 4 ft of rebar into the ground and encasing the rebar with 5 ft of 2 in schedule 40 PVC pipe. Monuments were set back from the bank edge to allow future measurements even if channels migrate laterally. Each monument was also measured with high-precision RTK GPS equipment to assign a horizontal position and elevation; positions were referenced to UTM Zone 10N and NAVD88 (see Appendix 1 for details on spatial reference system).

At each transect, we established a transect baseline using a 300 ft CAM-Line thin-diameter graduated metal tape stretched between transect endpost monuments. We used a laser level to measure elevation at topographic breaks along the transect relative to the endpost monument. For each elevation measurement, we recorded the distance of that measurement along the transect and attributed each feature with a description of what was measured (e.g., left bank, flowpath, right bank). Within the GIS, we calculated the horizontal position referenced in UTM Zone 10N and elevation referenced in NAVD88. For each transect, we calculated flowpath distance to the intersection of the channel and main river from NAIP 2009 Imagery.

Derived metrics

We combined channel morphology data from Waite Ranch, Cox Island, and S30 and calculated various metrics to describe and compare channel structure. Primary metrics included:

- Channel network metrics (length, density, and sinuosity)
- Bank-full width (BFW)
- Mean and maximum channel depth
- Mean channel elevation
- Minimum channel elevation (flowpath elevation)
- Bank slope
- Width-to-depth (WTD) ratio
- Flowpath depth / min elevation (i.e., lowest point in the transect)

Channel length and density are important expressions of available habitat for aquatic organisms such as salmon. Sinuosity is often very high in tidal channel networks, but much lower in restoration sites.

Bank-full width (BFW) is the width of the channel when fully filled with water. BFW was used to stratify the channels as described in the statistical analysis section below.

Mean channel depth is the average vertical distance between channel bottom and top of bank elevation. We calculated mean channel depth by taking average depth at 10% to 90% of channel width. Mean channel depth was calculated by taking the mean of linearly interpolated channel depths, determined at 10% intervals from 10% to 90% of BFW. Using this method, eight measurements were averaged regardless of channel width or field procedures; channel depths are therefore directly comparable among transects. We also calculated the maximum channel depth, representing the greatest measured depth in each transect.

While channel depth is a useful measure for describing the relationship between top of bank and channel bottom, it does not relate channel bottom to the tide frame. Therefore, we also calculated mean channel bottom elevation, which measures the elevation of channel bottom relative to the Mean Lower Low Water (MLLW) tidal datum (that is, the “tidal elevation”), instead of relative to top of bank. We also calculated the tidal elevation of the minimum channel elevation (that is, the “flowpath” elevation).

Width-to-depth (WTD) ratio summarizes width and depth of a channel into a metric that can be directly compared to similar channel networks in other systems (Rosgen 1994).

Statistical analysis

Many channel characteristics scale with channel size/drainage area, so we needed to account for drainage area when analyzing the data. However, determination of drainage area was beyond the scope of this project. Therefore, we sought a surrogate metric for drainage area. Of the channel characteristics we measured, bankfull width (BFW) was most closely related to channel size and subbasin area. Therefore, when comparing channel metrics between Waite Ranch and the reference sites, the analysis was stratified by BFW. We pooled Waite Ranch and reference site transects and assigned BFW classes using the quantile breaks algorithm implemented in the R package *classInt* (version 0.1-22). Means were compared using two-way ANOVA. Differences among levels were determined using LSMeans. All analyses were completed in R (Version 3.1.1). The smallest channels (BFW of 2.0 ft to 4.7 ft) were dropped from the analysis because channels of this size class were present only at the reference sites. For analysis of width-to-depth (WTD) ratio, we also added a supplementary analysis that excluded the largest BFW class (47.9 to 192.5 ft) because of the unusual characteristics of that BFW class. This allowed us to more thoroughly explore relationships between site and WTD ratio.

At Cox Island and S30, relationships between tidal elevation (*i.e.*, MLLW) and BFW, WTD, mean channel depth, and max channel depth were established by fitting polynomials in Microsoft Excel. This was not done for channels at Waite Ranch because the site currently has no tidal exchange, so relationships to tidal elevation were not expected to be meaningful.

Results and discussion

Ditching, channel dredging, diking, tide gate installation, and agricultural use at Waite Ranch have led to radical changes in the channels at Waite Ranch, as described below.

Channel network

Agricultural use and ditching at Waite Ranch have greatly decreased overall channel length, density, and sinuosity. The decrease is obvious through visual comparison to Cox Island (Figures 2 through 5). Quantitative comparison to the complete survey of least-disturbed tidal channels at Siletz Bay NWR (So *et al*. 2009) shows that ditching has reduced channel density by 87% (to only 13% of the Siletz site's density), and has reduced channel length by 91% (to only 9% of the Siletz site's length) (Figure 16). Sinuosity is near zero for Waite Ranch (i.e., the site's ditches are straight), compared to sinuosities of 1.5 to 2.0 for middle-order channels at the Siletz Bay site (So *et al*. 2009).

Figure 16. Channel network density comparison. **Left:** simplified channel (ditch) network in a 75 acre section of Waite Ranch. Channel density is about 0.02 mi/acre; channel length is about 1 mi. **Right:** dense, dendritic channel network in a 75 acre section of least-disturbed tidal marsh (Millport Slough, Siletz Bay NWR, surveyed by So *et al*. (2009). Channel density is about 0.15 mi/acre; channel length is about 11 mi. Figure from Brophy and Lemmer (2013).

Mean channel depth

Channels at Waite Ranch were significantly shallower than at the reference sites (Tables 17 and 18). Although the contrast was not significant for all BFW classes (Figure 17), the direction of the effect was always consistent (that is, Waite Ranch channels were shallower in all BFW classes). The effect of channel width was also significant (narrower channels were deeper than wider channels) (Tables 17 and 19, Figure 17). There was no significant interaction between BFW class and site (Table 17). These results are consistent with observations at other restoration sites: channels in former tidal wetlands converted to pasture are often shallower than those at nearby least-disturbed reference sites, because livestock trampling and machinery operations can degrade channel banks, and because subsidence affects the relationship between bank elevation and channel flowpath elevation. As part of our analysis we also performed statistics on maximum channel depth, representing the greatest measured depth in each transect. Results were similar to mean channel depth and are reported in Appendix 3.

Table 17. Results of two-way ANOVA for mean channel depth at Waite Ranch and reference sites (Cox Island and S30). The smallest channels (*i.e.*, “[2.0, 4.7)”) were excluded from the statistical analysis because they were missing from Waite Ranch. Bold text indicates significant differences (p < 0.05).

	F-value	**p-value**
site	39.40	**< 0.001**
BFW	8.70	**< 0.001**
site x BFW	2.47	0.07

Table 18. Mean channel depth at Waite Ranch and reference sites (Cox Island and S30). The smallest channels (*i.e.*, "[2.0, 4.7)") were excluded from this summary because they were absent from Waite Ranch.

Site	Mean depth (ft)	Standard error (ft) (N)
Waite Ranch	1.81	0.20 (17)
reference	3.09	0.14 (20)

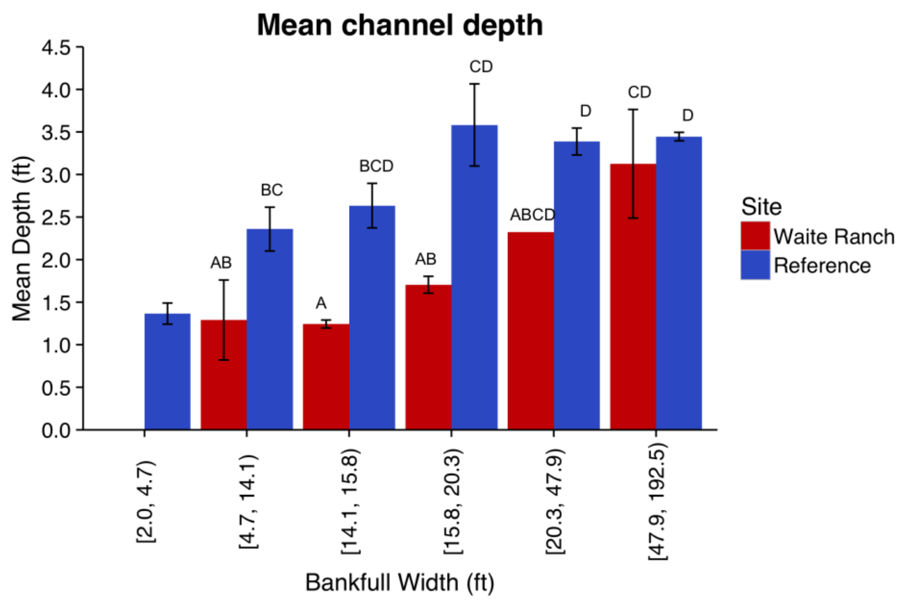


Figure 17. Mean channel depth by BFW class for Waite Ranch and reference sites (Cox Island and S30). Bars with no letters in common are significantly different ($p < 0.05$). Error bars represent one standard error. The smallest channels (*i.e.*, "[2.0, 4.7)") were excluded from the statistical analysis.

