RESEARCH

Vegetation of natural and artificial shorelines in Upper Klamath Basin's fringe wetlands

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Abstract

The Upper Klamath Basin (UKB) in northern California and southern Oregon supports large hypereutrophic lakes surrounded by natural and artificial shorelines. Lake shorelines contain fringe wetlands that provide key ecological services to the people of this region. These wetlands also provide a context for drawing inferences about how differing wetland types and wave exposure contribute to the vegetative assemblages in lake-fringe wetlands. Here, we summarize how elevation profiles and vegetation richness vary as a function of wave exposure and wetland type. Our results show that levee wetland shorelines are 4X steeper and support fewer species than other wetland types. We also summarize the occurrence probability of the five common wetland plant species that represent the overwhelming majority of the diversity of these wetlands. In brief, the occurrence probability of the culturally significant *Nuphar lutea* spp. *polysepala* and the invasive *Phalaris arundinacea* in wave exposed and sheltered sites varies based on wetland type. The occurrence probability for *P. arundinacea* was greatest in exposed portions of deltaic shorelines, but these trends were reversed on levees where the occurrence probability was greater in sheltered sites. The widespread *Schoenoplectus acutus* var. *acutus* occurred throughout all wetland and exposure type combinations but had a higher probability of occurrence in wave exposed sites. Results from this work will add to our current understanding of how wetland shoreline profiles interact with wave exposure to influence the occurrence probability of the dominant vegetative species in UKB's shoreline wetlands.

Key Words: shoreline wetlands, lake-fringe wetlands, Upper Klamath Lake

Introduction

Shoreline or lake-fringe wetlands are essential to the functioning and diversity of large lakes (Levine and Willard 1989; Keddy and Fraser 2000). These wetlands are subjected to large fluctuations in water levels, precipitous physical and nutritional gradients, and frequent disturbance from wave exposure and ice scour (Weisner 1987; Mortsch 1998; Keddy and Fraser 2000). Shoreline wetlands provide critical services to large lakes including nutrient sequestration (Sollie et al. 2008), wave attenuation (Pennings et al. 2009), and the provisioning of habitat for invertebrates and fish (Jude and Pappas 1992; Burton et al. 2002).

The characterization of vegetation in shoreline wetlands has been the focus of research efforts for decades (see Keddy 1983; Wilson and Keddy 1985; Nilsson and Keddy 1988), yet, in some regions, including the Upper Klamath Basin (UKB) of northern California and southern Oregon, little is known about the factors that influence vegetative assemblages. This lack of information is surprising given that UKB is recognized for its abundance of large shallow lake and associated fringe-wetland complexes (Bradbury et al. 2004; NRC 2004). In fact, lake-fringe wetlands historically represented about half the total lake area of Upper Klamath Lake (UKL)—the largest lake in the UKB. While still abundant, diking, draining, and cultivation reduced wetlands around UKL to < 20% of their original size (Akins 1970). Systematic draining and diking also contributed to land subsidence (upwards of 2 to 3 m behind dikes) from historic elevations (Wong et al. 2011), severely altered lake productivity (Eilers et al. 2004), and led to the decline of two federally-listed fish (Cooperman and Markle 2004).

Despite the dramatic loss of wetlands in this region, the UKL system still contains fringe wetlands and provides opportunities to document the occurrence of emergent vegetation along natural and artificial shorelines (Bradbury et al. 2004). Vegetative assemblages along shorelines are believed to be determined by hierarchies of competitive ability and physiological tolerances to stress and disturbance with species occupying unique, albeit overlapping, positions on lake shorelines (Keddy and Fraser 2000). Shoreline positions of vegetation can be described relative to lake surface elevation or expressed in absolute terms, but elevational positions are dynamic (Mortsch 1998).

