Assessing the effectiveness of restoration actions in the Nisqually Delta

Report To: National Fish and Wildlife Foundation,
Puget Sound Marine Conservation Fund. #2006-0180-017

REPORT BY:

US GEOLOGICAL SURVEY, WESTERN ECOLOGICAL RESEARCH CENTER

IN PARTNERSHIP WITH

THE NISQUALLY NATIONAL WILDLIFE REFUGE

AND THE

NISQUALLY INDIAN TRIBE

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EXECUTIVE SUMMARY

This final report was conducted under the National Fish and Wildlife Foundation, Puget Sound Marine Conservation Fund Grant # 2006-0180-017 for the period of 4/1/2010 to 9/30/2011. The monitoring plan leverages support from multiple sources. Portions of results were funded by other sources but are presented here for clarity.

- **Document habitat value of managed freshwater marsh enhancement**
  - Remote loggers: A remote logging system has completed trial testing, programming, data logging in an Access database, and troubleshooting for estuarine deployment. Range testing and test deployments are underway at the Nisqually National Wildlife Refuge.
  - Vegetation survey: A vegetation type map that focuses on invasive species and forage plants for waterfowl has been completed. Almost 50% of the freshwater wetlands are comprised of high quality forage vegetation for waterfowl.
  - Area and VCP Bird Surveys: 127 bird species and over 47,000 individuals were detected in the freshwater wetlands from Oct 09 to Jun 11 with area surveys. Dabbling ducks were most abundant guild comprising almost 22,000 birds. During migratory season dabblers were detected in the freshwater wetlands in greater abundance compared to the immediately surrounding estuarine habitat. 54 bird species were detected with VCP surveys with greater mean abundance detected in 2011.
- **Channel Development**
  - Channel sinuosity and channel cross-sections: We compared existing digitized channel maps from 1878 and 2009. Channel sinuosity in 2009 was low compared to historical channels and reflected initial phase of restoration prior to channel scour and deepening from tidal action. Channel cross section data showed little scour the first year after restoration, but more significant scour (~ 40cm of scour in Unit 3) after the second year.
  - Bathymetry: Digital Elevation Models were created from bathymetry surveys of major channels. Dredging of southern Leschi Slough was done to adaptively manage poor drainage and resulted in the deepening of the entire slough.
- **Experimental removal of Reed Canarygrass (RCG)**: Experimental RCG treatment plots were designed to test whether RCG removal (i.e., mowing, discing) would facilitate native plant colonization. After two years, the treatment and control consist primarily of bare ground; however, all treatment plots had greater vegetation cover than the control.
- **Web Outreach**: A partner website was developed to build an effective communication tool to the public and interested parties. Between October 2010 and mid-September 2011 there were 16,176 unique visits to the website and 795,223 hits.

INTRODUCTION

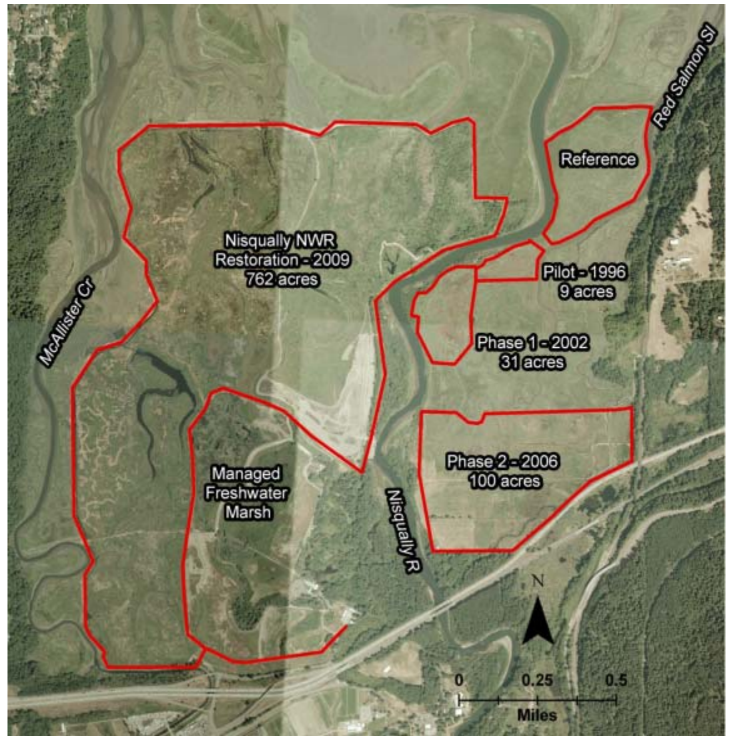


FIGURE 1. ESTUARINE RESTORATIONS IN THE NISQUALLY DELTA

In the fall of 2009 the U. S. Fish and Wildlife Service Nisqually National Wildlife Refuge (Refuge) restored tidal flow to over 760 acres of historical tidelands. On the east side of the Nisqually River, the Nisqually Indian Tribe (Tribe) completed restoration projects on tribal lands starting in 1996. Together, these restorations amount to over 900 acres of estuarine restoration in the Nisqually Delta and represent the single largest estuary restoration project in the Pacific Northwest (Figure 1). These collective restorations represent one of the most significant advances to date towards the restoration and recovery of Puget Sound. The restorations have the potential to increase salt marsh habitat in south Puget Sound by 50%, restore more than 21.4 miles of historical tidal sloughs and channels, and re-establish tidal flow to approximately 2.3 miles of historical floodplain and delta. In addition, the Refuge has enhanced 246 acres of managed freshwater ponds, creating a mosaic of estuarine habitat types to benefit salmonids (such as the threatened and the avian community alike.

ACTIVITIES

Our goal is to evaluate the Nisqually Delta estuarine restoration and its mosaic of habitats with a focus on assessing specific outcomes from restoration actions and habitat drivers that can be fine-tuned by management actions. Specifically, we will address the following objectives: 1). Document the habitat value of the managed freshwater marsh enhancement area; 2). Assess channel development; 3). Evaluate experimental removal of reed canarygrass on native plant colonization; 4). Disseminate data summaries to the project website: www.nisquallydeltarestoration.org.

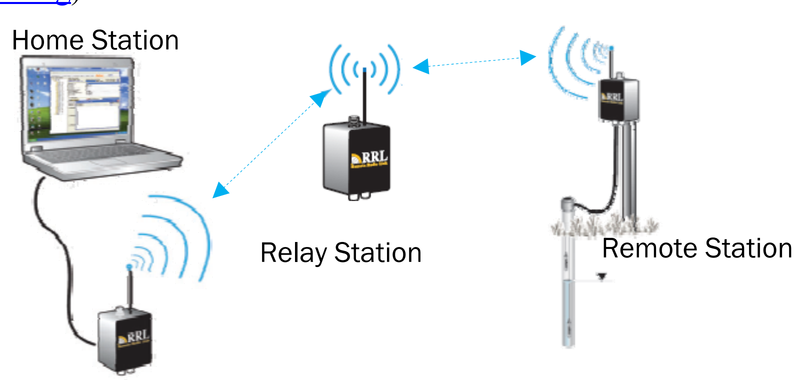
1). Document the habitat value of the managed freshwater marsh enhancement area.

1a). Install and maintain water quality instruments for remote data acquisition

Few natural resource areas have continuous datasets encompassing existing tidal ranges within their properties. Furthermore, field access to some sites can be difficult, making data downloads and logger visits cumbersome. We proposed to use Nisqually NWR data to develop a system of continuous tidal level data with water level loggers (Solinst), barologgers, and remote radio links (Solinst) so that water level data can be acquired remotely and eventually put on the web for real-time data viewing. Real time data can provide current tide conditions to managers and the public to inform them of estuarine conditions over a period of time, assist with logistical field work, as well as inform us if and when there are logger malfunctions or knockdown by large woody debris.

We purchased and tested a telemetry system that includes two remote radio links with a signal range of about 20 miles. Working with the manufacturer, we discovered that the range is greatly reduced for water deployments, cutting the range down to about < 10 miles, and that a direct line-of-sight is required to transfer data between the Remote Station to the Home Station (Figure 2). In some instances a Relay Station is needed to receive information from the Remote Station and to relay it back to the Home Station. We initially anticipated that the Home Station would reside at the Refuge; however, because of the large number of trees, we are unable to achieve line-of-sight deployment within the tidal estuary. This may be possible within the freshwater management area; but, this is not an ideal location since the information would provide limited value of rather static water levels that can already be measured visually with a staff gage. The alternate plans include deploying the Remote Station near the Delta front and working with the Nisqually Reach Nature Center to house the Home Station so that there is line-of-sight for the data transfer; or investigating a broadband telemetry system that does not depend on line-of-sight for signal transfer and will allow the Home Station to be housed at the Refuge.