Table 19. Mean channel depth by BFW class at Waite Ranch and reference sites (Cox Island and S30).

Bankfull width (ft)	Site	Mean depth (ft)	Standard error (ft) (N)
[2.0, 4.7)	Waite Ranch	N/A	N/A (0)
	reference	1.37	0.12 (8)
[4.7, 14.1)	Waite Ranch	1.29	0.47 (2)
	reference	2.36	0.26 (5)
[14.1, 15.8)	Waite Ranch	1.24	0.05 (5)
	reference	2.63	0.26 (2)
[15.8, 20.3)	Waite Ranch	1.70	0.10 (6)
	reference	3.58	0.48 (2)
[20.3, 47.9)	Waite Ranch	2.32	N/A (1)
	reference	3.39	0.16 (6)
[47.9, 192.5)	Waite Ranch	3.13	0.64 (3)
	reference	3.45	0.05 (5)

Channel bottom elevation

Channel bottom elevation expresses the position of the channel bottom relative to the tides (as opposed to channel depth, which measures the depth of the channel below the wetland surface). Channel bottom elevations at Waite Ranch were significantly lower than the reference channels (Tables 20 and 21), generally by about 4-5 ft. The difference was statistically significant for all channel BFW classes except those 14.1 to 20.3 ft wide, and even those BFW classes followed the same pattern (Figure 18, Table 22). There was no significant interaction between site and BFW class (Table 20).

The lower channel bottom tidal elevation at Waite Ranch relates primarily to the subsidence that follows agricultural conversion (Turner 2004; Frenkel and Morlan 1991). From our measurements, it appeared that the largest channels at Waite Ranch were also deeply excavated to allow water to effectively drain from the site.

The preliminary restoration design for Waite Ranch (ESA PWA 2011) includes excavation of tidal channels that will connect to existing remnant channels and parts of the ditch system. Because the channel bottom elevations in these remnant channels and ditches are so low, excavated channel flowpaths will also need to be low to maintain a continuous longitudinal gradient. However, given the site's very low elevation, excavation of an extensive, deep channel network is not necessary. Channels in low elevation marshes and mud flats are generally very shallow, and tributaries to the excavated channels can be expected to form quickly, since tidal forcing will be strong throughout the site.

We also analyzed flowpath elevation (minimum channel elevation), which is the lowest measured elevation in each transect. The results were similar to mean channel elevation; they are reported in Appendix 3.

Table 20. Results of two-way ANOVA for mean channel bottom elevation at Waite Ranch and reference sites (Cox Island and S30). The smallest channels (*i.e.*, "[2.0, 4.7)") were excluded from the statistical analysis because they were absent from Waite Ranch. Bold text indicates significant differences ($p < 0.05$).

	F-value	p-value
site	60.01	**< 0.001**
BFW	6.66	**< 0.001**
site x BFW	1.40	0.260

Table 21. Mean channel bottom elevation at Waite Ranch and reference sites (Cox Island and S30). The smallest channels (*i.e.*, "[2.0, 4.7)") were excluded from this summary because they were absent from Waite Ranch.

Site	Mean elevation (MLLW ft)	Standard error (ft) (N)
Waite Ranch	0.38	0.55 (17)
reference	3.46	0.23 (20)

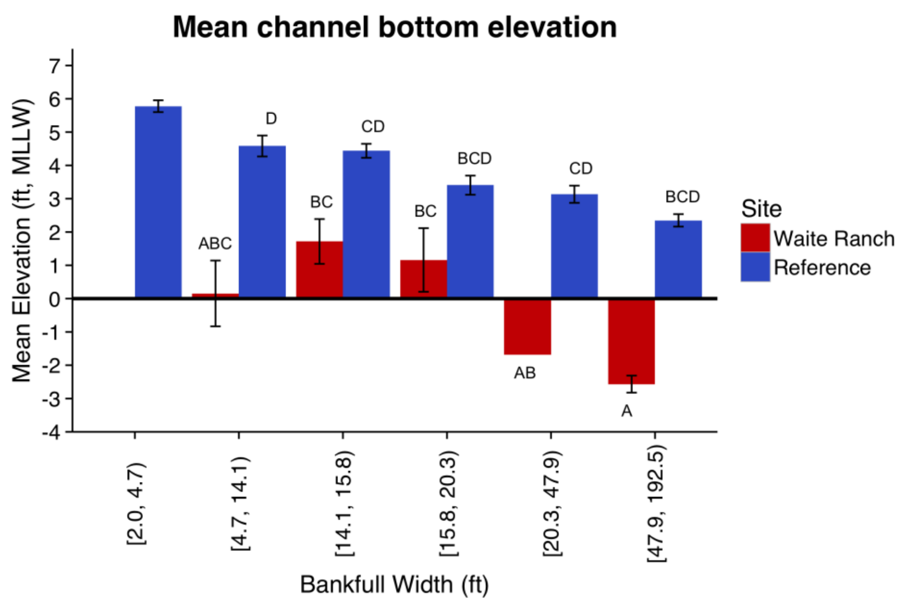


Figure 18. Mean channel bottom elevation by BFW class for Waite Ranch and reference sites (Cox Island and S30). Bars with no letters in common are significantly different ($p < 0.05$). Error bars represent one standard error. The smallest channels (*i.e.*, "[2.0, 4.7)") were excluded from the statistical analysis.

Table 22. Mean channel bottom elevation for each BFW class at Waite Ranch and reference sites (Cox Island and S30).

Bankfull width (ft)	Site	Mean elevation (MLLW ft)	Standard error (ft) (N)
[2.0, 4.7)	Waite Ranch	N/A	N/A (0)
	reference	5.78	0.18 (8)
[4.7, 14.1)	Waite Ranch	0.16	0.99 (2)
	reference	4.58	0.31 (5)
[14.1, 15.8)	Waite Ranch	1.72	0.67 (5)
	reference	4.44	0.21 (2)
[15.8, 20.3)	Waite Ranch	1.16	0.96 (6)
	reference	3.41	0.29 (2)
[20.3, 47.9)	Waite Ranch	-1.69	N/A (1)
	reference	3.13	0.26 (6)
[47.9, 192.5)	Waite Ranch	-2.57	0.26 (3)
	reference	2.35	0.19 (5)

Bank slope

In agricultural sites such as Waite Ranch, our field experience suggests the bank slope will be shallower than at reference sites. Machinery, livestock, and subsidence cause banks to slump and become degraded. At Waite Ranch, the average bank slope of the channels was 40% -- significantly less steep than reference site channels, which had a mean bank slope of 104% (Tables 23 and 24). The significance of the slope difference varied between BFW classes, but all BFW classes except the largest showed the same relationship (Waite Ranch bank slopes were much shallower) (Figure 19, Table 25). There was a significant interaction between site and BFW class (Table 23), showing that the relationship between restoration and reference site bank slopes varied by BFW class: specifically, the widest BFW class showed little difference in bank slope.

In narrow channels between 4.7 ft and 14.1 ft wide, average bank slope at reference sites was 181% slope and 50% slope at Waite Ranch (Table 25). In larger channels between 20.3 ft and 47.9 ft, slope was 84% slope at reference sites and 35% slope at Waite Ranch (Table 25). None of the BFW classes were statistically different from each other within Waite Ranch. Within the reference sites, the widest channels between 47.9 ft and 192.5 ft had a significantly shallower bank slope (mean 23%) compared to the other channels (Figure 19; Table 25). Bank slope relates closely to width-to-depth (WTD) ratio; see **Width-to-depth ratio** below for more discussion.

Table 23. Results of two-way ANOVA for channel bank slope at Waite Ranch and reference sites (Cox Island and S30). The smallest channels (*i.e.*, “[2.0, 4.7)”) were excluded from the statistical analysis because they were absent from Waite Ranch. Bold text indicates significant differences ($p < 0.05$).

	F-value	p-value
site	26.10	**< 0.001**
BFW	5.80	**0.002**
site x BFW	3.38	**0.02**

Table 24. Mean channel bank slope at Waite Ranch and reference sites (Cox Island and S30). The smallest channels (*i.e.*, "[2.0, 4.7)") were excluded from the statistical analysis because they were absent from Waite Ranch.