Although the flora of degraded or farmed wetlands whose hydrology has been restored has been described (Elseroad et al. 2011), information on the vegetation in wave exposed and sheltered regions of UKB shoreline wetlands is still needed. This information will help predict how vegetation may respond to future lake level scenarios or to the reconnection/restoration of former wetland habitats. As managers in the UKB work to restore culturally significant fish and plant communities, consideration of the factors contributing to the contemporary distribution of wetland vegetation is needed. For example, *Nuphar lutea* spp. *polysepala*, a species whose dietary importance to the Klamath people was second only to fish was once widespread along UKL shorelines (Deur 2009). The distribution of *N. lutea* in UKL has been reduced and restoration of this species to wetlands has been largely unsuccessful (Elseroad et al. 2009).

Here we describe the emergent and floating-leaved vegetation assemblages in shoreline wetlands of Upper Klamath and Agency lakes, Oregon (Fig. 1). We first summarize elevation profiles and vegetation richness of wave exposed and sheltered regions for three wetland types (deltaic, levee, and remnant). Because subsidence throughout human-modified wetlands of the UKL system has significantly deepened water depths (Wong et al. 2011), we document the minimum surface elevation with rooted vegetation along each wetland-exposure type combination to test the hypothesis that plants occupying wave exposed sites will grow at shallower depths than conspecifics occupying sheltered sites (Hypothesis 1; H1). Finally, we summarize the probability of occurrence for the dominant emergent species documented and explicitly test the hypotheses: N. lutea will be absent from wave exposed sites (H2), and the invasive Phalaris arundinacea will be most prevalent in wetlands that have been subject to significant alteration (e.g., received artificial fill to create levees; H3).

Methods

Study Site

The Upper Klamath Basin of California and Oregon, USA, is typified by broad valleys with large lake and wetland complexes (NRC 2004). At the heart of the basin is UKL, the largest lake in Oregon covering approximately 270 km^2 at full pool (Fig. 1). The UKL system includes two large, shallow hypereutrophic lakes – Upper Klamath and Agency lakes (Fig. 1). Combined, these lakes maintain minimum flows in the Klamath River, produce electricity, support irrigated agriculture, and provide critical habitat for waterfowl and federally-listed fish. Both lakes are supported by groundwater and riverine inputs (Sprague, Williamson, and Wood rivers). Storage and release operations create substantial water elevation fluctuations that are approximately 1 m below natural lake levels (Bradbury et al. 2004; Kann and Welch 2005).

Sampling Methods

We used 38 randomly selected locations to characterize vegetation along natural (deltaic [located along river mouths] and remnant lake fringe wetlands) and artificial (located on levees) shorelines of Agency Lake (Fig. 1). Within each wetland type we stratified sampling by wave exposed and sheltered shorelines (Table 1). At each location, transects were created perpendicular to the existing shoreline. The transect center was established at the lakeward extent of existing vegetation. We recorded species occurrence and rooting surface elevations in 1 m increments for 25 m in both lakeward and landward directions from the center. Total transect length was shorter at some locations due to the limited expanse of emergent vegetation (e.g., remnant exposed and levee exposed shorelines; Fig. 2). Often, emergent vegetation extended beyond the 25 m landward extension of some transects.