This current system will be deployed in 2011 and we have secured funds so that the data will be readily accessible to the Refuge and integrated within a web platform for dissemination on the web (www.nisquallydeltarestoration.org).



1b). Conduct vegetation surv

FIGURE 2. REMOTE RADIO LINKS SYSTEM CONFIGURATION.

We worked closely with the Refuge to develop a vegetation monitoring plan for the managed freshwater units that 1) meet the management goals for monitoring high quality foraging habitat for waterfowl and 2) can be repeatable over time by Refuge staff and biologists. Thus, we designed vegetation surveys to map and delineate the extent of vegetation cover types (i.e., high quality foraging plants and invasive species) within the managed freshwater units. These surveys will enable managers to track changes in vegetation types and to inform and assist in targeted management.

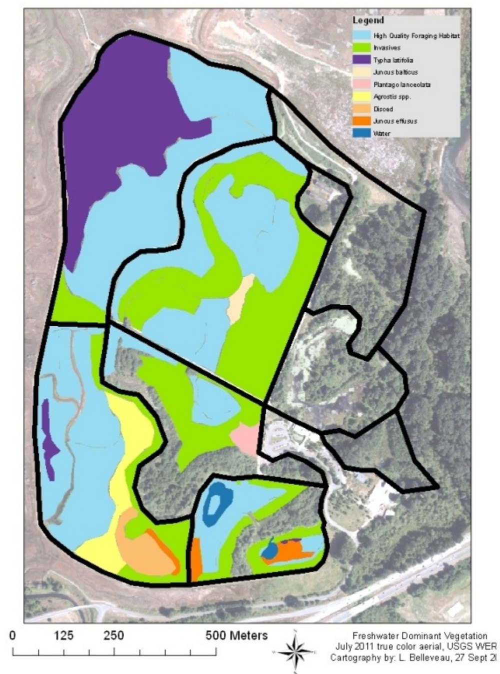


FIGURE 3. VEGETATION MAP OF THE MANAGED FRESHWATER UNITS.

Vegetation cover was visually delineated by two wetland plant experts in summer 2011. On-the-ground vegetation mapping was conducted by delineating vegetation cover categories by hand onto a printout of the summer 2011 aerial photograph (made possible from other funding sources). The observers walked and used binoculars to map the dominant vegetation type and extent within the freshwater management parcels. Target vegetation categories were established prior to the field survey based on their forage quality for waterbirds or invasive status, while other categories were identified in the field when observers encountered a unique vegetation type. Eight major vegetation types were identified, including: high quality foraging vegetation (*Biden* spp., *Polygonum* spp., *Alisma* spp., and *Rumex* spp.), invasive species (reed canarygrass, *Phalaris arundinacea* and *Cirsium* spp.), *Typha latifolia*, *Juncus* spp, *Agrostis* spp, *Platago lanceolata*, areas that were disced to reduce reed canarygrass, and open water. The hand-drawn vegetation maps were then digitized into ArcGIS (Figure 3) where we calculated the percent area cover for each vegetation type (Table 1).

TABLE 1. FRESHWATER UNIT VEGETATION AREA COVERAGE.

Vegetation type	Percent Cover
High Quality Veg	48%
Invasives	26%
Typha latifolia	16%
Juncus spp.	4%
Agrostis spp.	4%
Disced	2%
Plantago lanceolata	< 1%
Water	< 1%

Almost 50% of the managed freshwater units consisted of high quality vegetation and a little over a quarter of the area was comprised of invasive plant cover. The Refuge is actively pursuing methods to control invasives, including discing prior to fall/winter flooding. Open water was < 1% cover in the late summer and will increase as the Refuge floods the managed wetland in the fall for migratory waterbird habitat.

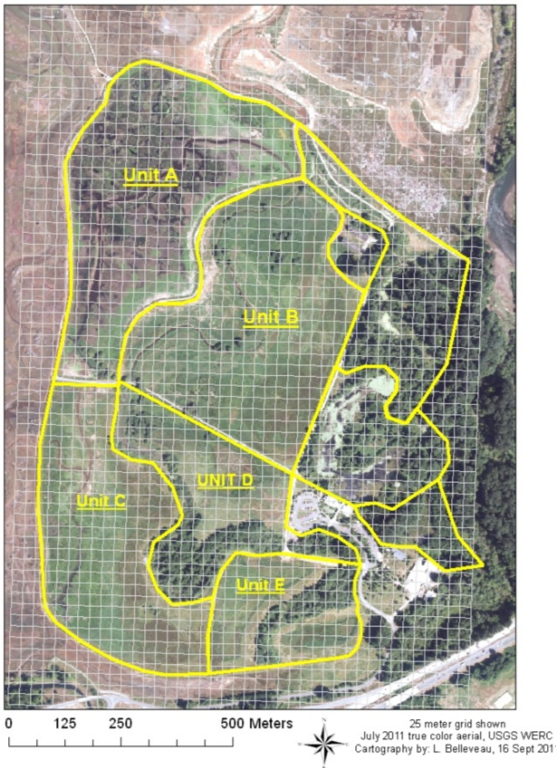


FIGURE 4. ELEVATION POINT DATA WAS COLLECTED AT THE INTERSECTION OF THE 25X25-M GRID OVERLAY.

In addition to the vegetation survey, the Refuge was interested in relating the extent and area of flooding in the managed freshwater marsh, given a particular water depth. This information would assist with their management of freshwater open water habitat for waterbirds. Thus we adapted our efforts to assist in mapping the elevations and creating a digital elevation model (DEM) of the freshwater units.

We used an RTK GPS (Leica Viva) to take elevations at the intersection of a 25 x 25 m grid overlaid onto an aerial photograph of the freshwater unit (Figure 4). Elevation data collection is underway and will be completed by the Refuge. USGS will then process the elevation datapoints and create an elevation DEM by using the Kriging interpolation method (Spatial Analyst; ArcGIS 9.3.1, ESRI, Redlands, CA). Combined with vegetation surveys, the DEM can help the Refuge manage water levels and available foraging habitat for overwintering waterfowl.

1c). Conduct area and variable circular plot bird surveys

Waterbirds, primarily shorebirds and waterfowl, respond to restorations and are good indicators of habitat change (Taft et al. 2008), hydrology, and water quality conditions (Takekawa et al. 2009). We monitored bird abundance, habitat, and behavior using area counts and variable circular plots (VCP) surveys.

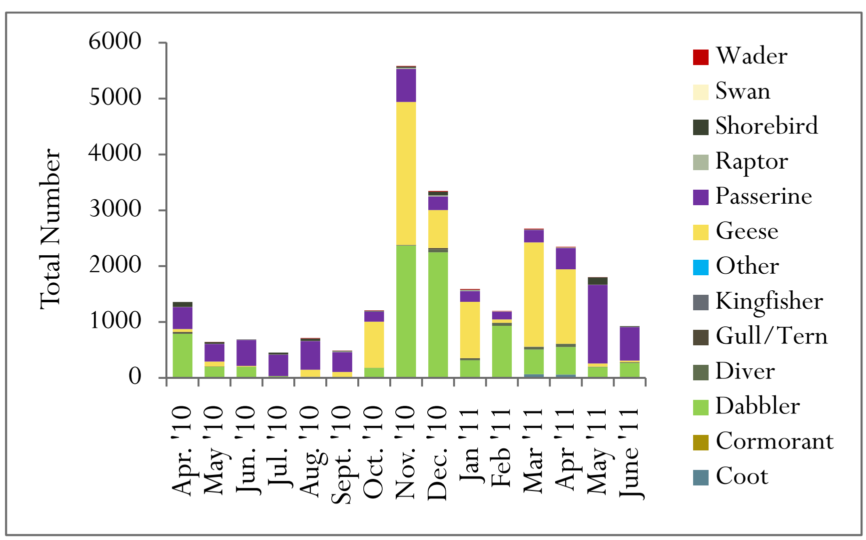


FIGURE 5. MONTHLY BIRD ABUNDANCE BY GUILD WITHIN THE MANAGED FRESHWATER WETLAND.

Area Bird Surveys

For area surveys, experienced birders visually scanned the freshwater units with binoculars and scopes monthly. They recorded species, number, bird behavior (i.e., foraging, roosting, swimming, and flying), and habitat type (i.e., mudflat upland, pond, marsh, and dike) in 250 m x 250 m gridcells and partitioned by freshwater unit.

127 bird species and over 47,000 individuals were detected in the freshwater wetlands from Oct 09 to Jun 11. Dabbling ducks were most abundant guild comprising almost 22,000 birds. Total bird abundance in the freshwater units varied by month and guild (Figure 5), with a peak count in the winter (5,513 birds in Nov 2010), primarily due to the influx of geese and dabblers. Geese had high abundance from Oct 2010 to Apr 2011, while dabblers were abundant in Nov and Dec of 2010. Passerine numbers increased in the spring (May-Jun), while other bird guilds (i.e., waders, shorebirds, and divers) were observed in low abundances throughout the year.