Site	Bank slope (% slope)	Standard Error (% slope) (N)
Waite Ranch	40%	2% (17)
reference	104%	17% (20)

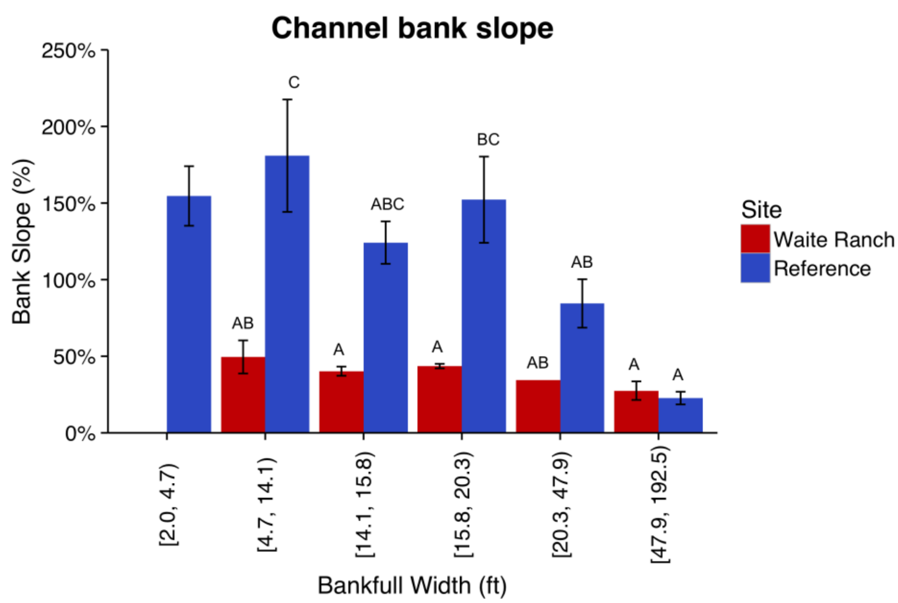


Figure 19. Channel bank slope by BFW class for Waite Ranch and reference sites (Cox Island and S30). Bars with no letters in common are significantly different ($p < 0.05$). Error bars represent one standard error. The smallest channels (*i.e.*, "[2.0, 4.7)") were excluded from the statistical analysis.

Table 25. Mean channel bank slope for each BFW class at Waite Ranch and reference sites (Cox Island and S30).

Bankfull width (ft)	Site	Bank slope (% slope)	Standard Error (% slope) (N)
[2.0, 4.7)	Waite Ranch	N/A	N/A (0)
	reference	155%	19% (8)
[4.7, 14.1)	Waite Ranch	50%	11% (2)
	reference	181%	37% (5)
[14.1, 15.8)	Waite Ranch	40%	3% (5)
	reference	124%	14% (2)
[15.8, 20.3)	Waite Ranch	44%	1% (6)
	reference	152%	28% (2)
[20.3, 47.9)	Waite Ranch	34%	N/A (1)
	reference	84%	16% (6)
[47.9, 192.5)	Waite Ranch	28%	6% (3)
	reference	23%	4% (5)

Width-to-depth ratio

Our field observations show that ditches in diked former tidal wetlands often have a high width-to-depth (WTD) ratio compared to the narrow, deep tidal channels in least-disturbed high marsh. However, this comparison is valid only for small and medium-sized channels; large, lower channels in least-disturbed tidal marsh often have much higher WTD depth ratios (i.e., they are much wider relative to their depth). In other words, WTD ratio is strongly related to channel size. This makes statistical comparison of WTC ratio between restoration and reference sites challenging. In addition, least-disturbed tidal wetlands have many small, narrow, deep channels, which make up the vast majority of the channel system (So *et al*. 2009). However, these small channels are almost always completely missing from restoration sites, since ditches are excavated to drain the site, and small channels are degraded by livestock and farm machinery operations, gradually disappearing over time. In other words, channel order (degree of branching, length of small tributaries *versus* larger channels) is not comparable between least-disturbed reference sites and restoration sites. Again, this complicates our efforts to compare WTD ratios.

Despite these challenges, we explored baseline WTD ratios at Waite Ranch and reference sites to help illustrate the impact of agricultural conversion on channels at Waite Ranch.

When all channels were pooled together, there was no significant difference in WTD ratio between Waite Ranch and reference sites, nor was there a significant difference among different BFW classes (Figure 20, Table 26). There was a significant interaction between site and BFW class, indicating that the WTD differences varied according to channel width (Table 26) – a result we expected, as described above. Although we calculated the mean WTD ratio, those data are not presented here; they are not considered meaningful because WTD ratio varied greatly by channel width.

Table 26. Results of two-way ANOVA for WTD ratio at Waite Ranch and reference sites (Cox Island and S30). The smallest channels (*i.e.*, “[2.0, 4.7)”) were excluded from the statistical analysis because they were absent from Waite Ranch. Bold text indicates significant differences ($p < 0.05$).

	F-value	p-value
site	0.29	0.59
BFW	1.06	0.39
site x BFW	4.12	**0.01**

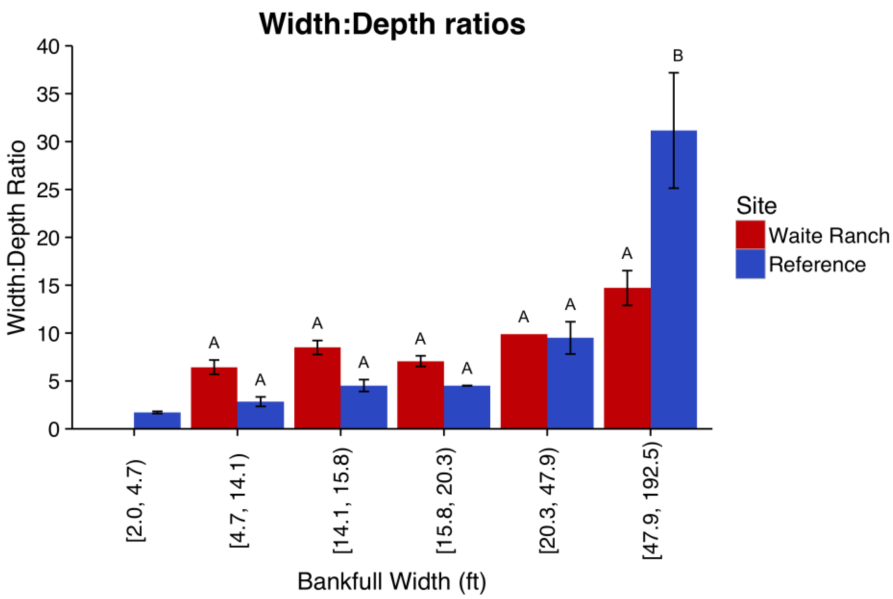


Figure 20. WTD ratios by BFW class for Waite Ranch and reference sites (Cox Island and S30). Bars with no letters in common are significantly different ($p < 0.05$). Error bars represent one standard error. The smallest channels (*i.e.*, “[2.0, 4.7)”) were excluded from the statistical analysis because they were absent at Waite Ranch.

In the small and medium BFW classes (4.7 to 47.9 ft), Waite Ranch channels consistently had a higher WTD ratio compared to reference channels (Figure 20, Table 27). The difference was greatest for small to medium channels (4.7 to 20.3 ft), where Waite Ranch channels had about double the WTD ratio compared to reference sites (Table 27). However, this relationship was reversed for the largest BFW class (47.9 to 192.5 ft); in this class, Waite Ranch channels had a WTD ratio of 14.71, compared to 31.16 at reference sites; the difference was significant ($p < 0.05$) (Figure 20, Table 27). This is probably because Cox Island channel shape reflects natural forces such as subbasin drainage area, landscape setting, and sediment regime, whereas Waite Ranch channels are artificially manipulated. In particular, construction of Highway 126 in the middle of the historic channel mouth at Waite Ranch has resulted in a notably narrower main channel “footprint” compared to the typical mouth for a least-disturbed wetland of this size in a similar landscape setting. Based on historic mapping of vegetation and water features (Hawes *et al.* 2008), the mouth of Waite Ranch’s main channel was probably over 460 ft (140 m) wide prior to the construction of Highway 126 – a width similar to the lower channel at Cox Island.

Table 27. Mean WTD ratio for each BFW class at Waite Ranch and reference sites (Cox Island and S30).