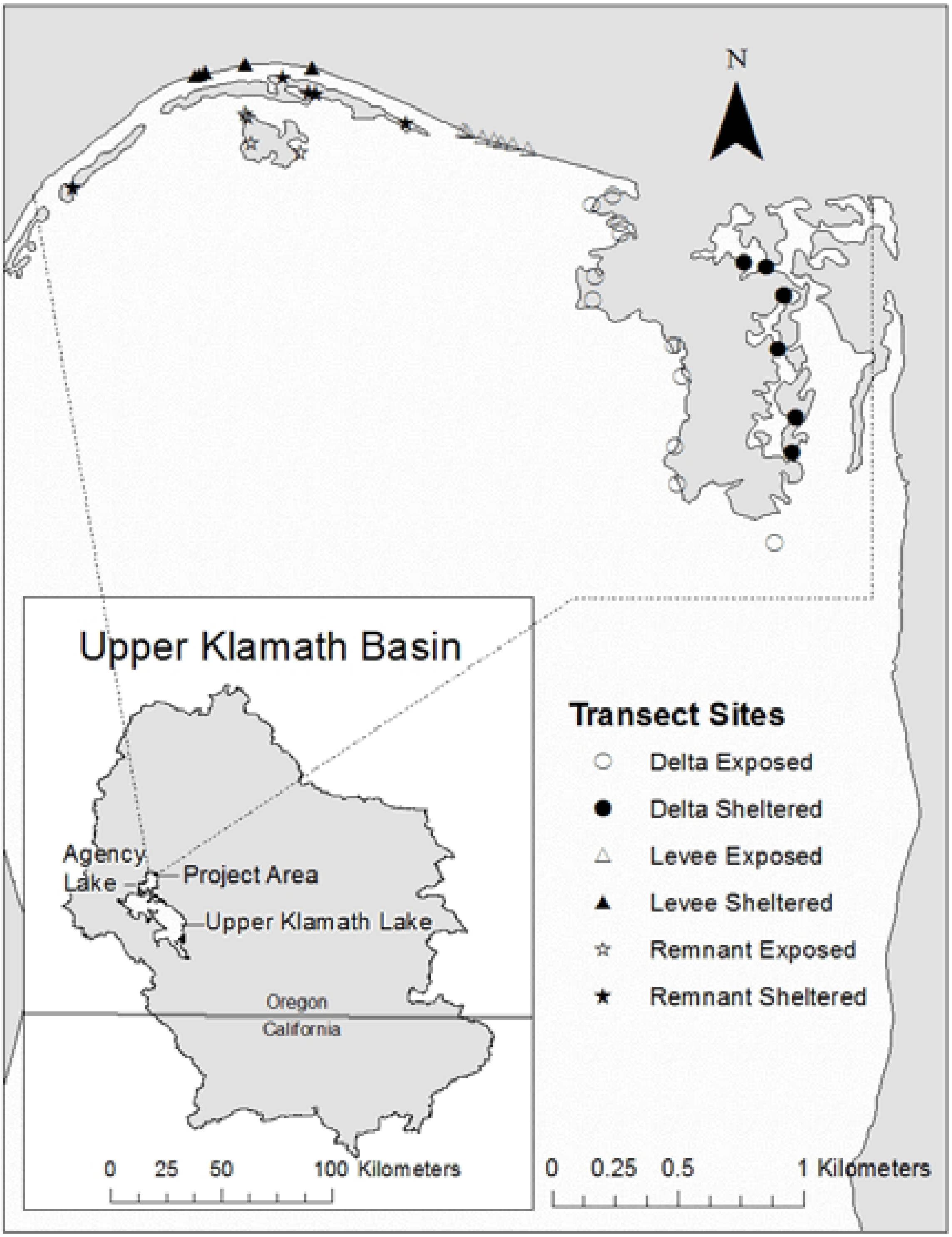

Figure 1: Location of Upper Klamath Basin and Upper Klamath and Agency lakes (inset). Shoreline sampling locations are shown for each wetland and exposure type.

Water depths, the difference between the water surface and firm rooting substrates, were collected at 1 m increments and calculated using the average of three measurements. Rooting surface elevations for transect locations present above the water surface were estimated using a level transit and surveyor's rod. Relative elevations were converted to elevations in meters above sea level (m.a.s.l.) in the laboratory based on the average daily water level elevations published on the U. S. Geological Survey's UKL surface elevation readings (USGS 11507000 Gage) using the U.S. Bureau of Reclamation's Upper Klamath Lake Vertical Datum. Ground surface elevations for transect locations in standing water were calculated by subtracting the depth of standing water from the daily water level elevation from the USGS gage. This approach provides an estimate of water depths that are < 0.02 m from true depths

(Dunsmoor et al. 2000).

To document the presence and absence of common rooted emergent vegetation (e.g., *Schoenoplectus acutus* var. *acutus* and *Typha latifolia*) we used 0.1 m2 quadrats (dimensions 0.2 m x 0.5 m). For floating-leaved macrophytes (e.g., *N. lutea*) we used larger, 1 m x 1 m, quadrats to detect their presence (Ray et al. 2001).