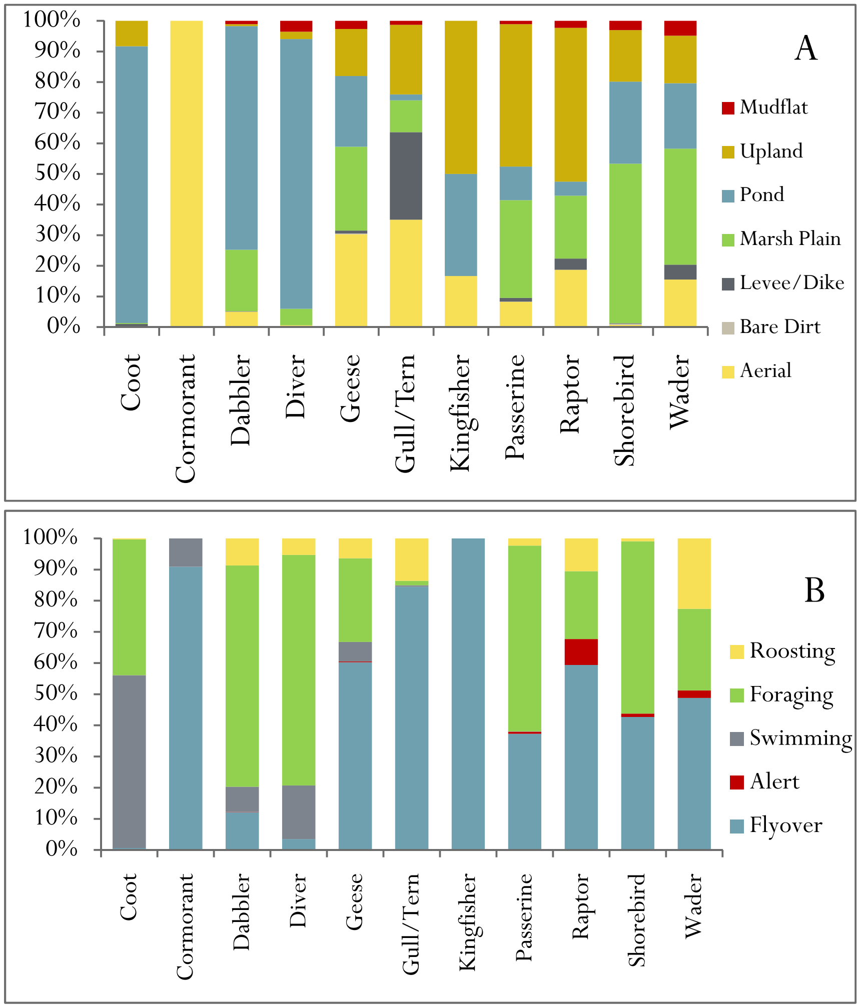


FIGURE 6A,B. RELATIVE BIRD OCCURRENCE IN HABITAT TYPES (A) AND DISPLAYING BEHAVIORS (B) WITHIN THE FRESHWATER UNITS.

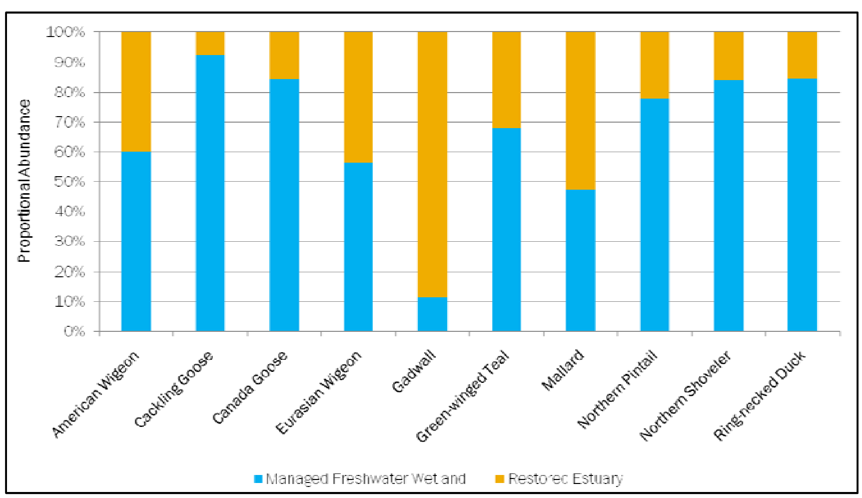


FIGURE 7. PROPORTION OF DABBLING DUCKS OBSERVED IN THE NNWR RESTORED ESTUARY (ORANGE) AND MANAGED FRESHWATER WETLANDS (BLUE; OCT' 09 – FEB '10 AND OCT '10).

We observed a variety of habitats (i.e., mudflat upland, pond, marsh, and dike) and behaviors (i.e., roosting, foraging, swimming, and flying) within the managed freshwater wetland (Figure 6 a,b). Dabbling ducks were most often observed foraging in ponded water, whereas, passerines foraged in upland and marsh plain habitats. Geese were most frequently recorded during flyovers as they moved in, out, and around the freshwater units. They were also often observed foraging in marsh plain, upland, and ponded habitats.

Bird abundance, density, behavior, and habitat use in the freshwater wetlands will be monitored over time and can also be compared to the adjacent restored estuary (Figure 7). We found that many dabbling duck species (wigeon, geese, green-winged teal, northern pintail, northern shoveler, and ring-necked duck) used the freshwater wetlands in higher proportions than the adjacent restored estuarine environment during the fall/winter migratory season (Oct 2009-Feb 2010 and Oct 2010).

We acknowledge that there may be difficulties counting waterbirds in the estuarine area, especially during a low tide when they are hidden within the sloughs or obscured by remaining vegetation; however, we conducted surveys during high tide to help maximize waterfowl detection and so that survey areas can be accessed by boat.

Variable circular plot (VCP) surveys

Marsh birds are secretive and difficult to survey by sight so we incorporated auditory and visual cues to bird detection with variable circular plot (VCP) surveys (DeSante 1981). VCP surveys were conducted in the managed freshwater wetland in spring when marsh birds are more vocal. VCP surveys were conducted at three monitoring stations within in May and June 2010 and May, June, and July 2011 during the peak passerine nesting season. We detected a total of 54 bird species: 31 bird species were detected in 2010 and 46 species were detected in 2011 (Table 2).

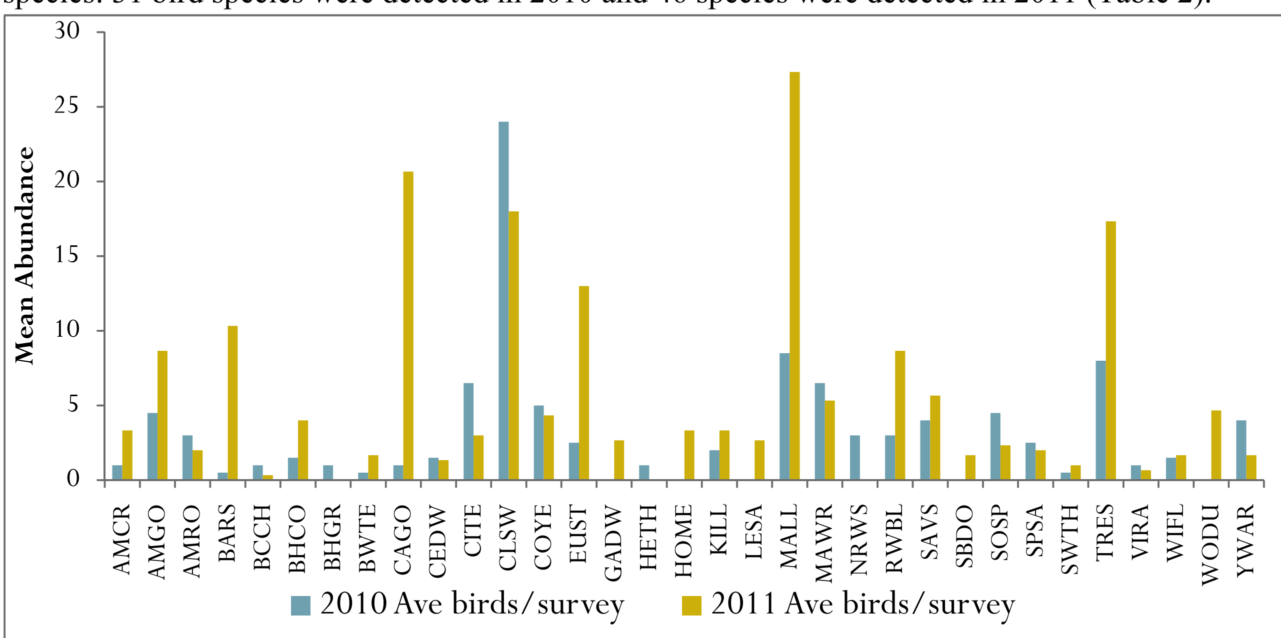


FIGURE 8. AVERAGE ABUNDANCE OF BIRD FROM VCP SURVEYS IN 2010 AND 2011. SPECIES CODES FOLLOW THOSE IN TABLE 2.