Bankfull width (ft)	Site	Mean WTD ratio	Standard error (N)
[2.0, 4.7)	Waite Ranch	N/A	N/A (0)
	reference	1.71	0.11 (8)
[4.7, 14.1)	Waite Ranch	6.44	0.74 (2)
	reference	2.84	0.50 (5)
[14.1, 15.8)	Waite Ranch	8.49	0.73 (5)
	reference	4.52	0.62 (2)
[15.8, 20.3)	Waite Ranch	7.07	0.56 (6)
	reference	4.51	0.02 (2)
[20.3, 47.9)	Waite Ranch	9.91	N/A (1)
	reference	9.50	1.68 (6)
[47.9, 192.5)	Waite Ranch	14.71	1.82 (3)
	reference	31.16	6.03 (5)

Because the construction of Highway 126 has strongly affected channel morphology in the largest BFW class at Waite Ranch, WTD ratio comparisons within this BFW class may be less useful than for other classes. Therefore, as an exploratory exercise, we re-ran the two-way ANOVA after excluding this BFW class. The results showed a significantly greater WTD ratio for Waite Ranch compared to the reference sites ($p < 0.05$; (Tables 28 and 29). BFW did not significantly affect this relationship (Table 28, Figure 21). Although this result matches better with our field observations described above, it is clear that interpreting width-to-depth ratio is challenging, and this metric may not be very useful for analyzing restoration effectiveness.

Table 28. Results of two-way ANOVA for WTD ratio at Waite Ranch and reference sites (Cox Island and S30), excluding the smallest and largest channels (*i.e.*, “[2.0, 4.7)” and “[47.9, 192.5)”). Bold text indicates significant differences ($p < 0.05$).

	F-value	p-value
site	6.45	**0.02**
BFW	0.85	0.48
site x BFW	0.49	0.69

Table 29. Mean WTD ratio at Waite Ranch and reference sites (Cox Island and S30), excluding the smallest and largest channels (*i.e.*, “[2.0, 4.7)” and “[47.9, 192.5)”).

Site	Mean WTD ratio	Standard error (N)
Waite Ranch	7.69	0.44 (14)
reference	5.95	1.03 (15)

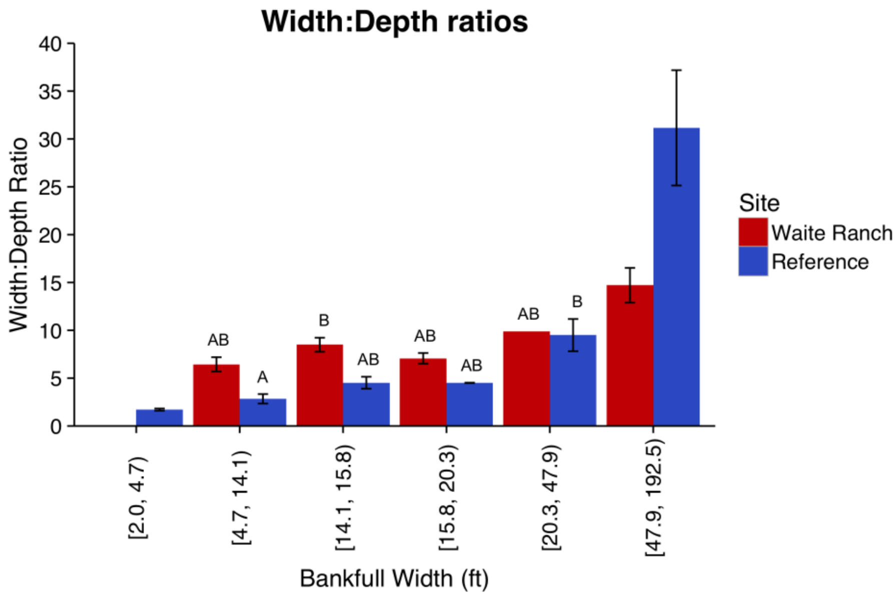


Figure 21. WTD ratios by BFW class for Waite Ranch and reference sites (Cox Island and S30). Bars with no letters in common are significantly different ($p < 0.05$). Error bars represent one standard error. The smallest and largest channels (*i.e.*, “[2.0, 4.7)” and “[47.9, 192.5)”) were excluded from the statistical analysis.

Longitudinal profiles of channel flowpath elevation

Longitudinal profiles describe the tidal elevation of the lowest part of the channel, from channel mouth to headwaters. Instead of only measuring elevation, profiles reveal dips and peaks within the flowpath. Figure 22 shows the shape of the longitudinal profile of each channel network from the mouth of the channel network (junction with the Siuslaw River) up to the highest channel morphology transect. Waite Ranch and Cox Island (S11) had similarly low gradients (under 0.5%) for most of their length. However, the gradient rose (to around 1%) in the smaller “headwaters” channels at Cox Island. S30 (Duncan Island) had a relatively high gradient throughout the small channel network, closely resembling the Cox Island channel network near 5,500 ft from the channel mouth. The rapid transition appears to begin at a channel bottom elevation of approximately 3 ft MLLW at both Cox Island and S30, in the high marsh zone. The entire length of the measured channel at S30 is in high marsh, which may explain its consistently high gradient (around 1%); other factors include the small size and resulting small drainage area. Our work at other least-disturbed high marsh sites near Bandon and Tillamook, OR has documented similar patterns (Estuary Technical Group, unpublished; Brophy *et al.* 2014). Relationships between channel network characteristics (length, density, area, gradient, etc.) and site characteristics (area, elevation, landscape setting, etc.) have been explored by Hood (2002, 2007, 2014), Coats *et al.* (1995), Williams *et al*. (2002), and others.

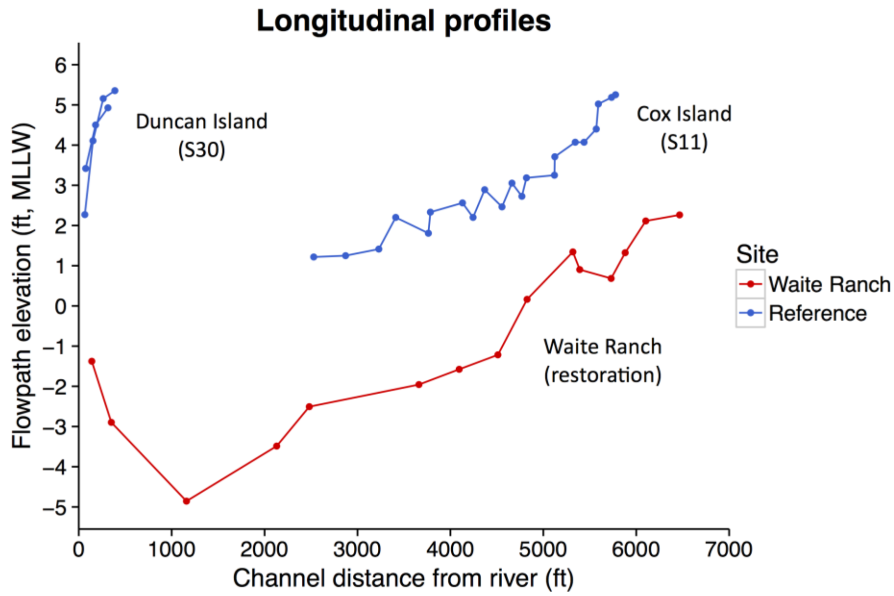


Figure 22. Longitudinal profiles for Waite Ranch and reference sites (Cox Island and S30). Each profile shows a rapid gain in elevation in channels higher in the landscape. S30 shows a particularly short channel network, corresponding to its small drainage area.

Reference sites: relationship between tidal elevation, BFW, channel depth, and bank slope

Our results at Waite Ranch and nearby reference sites (Cox Island and S30) provide insight into potential relationships between tidal elevation and various channel morphology metrics that may aid restoration channel design (Williams *et al*. 2002). One important relationship was between tidal elevation and BFW. Figure 23 shows the exponential relationship between BFW and MLLW at reference sites.