Statistical Analyses

We calculated slope by dividing the elevation change by total transect length for each transect. We used a two-way ANOVA to explore variations in shoreline slope, vegetative richness, and rooting surface elevation at the vegetative edge. Our factors were wetland type (deltaic, levee, and remnant) and wave exposure type (exposed or sheltered). If no interaction was detected, we used a main effects only model. To address H1 we subset the data for each species to transects that had at least one observation for that species. For these transects, we then calculated the minimum elevation (m) that each species was recorded. Based on this restricted dataset, we were able to make comparisons of exposed and sheltered transects for the most abundant species and for different wetland types. For those species only recorded in both exposure types within a single wetland type, we used a two-sample t-test with unequal variances. For multi-group comparisons we used a one-way ANOVA with six groups and a Tukey HSD test to control for all pairwise comparisons. For evaluation of species occurrence by wetland and exposure type and to explicitly test H2 and H3, we used binomial logistic regression with over-dispersion.

Results

Wetland Type	Exposure Type	Number of Transects	Average Slope	Average Elevation (m) at Margin of Vegetation	Average Vegetative Richness
D	E	11	0.01	1261.30	2.0
D	S	6	0.01	1261.52	3.2
L	E	7	0.07	1261.67	0.6
L	S	5	0.07	1261.52	2.6
R	E	4	0.01	1261.23	1.5
R	S	5	0.02	1261.29	3.0

Table 1: Total number of transects sampled from deltaic (D), levee (L), and remnant (R) wetlands summarized by sheltered (S) and exposed (E) locations within each wetland type. The average slope, elevation at vegetative margin, and vegetative richness are summarized by each wetland X exposure combination. Elevations are based on the Upper Klamath Lake Vertical Datum used by U.S. Bureau of Reclamation in reporting elevation in Upper Klamath Lake.