Eight birds were unique to the 2010 survey and 22 birds were unique to the 2011 bird survey. The higher number of unique detections in 2011 may be due to the additional month of surveying.

Cliff Swallows were the most abundant passerine observed both years, averaging 24 individuals per survey in 2010 and 18 individuals per survey in 2011 (Figure 8). Cinnamon Teal, Common Yellowthroat, Mallard, Marsh Wren, and Tree Swallows had average abundances at or greater than 5 individuals per survey in 2010. Mallard, American Goldfinch, Barn Swallow, Canada Goose, European Starling, Marsh Wren, Red-winged Blackbird, Savannah Sparrow, and Tree Swallows had average abundances greater than 5 individuals per survey in 2011. The average number of birds detected at each monitoring station per survey increased from 35 to 64 between 2010 and 2011 (SD $\pm$ 7.66 and 36.18, respectively), although many of the larger counts in 2011 can be attributed to groups of waterfowl with young.

TABLE 2. SPECIES LIST FOR MANAGED FRESHWATER WETLAND VCP COUNTS IN 2010 AND 2011. *INDICATES AVERAGE INDIVIDUALS COUNTED PER SURVEY WAS LESS THAN 1 AND IS NOT INCLUDED IN FIGURE 8.

Code	Common Name	2010	2011	Code	Common Name	2010	2011
AMBI	American Bittern*		X	LESA	Least Sandpiper		X
AMCR	American Crow	X	X	MALL	Mallard	X	X
AMGO	American Goldfinch	X	X	MAWR	Marsh Wren	X	X
AMRO	American Robin	X	X	NOHA	Northern Harrier*		X
BARS	Barn Swallow	X	X	NRWS	Northern Rough-winged Swallow	X	
BCCH	Black-capped Chickadee	X	X	PBGR	Pied-billed Grebe*		X
BEKI	Belted Kingfisher	X		PUFI	Purple Finch*		X
BEWR	Bewick’s Wren		X	RBGU	Ringed-billed Gull		X
BHCO	Brown-headed Cowbird	X	X	RUHU	Rufous Hummingbird*	X	
BHGR	Black-headed Grosbeak	X		RWBL	Red-winged Blackbird	X	X
BUSH	Bushtit*	X	X	SAVS	Savannah Sparrow	X	X
BWTE	Blue-winged Teal		X	SBDO	Short-billed Dowitcher		X
CAGO	Canada Goose	X	X	SORA	Sora*		X
CATE	Caspian Tern	X		SOSP	Song Sparrow	X	X
CEDW	Cedar Waxwing	X	X	SPSA	Spotted Sandpiper	X	X
CITE	Cinnamon Teal	X	X	SPTO	Spotted Towhee	X	
CLSW	Cliff Swallow	X	X	SWTH	Swainson's Thrush	X	X

Code	Common Name	2010	2011	Code	Common Name	2010	2011
COYE	Common Yellowthroat	X	X	TRES	Tree Swallow	X	X
DOWO	Downy Woodpecker*		X	VGSW	Violet-green Swallow*		X
EUST	European Starling	X	X	VIRA	Virginia Rail	X	X
GADW	Gadwall	X	X	WIFL	Willow Flycatcher	X	X
GBHE	Great Blue Heron*	X	X	WISN	Wilson's Snipe		X
GRYE	Greater Yellowlegs*	X		WIWA	Wilson's Warbler*		X
GWGU	Glaucous-winged Gull*	X	X	WODU	Wood Duck		X
HETH	Hermit Thrush	X		YHBL	Yellow-headed Blackbird		X
HOME	Hooded Merganser		X	YRWA	Yellow-rumped Warbler		X
KILL	Killdeer	X	X	YWAR	Yellow Warbler	X	X

2). Assess channel development

FIGURE 9. NISQUALLY ESTUARY MAJOR CHANNELS, JULY 2010.

The full removal of the dike surrounding the Nisqually NWR restoration site has the potential to restore over 21 miles of historical sloughs and channels. Channels are critical features that function as a pathway of water, energy, and other material (nutrients, sediment, organic matter) exchange and drainage in tidal marshes. Because of their importance in determining vegetation and invertebrate communities as well as fish passage and access, characterizing tidal channel geometry is critical in understanding ecological processes (Zeff 1999, Sanderson et al. 2000, Hood 2007, Hood 2009). One of the critical questions in evaluating estuarine restorations is "How quickly can tidal channels develop through tidal erosion?" (Hood 2009). Monitoring tidal marsh channel morphometry (i.e., channel width, length, sinuosity, cross-section) and comparing these metrics pre- and post-construction will allow us to relate these physical parameters to biological responses (i.e., vegetation, invertebrate, fish) at Nisqually Delta restoration sites.

We used a combination of remote sensing, shallow water bathymetry, and on-the-ground GPS surveys of channel cross sections to assess channel development in major channel systems within the Refuge (Figure 9). Channels were mapped using color infrared aerial photographs base layers, which were previously flown, mosaicked, and georeferenced to existing imagery (UTM NAD 83). Major channel features were delineated, digitized in ArcGIS, and analyzed over time (pre-restoration compared to post-restoration aerials), and changes in channel length and sinuosity were completed in ArcGIS. Three dimensional metrics of channels included channel cross-sections, which were repeated annually to detect change and a bathymetric coverage was completed in 2010 and will be used as a baseline from which future comparisons can be made.

The funding for aerial photography, field studies, and analyses came through multiple sources, but preliminary results are provided here for clarity.

2a). Digital Channel Mapping

Repeated aerial photographs were part of the baseline monitoring program, and the channel maps were completed under different funding sources. This grant funded additional analyses of remotely acquired spatial data and the comparison of channel length and sinuosity of restored channels within the Refuge. Historical channels were digitized from 1878 US Coast & Geodetic Surveys by the Nisqually Indian Tribe (cartography by J. Cutler). Using the same digitizing methods as the Tribe, USGS (cartography by H. Minella) digitized channels from a Dec 2009 aerial photograph that was flown three months after dike removal (Figure 10, Table 3). These coverages were analyzed for channel length and sinuosity in ArcGIS and changes are presented for the major channels within the Refuge restoration.

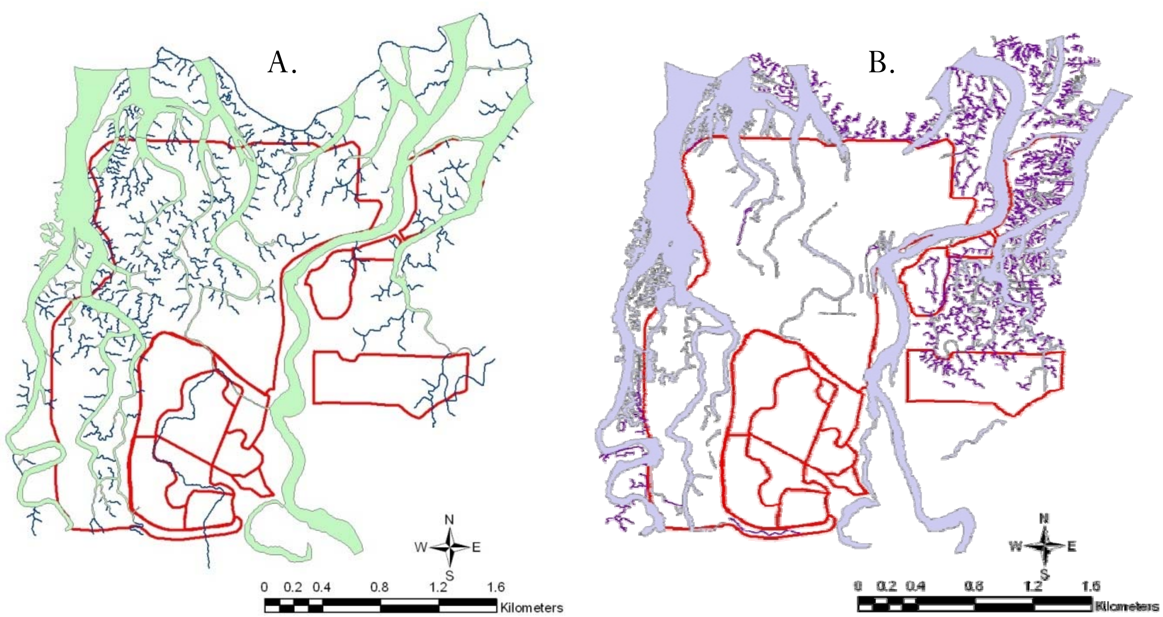


FIGURE 10. CHANNEL MAP FROM A) 1878 (J. CUTLER, NISQUALLY TRIBE) AND B) DEC 2009 (USGS WERC)

After three months of dike removal, over 9,800 meters (> 6 miles) of major channels had been restored to tidal flow. Channel sinuosity (*K*) is usually greater in natural vs. restored marshes and is defined as the ratio of sinuous length of the channel segment (*C* -- *D*) to the straight line length of the channel segment (*A* -- *B*) (Figure 11, Doll et al. 2003):

$$K = \frac{\underline{C \leftrightarrow D}}{A \leftrightarrow B}$$

where values closer to 1 approximate a straight channel or ditch and greater values represent more sinuous and meandering channels. Channel sinuosity is often related to channel width and depth (Leopold et al. 1964) and flow regimes: straight channels and ditches often convey faster moving water and conversely low velocity channels often meander and have higher sinuosity values (Pestrong 1965, Doll et al. 2003).