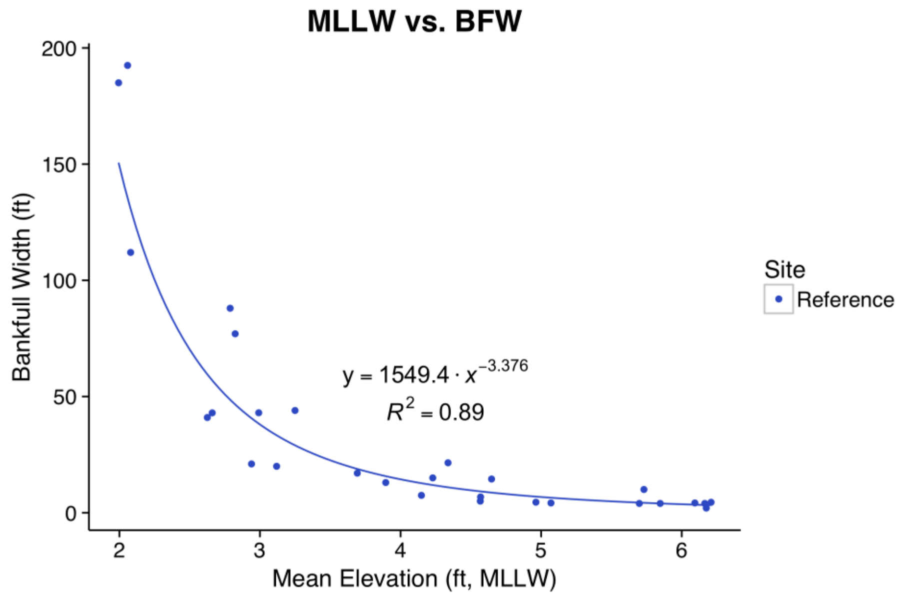


Figure 23. Bankfull width as a function of tidal elevation at Cox Island and S30 reference sites

There was also a strong relationship between tidal elevation and mean channel depth. As elevation in the tide frame was reduced, mean channel depth increased (Figure 24).

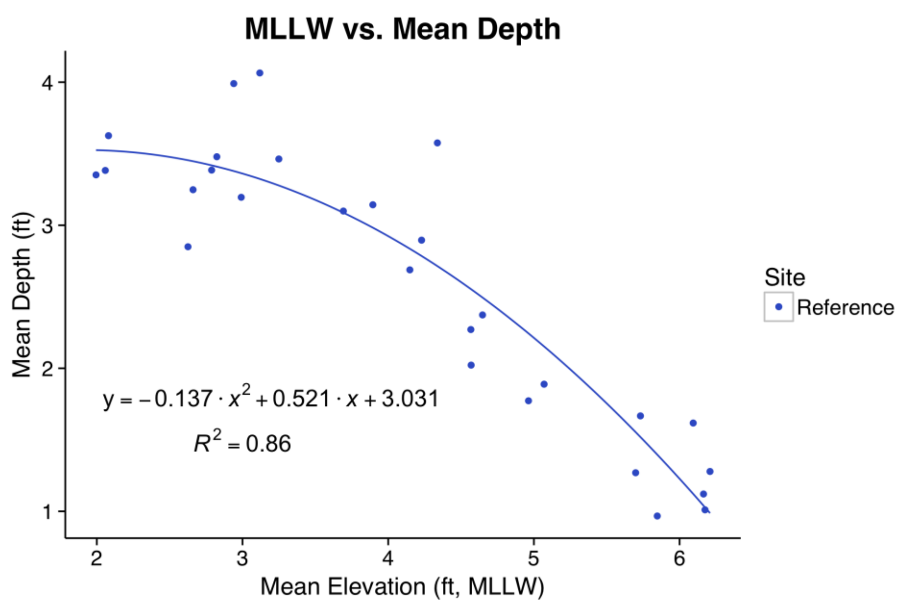


Figure 24. Channel depth (relative to top of bank) as a function of tidal elevation at Cox Island and S30 reference sites.

The relationship between tidal elevation and bank slope was noisy and likely not informative for engineering new channels. However, as elevation in the tide frame increased, bank slope appears to also increase (Figure 25).

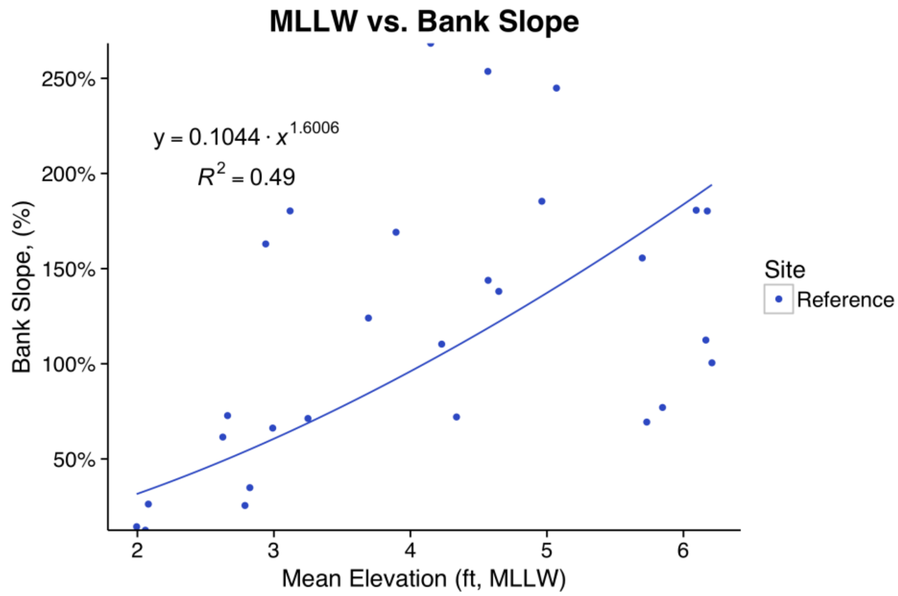


Figure 25. Channel bank slope as a function of tidal elevation at Cox Island and S30 reference sites.

Summary

Our results fit with expectations for the diked, ditched, and disconnected hydrological context of Waite Ranch. Channels at Waite Ranch have a lower absolute elevation, reduced channel depth relative to top of bank, shallower bank slopes, and therefore larger width-to-depth ratios. Loss in tidal elevation of channels at Waite Ranch is likely the result of loss of soil organic matter (*via* drainage and oxidation) and soil compaction by livestock, leading to local subsidence. Comparison to the nearby S30 reference site suggests that subsidence has probably been 3 to 6 ft at Waite Ranch.

The main channel at Waite Ranch (Prosser Slough) appears to have been excavated near its junction with the Siuslaw River and probably along Highway 126; its channel bottom elevation is much lower than the lower portions of channels at the Cox Island reference site (Figures 18 and 22). Across all channels at Waite Ranch, bank slope is significantly less than at the reference sites (Figure 19). Our measurements at the reference sites yielded strong relationships between tidal elevation and channel morphology metrics (bankfull width, channel depth, and bank slope) (Figures 23 through 25).

For bank slope and WTD ratio, differences between Waite Ranch and reference sites were strongest in small to medium-sized channels. Therefore, monitoring channel morphology at representative locations along the full length of the channel system is important to understanding channel recovery.

Recommendations

Future monitoring

Methods

Post-restoration effectiveness monitoring should use the same methods as the baseline monitoring, to allow comparisons and determination of project effectiveness. The recommended effectiveness monitoring program is included in the Waite Ranch Interim Management Plan (Brophy and Lemmer 2013).

Soils and groundwater in forested wetlands

Data on soils and groundwater have been vital to our understanding of tidal swamps elsewhere on the Oregon coast (e.g. Brophy 2009, Brophy *et al*. 2011). However, soils and groundwater monitoring for Waite Ranch and reference sites was conducted in 2010, prior to establishment of the forested wetland transects. Therefore, we do not yet have data on soils and groundwater for the Cox Island and S30 tidal swamps. We recommend obtaining soils and groundwater data for these sites during future monitoring efforts for the Waite Ranch project. Combined with post-restoration data on soils and groundwater at Waite Ranch, these data will be very important for understanding restoration trajectory and success of plantings at Waite Ranch, and for relating this project's outcomes to other data across the Oregon coast and the Pacific Northwest.

Accretion and vegetation monitoring

To provide further data on likely restoration trajectories at Waite Ranch, we recommend future monitoring efforts include measurements of vegetation and accretion rates at lower elevations at the site. Accretion monitoring for these areas can begin after restoration, once site work has been completed and the risk of plot disturbance due to earthmoving activities is past. Planning for any monitoring at low elevations should recognize the limited tide windows during which these lower elevations will be accessible.

Channel morphology monitoring

For two channel morphology metrics (bank slope and WTD ratio), differences between Waite Ranch and reference sites were strongest in small to medium-sized channels. The largest channels did not follow patterns that were clear throughout the rest of the site. Therefore, we recommend monitoring channel morphology at representative locations along the full length of the channel system, to allow accurate assessment of channel characteristics and restoration site channel development.