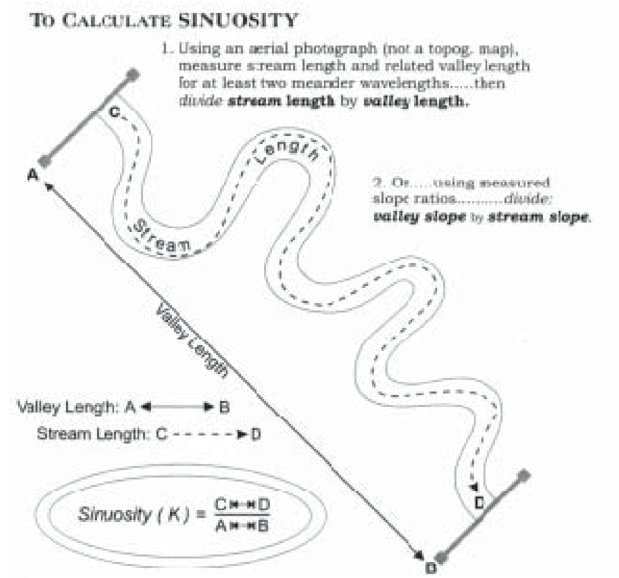


FIGURE 11. CALCULATING CHANNEL SINUOSITY (FROM DOLL ET AL. 2003).

Channels within the restoration were marked by relatively low measured sinuosity in 1878 and in 2009 (Table 3). Overall channel sinuosity in the major channels decreased slightly from 1878 to 2009, except for Shannon Slough A, where channel sinuosity increased from 1.31 in 1878 to 1.37 in 2009. In 1878 channel sinuosity in the major slough channels within the Refuge ranged from 1.59 at Leschi Slough to 1.30 at Unit 3 (Table 3, Figure 10). After three months of dike removal in Dec 2009, the channel sinuosity was slightly lower at 1.54 for Leschi Slough, and 1.00 at Unit 3, primarily due to degradation of the channel and poor detection of channel edges soon after restoration. The relatively low channel sinuosity for these large channels are consistent with Pestrong (1965) in that the highest order channels that extend past the marsh and out to mudflats or delta, usually have lower sinuosity values.

TABLE 3. LENGTH AND SINUOSITY OF MAJOR CHANNELS IN HISTORICAL (1878) AND POST-RESTORATION (DEC 2009) DIGITIZED CHANNEL MAPS

Channel	Length (m)		Sinuosity	
	1878	Dec 2009	1878	Dec 2009
Unit 1	1381	1296	1.48	1.36
Madrone	1450	1094	1.17	1.14
Leschi	2903	2148	1.59	1.54
Unit 3	640	80	1.30	1.00
Shannon				
ShannonA	2117	2207	1.31	1.37
ShannonB	2170	1540	1.31	1.26

We did not compare the smaller primary channels within the restoration because within the Refuge restoration, channels initially had undefined banks and were filled with sediment and vegetation such as cattail (Figure 10), making channel delineations difficult, except for the largest channels. Over time, we've observed the Refuge restoration transition from a diked freshwater marsh with vegetation-choked channels to more estuarine conditions as the relic plants decompose in the now tidally influenced restoration. With time, we expect channels to develop naturally as in Unit 3 where the July

2011 aerial photograph shows more defined channels that now drain former areas of low-lying shallowly pooled water (Figure 12). These digitized channel maps and calculations form a basis for future comparisons of channel metrics as the restoration progresses.

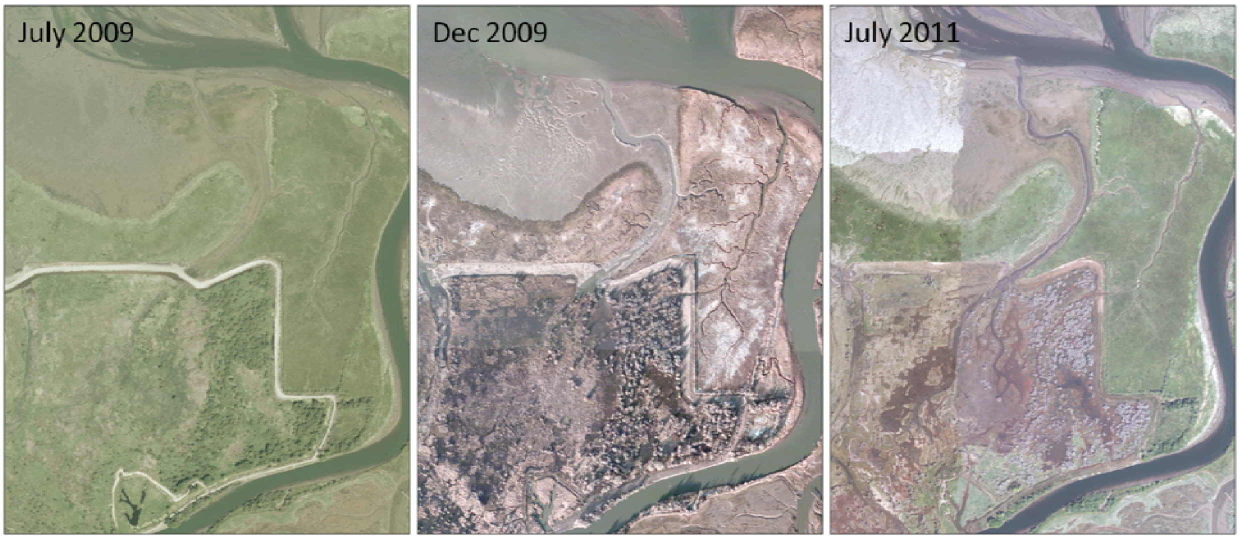


FIGURE 12. TRUE COLOR AERIAL PHOTOGRAPHS SHOWING CHANNEL DEVELOPMENT AT RESTORED UNIT 3 TIDAL CHANNEL.

2b). Channel Cross-Sections

Channel cross-sections were completed pre-restoration (Summer 2009) and post-restoration (October 2010) at the North, Middle, and South monitoring stations of Shannon, Unit 1, Leschi, and Unit 3 channels (Figure 13) and funded by baseline monitoring. This grant funded the field work for 2011 channel cross-sections. We detected increased elevations in the channel cross section data from Unit 3 North after the first year following restoration (Figure 13). The increase in elevation may be due to vegetation mats within the middle of the channel loosening and floating up as they begin to die back in response to estuarine conditions. In the second year, many of these vegetation mats had decomposed and washed away with tidal exchange, and we detected approximately 40 cm of scour in our 2011 channel cross section survey (Figures 13, 14).

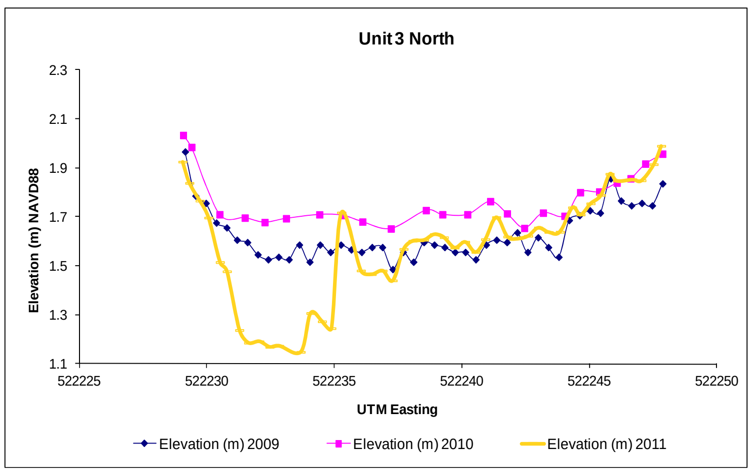


FIGURE 13. CHANNEL CROSS-SECTION FROM UNIT 3 NORTH IN 2009 (BLUE), 2010 (PINK) AND 2011 (YELLOW).

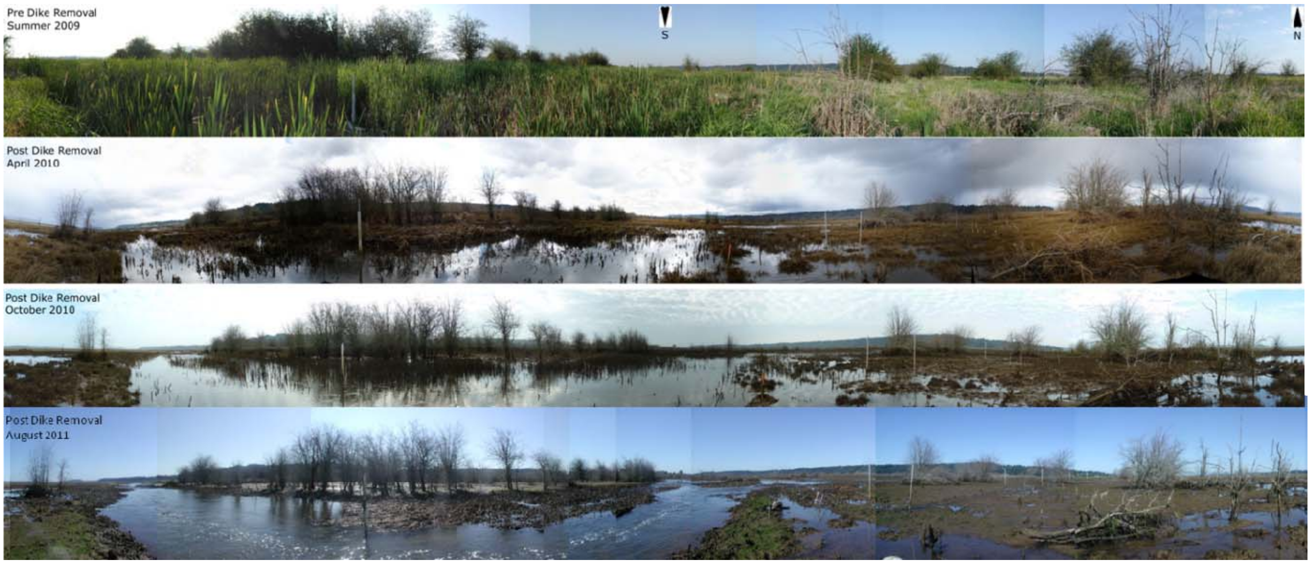


FIGURE 14. PANORAMIC PHOTOPOINT OF UNIT 3 NORTH SHOWING CHANNEL DEVELOPMENT.

2c). Bathymetry and Digital Elevation Model

Shallow water bathymetry surveys repeated over time can be analyzed for channel development and quantification of potential impediments to drainage.

We used a shallow-water echo-sounding system (Takekawa et al. 2010) comprised of an acoustic profiler (Navisound 210, Reson, Inc.; Slangerup, Denmark), a survey grade Real Time Kinematic GPS (Leica RTK GPS Viva, Leica Geosystems Inc., connected to the Leica Washington Real Time Network) for three dimensional coordinates, and laptop computer to integrate the data all mounted on a shallow-draft, portable flat-bottom boat. The RTK GPS obtained high resolution elevations of the water surface (reported precision < 1 cm; estimated accuracy ± 3 cm), while the variable frequency transducer and echosounder measured water depth. The echosounder functions in areas of > 10 cm of water. We calibrated the system before use with a bar-check plate and adjusted the sound velocity for salinity and temperature differences.

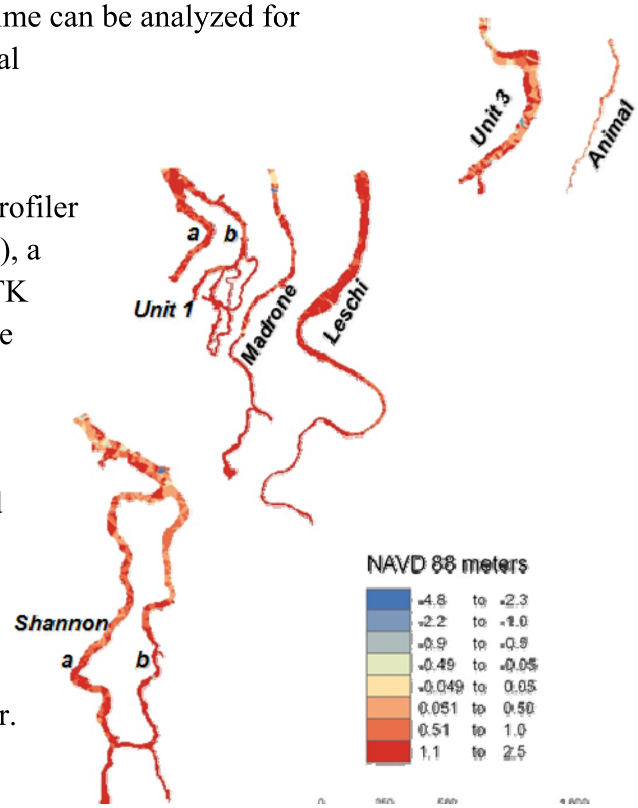


FIGURE 15. DIGITAL ELEVATION MAP OF MAJOR CHANNELS , SUMMER 2010.

Surface elevations were calculated by adjusting the boat location and elevation with corresponding water depth readings. Data were interpolated with Kriging (Spatial Analyst; ArcGIS 9.3.1, ESRI, Redlands, CA) to generate a bathymetric grid from elevation datasets, using a 5 m^2 grid cell size (Figure 15).

Bathymetric surveys were conducted in Summer 2010 within large restored tidal channels in the NNWR restoration site (Shannon, Unit 1, Madrone, and Leschi), a surrounding tidal marsh channel (Unit 3), and a reference channel at the mouth of the Nisqually River (Animal; Figure 15). We also conducted limited survey lines in the delta flat channels north of the NNWR Restoration Site; however, due to the width of the channels, the paths did not provide enough coverage to create an accurate interpolation and were left out of the DEM.

Newly restored channels within the Refuge were relatively large with elevation ranges between 7 m (Shannon slough and Madrone Slough) to 2 m at Unit 1. The large elevation ranges are mainly due to deep pocket areas that were encountered near the mouths of the sloughs (Figure 15, Table 4). Unit 3 had the lowest mean elevation at < 1 m and only recently (summer 2011) have we detected scouring of the channel in our channel cross section data (Figure 13). Animal Slough is the narrowest channel we surveyed with our shallow water bathymetry boat and had a mean elevation of < 1 m with a < 2 m elevation range.

We also coordinated our bathymetry surveys to supplement LiDAR surveys that had been planned for the Nisqually Delta. Thus, we targeted the large channel systems that would likely not register LiDAR returns because they would still hold water during a low tide. Nisqually Delta LiDAR (Watershed Sciences 2011) was flown on Jan 3, 2011, during a low tide and we are planning to work with partners to merge these datasets. A complete elevation DEM will provide the foundation for numerous future analyses to determine progress of the restoration: such as integrating water levels with elevation to create inundation models for vegetation colonization, and analyses of time the marsh surface is accessible for fish or waterbirds.

TABLE 4. ELEVATION (METERS NAVD88) FROM BATHYMETRIC SURVEYS.

Channel	Site	Mean Elevation	Min	Max	Range	STD
Shannon	NNWR Restoration	1.06	-4.64	2.51	7.15	0.76
Unit 1	NNWR Restoration	1.3	-0.31	2.02	2.33	0.37
Madrone	NNWR Restoration	1.33	-4.76	2.28	7.04	0.86
Leschi	NNWR Restoration	1.42	-0.5	2.49	2.98	0.42
Unit 3	NNWR Adjacent and Restoration	0.79	-1.69	2	3.69	0.71
Animal	Reference Channel	0.58	0.21	1.67	1.46	0.24

Major adaptive management triggers were identified as part of the Refuge Monitoring Framework (Ellings 2008): including ponding with obvious and extensive fish kills. Although no fish kills were ever observed or detected, some shallow ponding was observed in the southern portion of Leschi Slough that indicated poor tidal drainage. As a pro-active measure, the Refuge dredged the southern portion of Leschi Slough in Sept 2010 (Figure 16). We captured the channel bathymetry prior to dredging (Jul 2010) and after dredging (Sep 2010), and analyzed the elevation difference between the coverages (Figure 17). Our bathymetry results show deepening of the channel not only in the southern portion of the slough, but also scour throughout the length of the channel. The dredging likely increased tidal flows through a bottleneck area that had been slowed down by remnant vegetation. As a result, tidal exchange throughout the channel has been enhanced, which has likely helped scour unconsolidated sediments and deepen the entire stretch of Leschi Slough. Readings from a handheld water quality multiprobe (YSI), also indicated improved dissolved oxygen and salinity from pre-dredge (DO at 6 mg/L; salinity at 1 ppt) to post-dredge (DO at 10 mg/L; salinity at 21 ppt) condition.