Salinity and planting plans

Baseline water quality monitoring at Waite Ranch and reference sites was conducted by the Siuslaw Watershed Council during 2011-2014 through the Council's Volunteer Water Quality Monitoring Program. Data collected include salinity, dissolved oxygen, and water temperature. The sample plan (developed with input from Laura Brophy of the Estuary Technical Group) involved monthly sampling at or near flood tide. Results (Steinberg 2014) showed surprisingly high salinities within Waite Ranch, with peaks reaching 15 to 25 ppt during the dry summer season. These salinities were higher than levels observed in the adjacent Siuslaw River (Steinberg 2014). Observations strongly suggest that despite the site's dike/tide gate system, there was salt intrusion either through leaks in the tide gate or through seepage under Highway 126 from the tidal slough to the north of the highway; and evaporative concentration of salt may have occurred inside Waite Ranch due to summer warming of surface waters. Such evaporative concentration appears to have occurred at restoration sites elsewhere in Oregon (e.g. Brophy and Janousek 2013).

As the final restoration design is developed for Waite Ranch, planting plans should incorporate understanding of salinity levels in adjacent reference sites and water bodies, as well as the possibility that post-restoration salinities may vary considerably from these reference data. For example, post-restoration salinities at the Pixieland restoration site in the Salmon River estuary were somewhat higher than expected, which may have affected survival of woody plantings (Brophy and Janousek 2013). Delaying woody plantings for a year after restoration of tidal flow would allow time for monitoring post-restoration salinity, which would assist development of an appropriate planting plan. However, delaying woody plantings may be undesirable from an engineering point of view. The trade-offs between early and delayed woody plantings should be considered in final restoration design.

Regardless of the salinity data used for developing the post-restoration planting plan at Waite Ranch, the focus should be on species tolerant of brackish salinities, such as Sitka spruce, Pacific crabapple, black twinberry, and cascara. Freshwater riparian species such as western red cedar (*Thuja plicata*), vine maple (*Acer circinatum*), Pacific ninebark (*Physocarpus capitatus*), and Douglas spiraea (*Spiraea douglasii*) have sometimes been planted on river banks at brackish tidal wetland restoration sites, but these are not recommended for Waite Ranch, since brackish salinities are likely to result in low survival.

Channel excavation methods

Our past work has highlighted the need to dig channels at restoration sites with grade control relative to tidal elevation (tidal datums), not relative to top of bank (Brophy *et al.* 2014). Grade control relative to tidal elevation is an accepted best practice for tidal restoration. When channels are dug relative to top of bank – a practice sometimes adopted to save costs -- an irregular longitudinal profile can result, with reverse gradients in some channel reaches, or "humps" in the profile that pool water (Brophy *et al.* 2014). Areas that do not drain freely may result in conditions less suitable for juvenile fish or other aquatic organisms, and channels with irregular longitudinal profiles may take longer to equilibrate towards reference conditions (although ultimately, that equilibration is still expected to occur).

As described in **Channel bottom elevation** above, flowpaths of excavated channels at Waite Ranch will need to be low to connect to the existing ditches and remnant channels. However, given the site's very low elevation, excavation of an extensive, deep channel network is probably not necessary. Tributary channels are expected to form quickly, since tidal forcing will be strong due to twice-daily inundation across most of the site.

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Appendix 1. Spatial reference information

GPS data collected in support of Cox Island and S30 channel morphology, vegetation, and sediment accretion work was collected using the spatial reference system described in Table A1.1. Channel morphology measurements at Waite Ranch used an unknown geoid to compute NAVD88 orthometric heights. We assume that this data was collected using NGS Geoid 03 and adjusted the data to NAVD88 (Geoid 12A) for our analysis.

Table A1.1. Horizontal and vertical coordinate systems for ETG-collected GPS data

Horizontal Coordinate System	Universal Transverse Mercator (UTM) Zone 10 North
Horizontal Datum	North American Datum of 1983 (NAD83) Adjustment 2011 Epoch 2010.00
Vertical Datum	North American Vertical Datum of 1988 (NAVD88)
Geoid model	NGS Geoid 12A
Units	Meters

Feet / Meters conversion

ETG performs all analysis in meters and converts to feet when necessary for reporting. We use the International Foot, which is equal to exactly 0.3048 m.

Tidal Datums

The tidal datums shown in the table below were derived as follows:

- For Waite Ranch, the values are taken directly from ESA PWA 2011, which reported elevations of 7.60 ft and -0.06 ft for MHHW and MLLW respectively. Although not stated in that report, the elevations presented most likely used the Geoid03 model rather than the Geoid model used in our study (Geoid12A). Therefore, we converted the datums to Geoid12A, resulting in a 14cm increase in elevation for each datum.
- For Cox Island (S11), we used data reported by ESA PWA (2011), interpolating between the values for Waite Ranch and Florence based on the proportional distance to Cox Island.
- For S30 (Duncan Island), we assumed tidal datums would be about the same as Waite Ranch, since the site is very close to Waite Ranch.

	NAVD88 (NGS Geoid 12A)		
Tidal datum	Waite Ranch	Cox Island (S11)	S30 (Duncan Island)
MHHW	2.359 m (7.74 ft)	2.265 m (7.43 ft)	2.359 m (7.74 ft)
MLLW	0.025 m (0.08 ft)	-0.111 m (-0.36 ft)	0.025 m (0.08 ft)

Appendix 2. Sediment accretion and erosion rates using sediment stake method

As mentioned in the methods section, sediment stakes were used as a backup to feldspar plots, or to indicate any significant erosion at a plot. They were not expected to provide high-accuracy data on sediment accretion or erosion. Average rates of accretion/erosion using this method ranged from -8.71 mm/yr (erosion) at Waite Ranch to 28.14 mm/yr (accretion) also at Waite Ranch. There were no consistent relationships between rates of sediment accretion between the two methods (Figure A2.1). Rates using the sediment stake method were as high as 28.14 mm/yr, but the standard error varied drastically using the sediment stake method compared to the marker horizon method (Figure A2.2).

Because of the high variability in accretion as measured using the sediment stake method, we recommend disregarding the data resulting from this method. Instead, data from the feldspar marker horizon method should be used to understand contrasts in accretion rates between Waite Ranch and the reference sites.

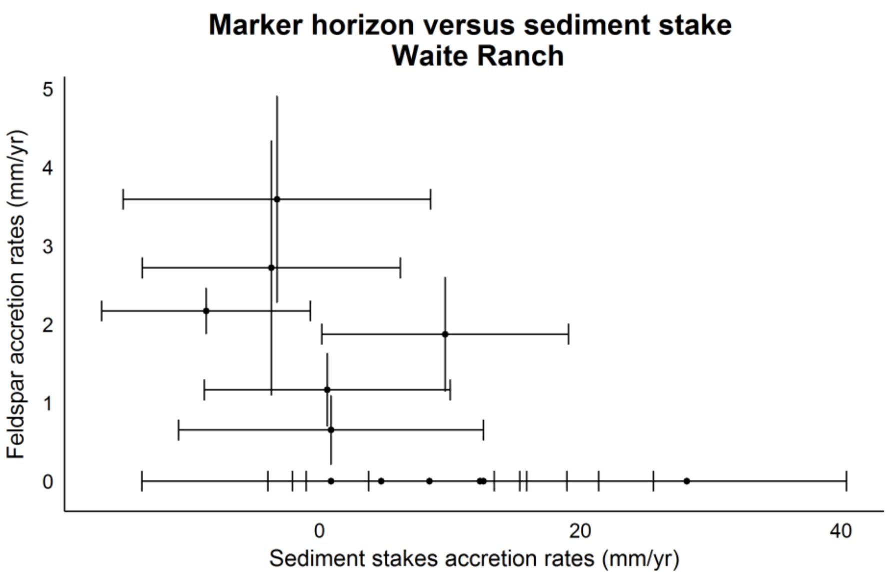

Figure A2.1. Scatter plot of sediment accretion/erosion rates using the feldspar marker horizon method and sediment stakes method at Waite Ranch. Error bars on the y-axis are one standard error of accretion rates using the feldspar method. Error bars on the x-axis are one standard error of accretion rates using the sediment stake method.