FIGURE 16. PHOTOGRAPHS OF LESCHI SLOUGH BEFORE, DURING, AND AFTER DREDGING

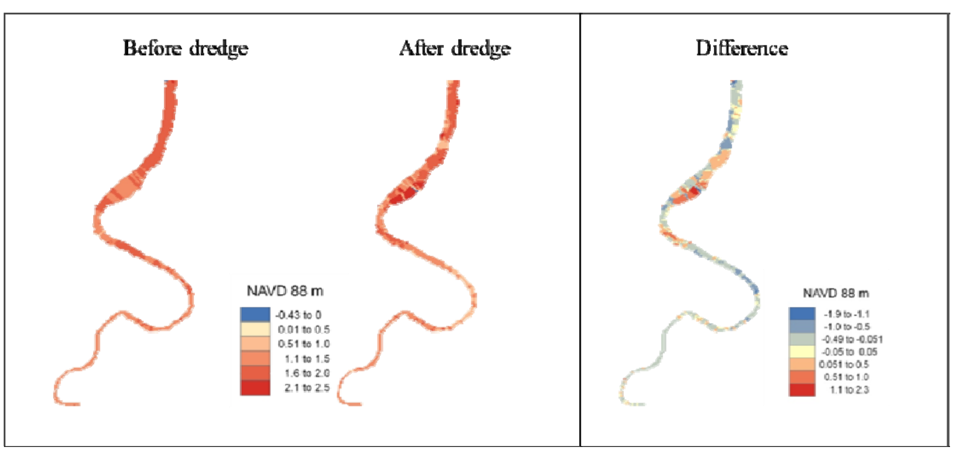


FIGURE 17. LESCHI SLOUGH BATHYMETRY BEFORE DREDGING (JUL 2010), AFTER DREDGING (SEPT 2010), AND ELEVATION CHANGES (M)

3). Evaluate experimental removal of reed canarygrass on native plant colonization

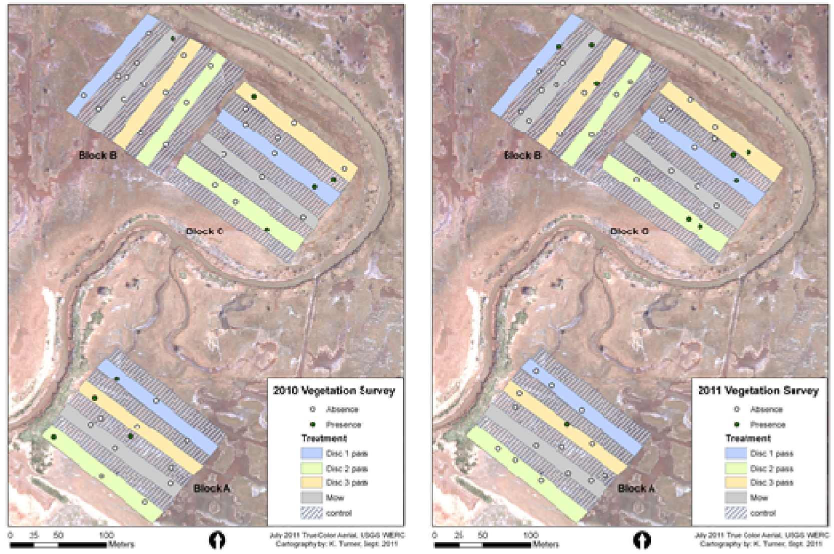


FIGURE 18. REED CANARYGRASS EXPERIMENTAL REMOVAL PLOTS

Invasive plant species such as reed canarygrass (RCG: *Phalaris arundinacea*), can significantly degrade the habitat value for wildlife. Prior to the restoration, RCG formed extremely dense and tall stands and it was predicted to dieback with the reintroduction to estuary conditions.

The concern was that the large amount of remaining dead biomass might impair native plant colonization. We hypothesized that discing and mowing dense monotypic stands of RCG would facilitate the colonization of native saltmarsh vegetation. To test this hypothesis, we set up four experimental RCG removal treatments; including mowing (no root disturbance) and discing intensity: high intensity (3 passes until RCG stand and roots are completely severed into pieces), discing medium intensity (2 passes, RCG and roots are broken into medium dirt wads), discing light (single pass, RCG and roots are broken into large dirt wads), and mowing treatment (mowing, no root disturbance) with control (Figure 18). Plots were approximately 15 m x 150 m and placed in a standardized random block design. Vegetation colonization data will be compared between treatments and control in a randomized, split-plot block ANOVA. Vegetation, elevation, and sedimentation measurements were conducted at each experimental plot in Summer 2010 and 2011.

TABLE 5. SPECIES LIST FOR REED CANARYGRASS REMOVAL EXPERIMENT IN 2010 AND 2011

Species	2010	2011
Atriplex patula	X	
Chenopodium macrospermum	X	X
Eleocharis acicularis		X
Elymus repens	X	
Sarcocornia pacifica		X
Scirpus maritimus	X	
Spergularia canadensis		X

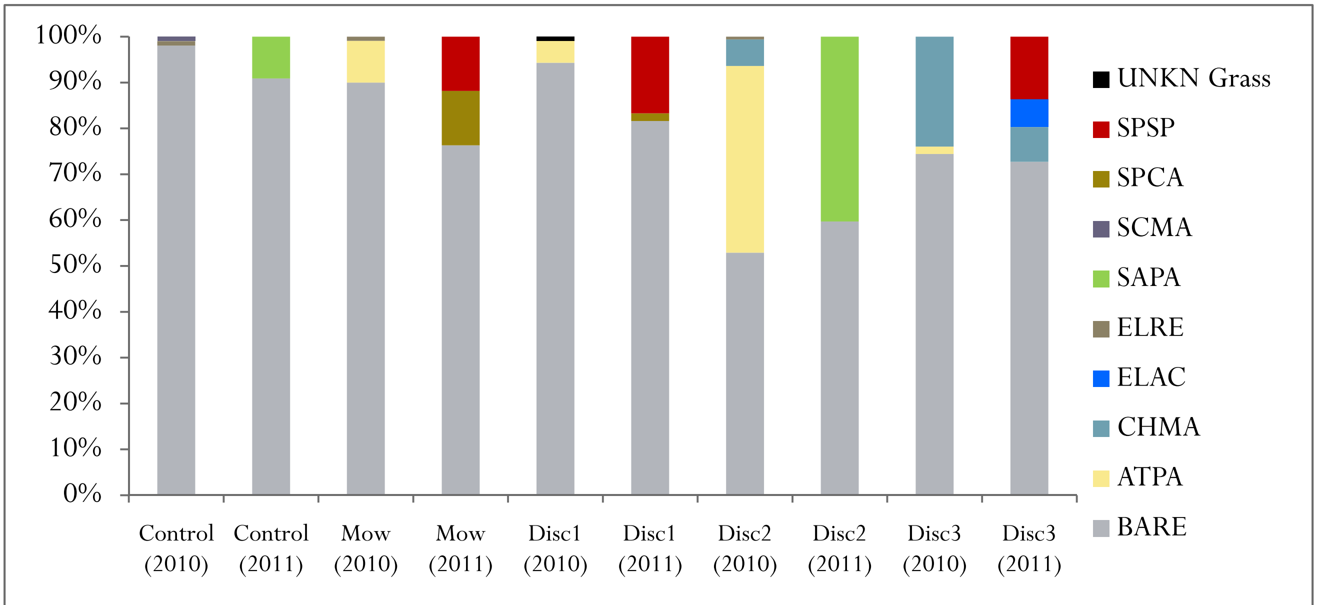


FIGURE 19. RELATIVE PERCENT COVER (QUADRATS) IN CONTROL AND TREATMENT PLOTS IN 2010 AND 2011. SPECIES CODES ARE LISTED IN TABLE X. "BARE" INCLUDES BARE GROUND, ALGAE, LITTER, AND WRACK.

In Summer 2010, one year following dike removal and reintroduction of tidal flow, almost all of the invasive reed canarygrass (RCG: *Phalaris arundinacea*) and other freshwater species had died. A few tidal marsh species had also colonized the site within that first year (Table 5, Figure 19). In Summer 2011, there were still only a few tidal marsh species, such as pickleweed (*Sarcocornia pacifica*) and sand-spurry (*Spergularia canadensis),* observed. Our results suggest that vegetation colonization is at initial phases, since 80% of the quadrats were bare. In both summer 2010 and summer 2011, only 20% of the quadrats surveyed contained live vegetation, which indicates that more time is necessary for plant colonization to occur.

Initial results show that all of the treatment plots had a higher average vegetative cover than the control in both 2010 and 2011 (Figure 19). Disc 2 treatment had the highest relative plant cover, although this plot also had the highest mean elevation (2.53 m NAVD 88), suggesting that plant colonization may be related to elevation (Table 6). Environmental factors, such as initial elevation, sedimentation rates, salinity, and local hydrologic regime can also affect plant colonization. And at this time, it is not known whether environmental effects will be greater than treatment effects for native plant colonization.

TABLE 6. MEAN, MINIMUM AND MAXIMUM QUADRAT ELEVATIONS (NAVD 88, M) WITHIN REED CANARYGRASS TREATMENT BLOCKS.

Treatment	Min (m)	Mean (m)	Max (m)
Mow	2	2.44	2.75
Control	2	2.45	2.78
Disc2	2.05	2.53	3.12
Disc3	2.08	2.45	2.76
Disc1	2.12	2.5	2.75

4). Disseminate data summaries to the project website: www.nisquallydeltarestoration.org

A partner website was developed to provide a centralized location for updates of the restoration project and to build an effective communication tool to the public, restoration practitioners, land managers, and scientists alike (Figure 20). The initial development and launch of the website was funded by several sources and partners. Additional funds were acquired to fund a professional web developer for development of web databases, programming of databases for real time data viewing, optimization of web graphics for rapid displays of photographic imagery, and site maintenance. This grant helped fund further web development of real time data displays and updated summaries that are easily viewed by the public with cross-browser and cross platform consistency, and built-in 508 compliance (for the visually impaired).

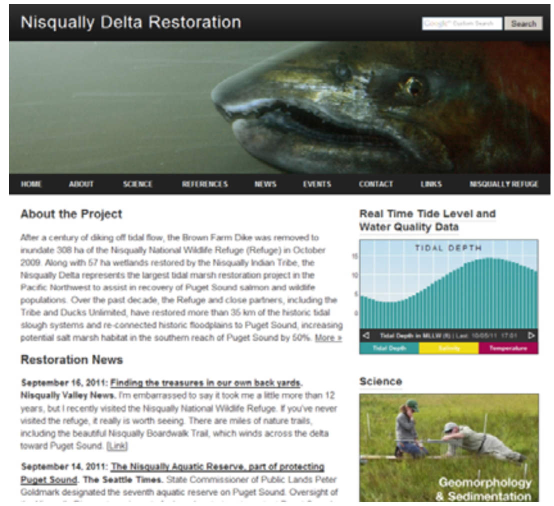


FIGURE 20. WWW.NISQUALLYDELTARESTORATION.ORG

WERC has coordinated with partners to establish, maintain, and provide regular science updates including real time weather data, real time water level and quality data, updated restoration photos, and 360° panoramic photographs of pre- and post-restoration conditions. Between October 2010 and mid-September 2011 there were 16,176 unique visits to the website and 795,223 hits.

Some highlights of the website updates include:

- Water quality and level**:** Continuously updated data displaying current tide depth (MLLW), salinity, and temperature.
- Weather Station: Continuously updated temperature, wind, humidity, rain, and barometric pressure data from the restoration.
- Birds: Updated in spring 2011 with new visuals for displaying bird species abundance; and more specific graphs of abundance and distribution for focal species (Figure 21).

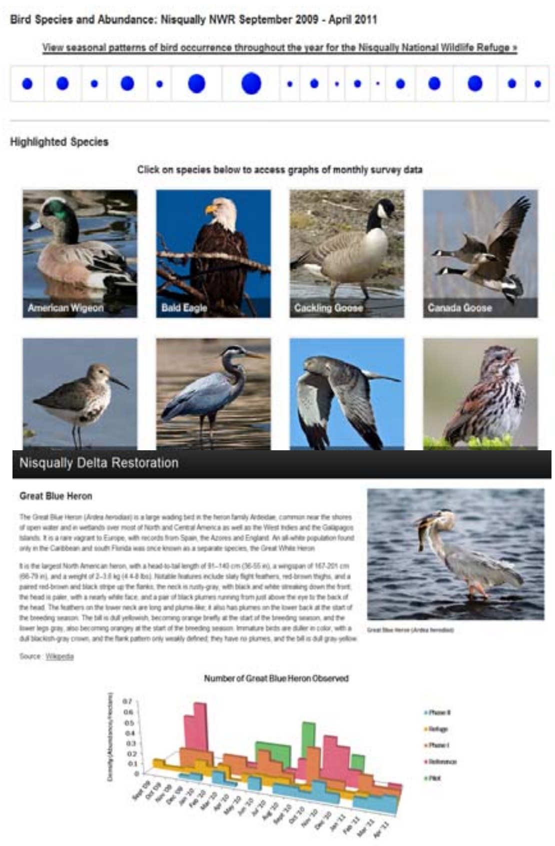


FIGURE 21. BIRD UPDATES ON WWW.NISQUALLYDELTARESTORATION.ORG

- Fish: Summary of 2010 fyke, beach seine, and lampera surveys including seasonal abundance and site composition graphs, as well as Chinook micro-otolith growth rate graphs provided by the Nisqually Indian Tribe Salmon Recovery Team.
- Vegetation: Updated plant sampling map, species list in the Nisqually Delta, percent cover by site and year, as well as height, and density graphs from summer 2010.
- Photo-documentation: Updated map displaying 360° panoramic photos in two different ways; one as a 2D images and the other as 3D. For the website, 12 key monitoring stations were selected for repeat photo-documentation to show qualitative changes as a result of restoration. Currently, there are three time periods displayed on the website: July 2009 (prior to dike removal), April 2010, and October 2010 (both post-dike removal; Figure 22).
- Tide Time Lapse Videos: Several time lapse videos showing tidal changes at vantage points throughout the restoration site have been posted. These videos provide the public with views of areas no longer accessible as well as a better understanding of the dynamic tidal range in the Nisqually estuary.

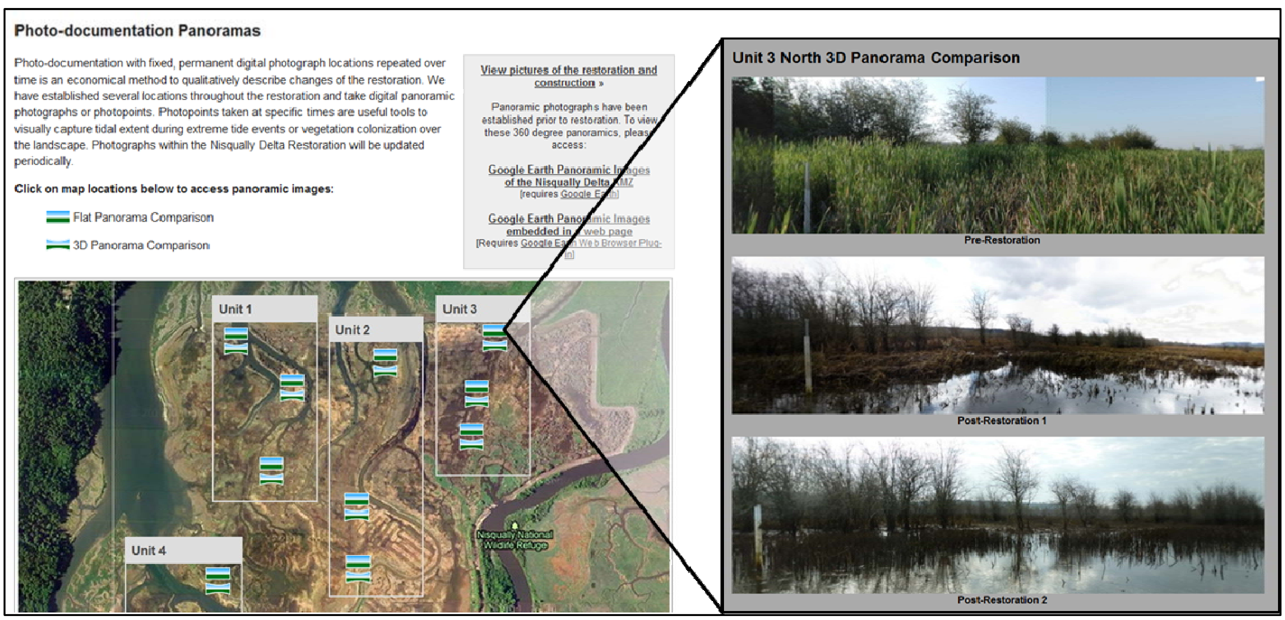


FIGURE 22. PANORAMIC PHOTOGRAPHS ON WWW.NISQUALLYDELTARESTORATION.ORG

In addition to providing information updates on the web, WERC is actively involved in sharing from our restoration experiences through other avenues including: workshops, presentations at conferences (local, regional, and national), and through field trips with the Skokomish, Snohomish, and Stillaguamish estuaries and others. We have conducted reciprocal site visits, shared survey protocols, and have been in regular communications with the local restoration community.

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