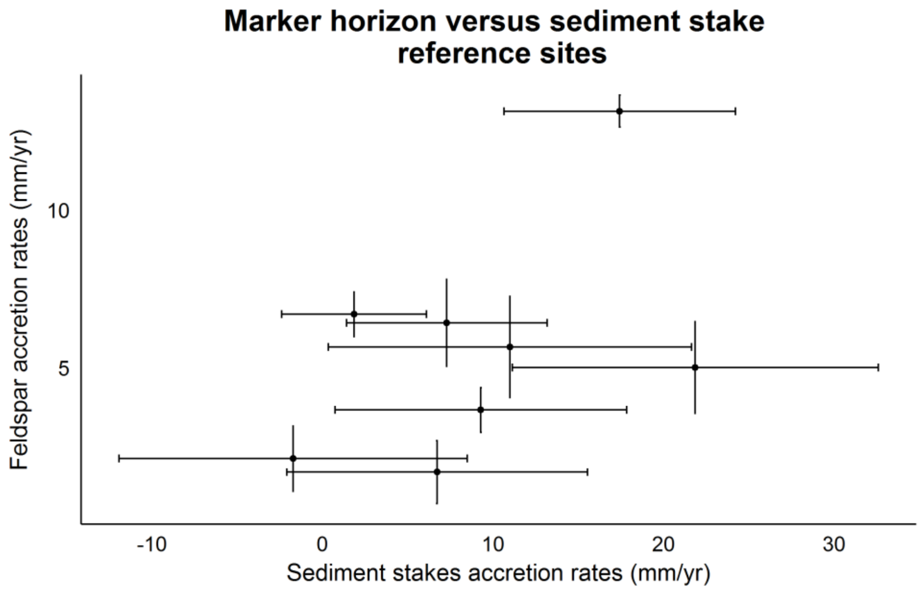

Figure A2.2. Scatter plot of sediment accretion/erosion rates using the feldspar marker horizon method and sediment stakes method at reference sites (Cox Island and S30). Error bars on the y-axis are one standard error of accretion rates using the feldspar method. Error bars on the x-axis are one standard error of accretion rates using the sediment stake method.

There were no significant differences between Waite Ranch and reference sites, or between high marsh and low marsh in accretion rates when using the sediment stake method (Figure A2.3; Table A2.1). There also was no significant relationship between elevation and accretion rates using the sediment stake method (Figures A2.4 and A2.5).

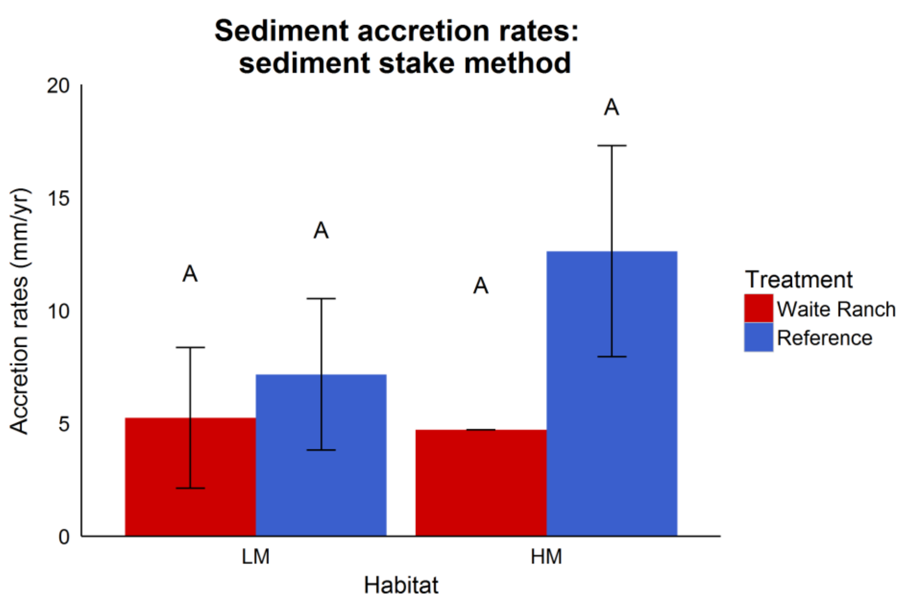

Figure A2.3. Waite Ranch versus reference sites comparisons for sediment accretion rates in low marsh (LM) and high marsh (HM) habitats using the sediment stake method. Bars with no letters in common are significantly different ($p < 0.05$). Error bars represent one standard error.

Table A2.1. Summary of two-way ANOVA results for sediment accretion rates in two habitat types (low and high marsh) at Waite Ranch and reference sites (Cox Island and S30), using two different measurement methods. Bold text indicates significant differences ($p < 0.05$).

		F-value	p-value
Marker horizon	site	4.54	**0.05**
	habitat	1.66	0.22
	site x habitat	0.00	0.95
Sediment stakes	site	0.53	0.48
	habitat	0.63	0.44
	site x habitat	0.25	0.63

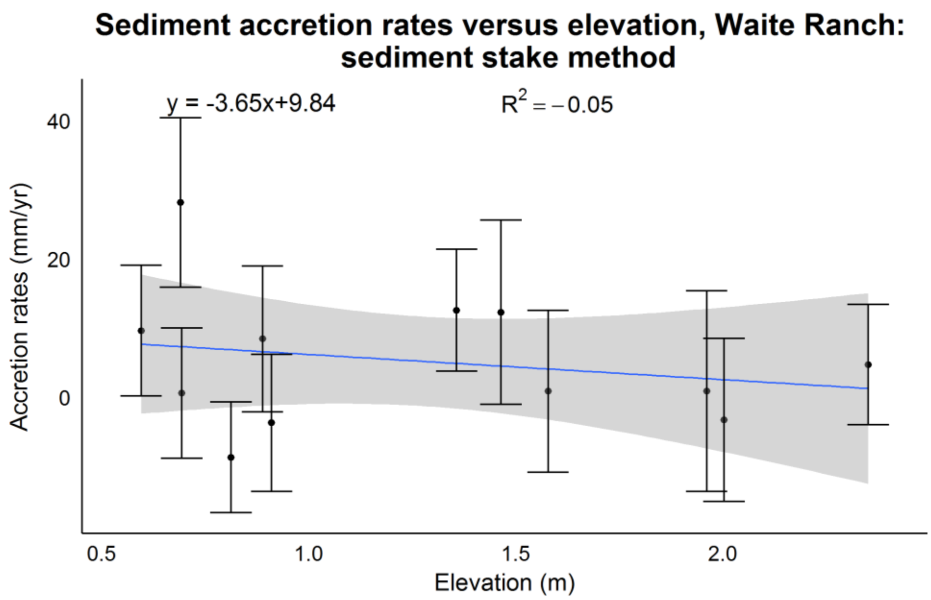

Figure A2.4. Accretion rates along an elevation gradient for all plots at Waite Ranch using the sediment stake method. The gray region is one standard error from the predicted line. Error bars represent one standard error for each point.

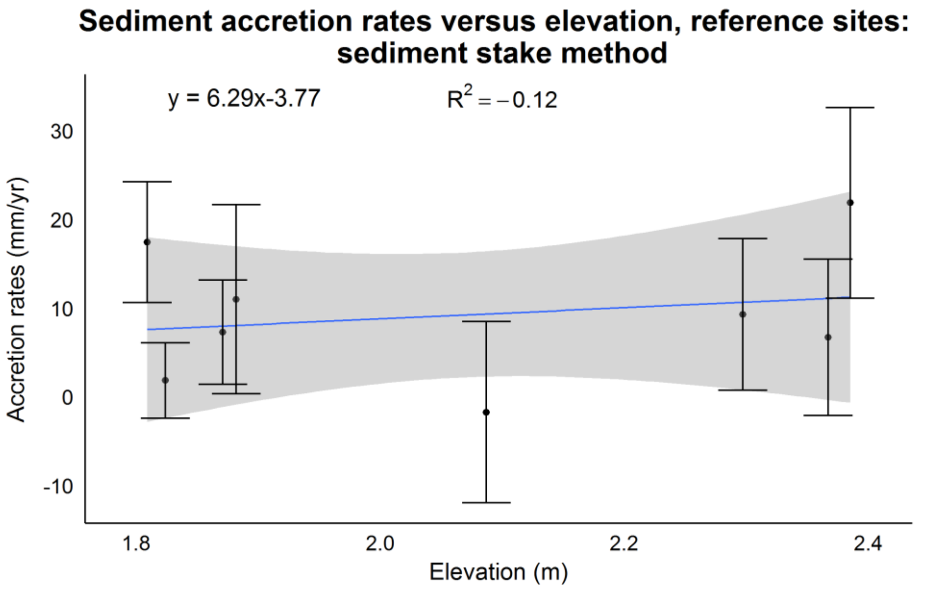

Figure A2.5. Accretion rates along an elevation gradient for all plots for reference sites on Cox Island and S30 using the sediment stake method. The gray region is one standard error from the predicted line. Error bars represent one standard error for each point.

Appendix 3. Maximum channel depth and minimum channel elevation

Maximum channel depth

Maximum channel depth represents the distance from top of bank to the flowpath of the channel. While similar to mean channel depth, this metric differs from mean channel depth where the slope of the channel bottom resembles a stronger “V” shape than a plane. Mean maximum channel depth was 2.56 ft at Waite Ranch and 3.78 ft at the reference sites and statistically significant (Table A3.1). Channels were also statistically significant among different BFW classes (Table A3.2) but without a significant interaction between site and BFW class (Table A3.2). The difference between Waite Ranch and reference sites within each BFW class was not statistically different (Figure A3.1).

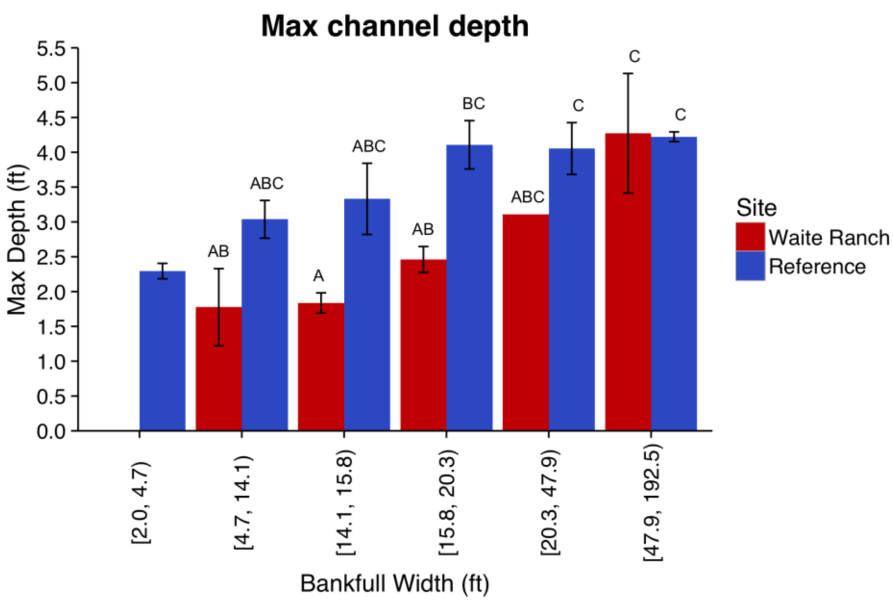

Figure A3.1. Maximum channel depth by BFW class for Waite Ranch and reference sites (Cox Island and S30). Bars with no letters in common are significantly different ($p < 0.05$). Error bars represent one standard error.

Table A3.1. Maximum channel depth at Waite Ranch and reference sites (Cox Island and S30), excluding the smallest channels (*i.e.*, "[2.0, 4.7)").

Site	Mean max channel depth (ft)	Standard error (ft) (N)
Waite Ranch	2.56	0.27 (17)
reference	3.78	0.17 (20)

Table A3.2. Maximum channel depth two-way ANOVA results summary for channels at Waite Ranch and reference sites (Cox Island and S30). The smallest channels (*i.e.*, "[2.0, 4.7)") were excluded from the statistical analysis. Bold text indicates significant differences (p < 0.05).

	F-value	p-value
site	15.49	**< 0.001**
BFW	7.52	**< 0.001**
site x BFW	1.63	0.195

Table A3.3. Maximum channel depth for each BFW class at Waite Ranch and reference sites (Cox Island and S30).

Bankfull width (ft)	Site	Average depth (ft)	Standard error (ft) (N)
[2.0, 4.7)	Waite Ranch	NA	N/A (0)
	reference	2.29	0.11 (8)
[4.7, 14.1)	Waite Ranch	1.78	0.55 (2)
	reference	3.04	0.27 (5)
[14.1, 15.8)	Waite Ranch	1.84	0.14 (5)
	reference	3.33	0.51 (2)
[15.8, 20.3)	Waite Ranch	2.46	0.19 (6)
	reference	4.11	0.35 (2)
[20.3, 47.9)	Waite Ranch	3.11	N/A (1)
	reference	4.05	0.37 (6)
[47.9, 192.5)	Waite Ranch	4.27	0.86 (3)
	reference	4.22	0.07 (5)

Flowpath elevation

Flowpath elevation is the absolute tidal elevation of the lowest point measured within a channel. The flowpath elevation of reference channels was statistically higher than Waite Ranch channels (Tables A3.4 and A3.5). There was no significant interaction between site and BFW class (Table A3.5). Flowpath tidal elevation of channels between 4.7 ft and 14.1 ft wide, between 20.3 ft and 47.9 ft, and between 47.9 ft and 192.5 ft wide at Waite Ranch were statistically different from channels of the same width at reference sites (Figure A3.2). Mean channel flowpath elevation at Waite Ranch was -0.37 ft MLLW compared to 2.76 ft MLLW at references sites.

Table A3.4. Mean flowpath elevation at Waite Ranch and reference sites (Cox Island and S30), excluding the smallest channels (*i.e.*, "[2.0, 4.7)").

Site	**Mean flowpath elevation (MLLW ft)**	**Standard error (ft) (N)**
Waite Ranch	-0.37	0.58 (17)
reference	2.76	0.23 (20)

Table A3.5. Flowpath elevation two-way ANOVA results summary for channels at Waite Ranch and reference sites (Cox Island and S30). The smallest channels (*i.e.*, "[2.0, 4.7)") were excluded from the statistical analysis. Bold text indicates significant differences (p < 0.05).

	F-value	**p-value**
site	68.41	**< 0.001**
BFW	8.99	**< 0.001**
site x BFW	1.82	0.16

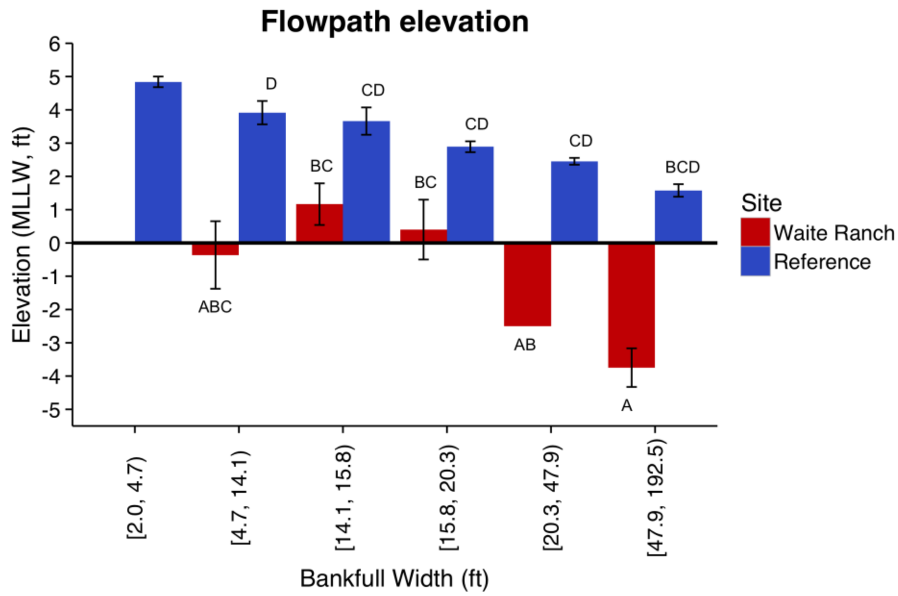

Figure A3.2. Flowpath elevation by BFW class for Waite Ranch and reference sites (Cox Island and S30). Bars with no letters in common are significantly different ($p < 0.05$). Error bars represent one standard error. The smallest channels (*i.e.*, "[2.0, 4.7)") were excluded from the statistical analysis.

Channels between 20.3 ft and 147.9 ft wide at Waite Ranch were about 5.0 ft below channels of the same width at reference sites and statistically different (Figure A3.2, Table A3.6). The smallest channels tested (between 4.7 ft and 14.1 ft wide) were statistically different from each other and Waite Ranch channels. Within these channels, flowpath elevation was 4.3 ft below reference channels (Table A3.6). This relationship was similar for the largest channels between 47.9 ft and 192.5 ft wide where the mean channel elevation of Waite Ranch channels were 5.3 ft below channels of the same width at reference sites and statistically different (Figure A3.2, Table A3.6).

Table A3.6. Mean flowpath elevation for each BFW class at Waite Ranch and reference sites (Cox Island and S30).

Bankfull width (ft)	Site	Flowpath elevation (MLLW ft)	Standard error (ft) (N)
[2.0, 4.7)	Waite Ranch	N/A	N/A (0)
	reference	4.84	0.16 (8)
[4.7, 14.1)	Waite Ranch	-0.36	1.02 (2)
	reference	3.91	0.35 (5)
[14.1, 15.8)	Waite Ranch	1.17	0.63 (2)
	reference	3.66	0.41 (2)
[15.8, 20.3)	Waite Ranch	0.40	0.90 (6)
	reference	2.89	0.16 (2)
[20.3, 47.9)	Waite Ranch	-2.51	N/A (1)
	reference	2.45	0.10 (6)
[47.9, 192.5)	Waite Ranch	-3.75	0.58 (3)
	reference	1.58	0.19 (5)