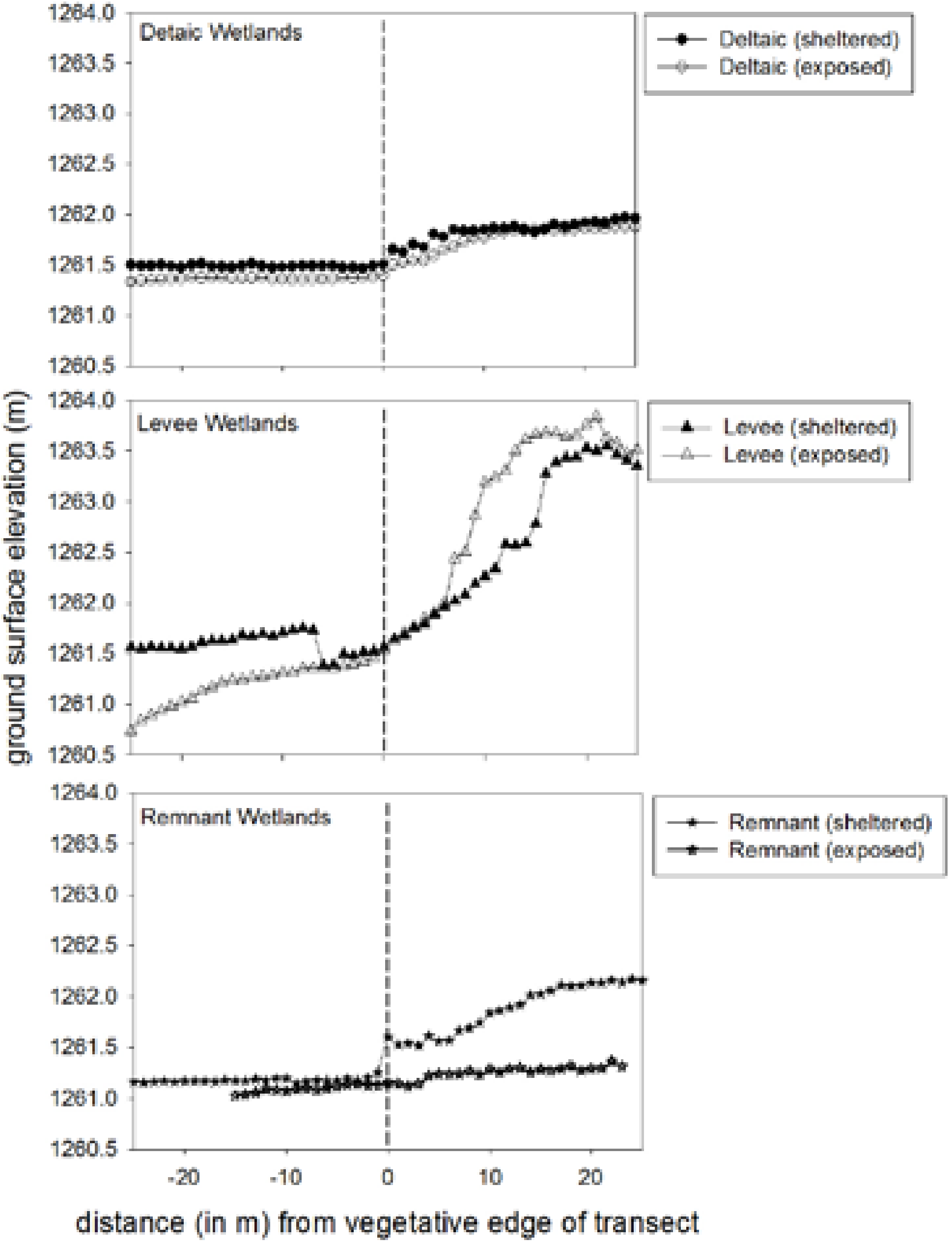

Figure 2: Representative shoreline elevation profiles for each wetland and exposure type. Elevations are based on the Upper Klamath Lake Vertical Datum used by U.S. Bureau of Reclamation in reporting elevation in Upper Klamath Lake. The total number of transects in each wetland x exposure combination is summarized in Table 1

Fringe wetlands of Agency Lake were comprised largely of five species: *N. lutea* (NULU), *P. arundinacea* (PHAR), *S. acutus* (SCAC), *Sparganium eurycarpum* (SPEU), and *Typha latifolia* (TYLA). Main effects models summarized differences in shoreline slope, the elevation of the vegetative margin, and vegetative richness by wetland type and exposure type. The slope of shorelines differed among wetland types; levee shorelines were nearly 4X steeper than the other wetland types (Table 1). Wave exposure did not influence shoreline slopes ($P = 0.255$). Wetland ($P = 0.003$) and wave exposure type ($P < 0.001$) affected vegetative richness (e.g., exposed remnant wetlands had fewer species than sheltered remnant wetlands) and levee wetlands had significantly fewer species than the other wetland types (Table 1). Importantly, culturally significant NULU was not present in levee wetlands and the invasive PHAR was absent from remnant wetlands. Finally, the rooting surface elevation of the vegetative margin differed by wetland type ($P = 0.020$) and was lower (by 0.35 m) for remnant wetland shorelines than for levee shorelines.

Contrary to our predictions, there was no evidence that the average minimum depth of NULU occurrences differed between wave exposed and sheltered portions of remnant wetlands (Fig. 3, $P = 0.314$). Also, there was no evidence that SPEU or TYLA grew at shallower depths based on exposure to waves within the deltaic wetlands (Fig. 3, one-sided $P > 0.500$). Finally, there was no evidence that SCAC grew at lower depths in wave exposed compared to sheltered portions of any wetland type (Fig. 3, all $P > 0.200$).
There was strong evidence that NULU occurrence probability in exposed versus sheltered sites varied based on wetland type (Fig. 4, interaction between wetland and exposure type, $P < 0.001$). Contrary to our predictions, there was a higher probability of NULU occurrence in exposed compared to sheltered regions of remnant wetlands (Table 2). In deltaic wetlands, the probability of NULU occurrence was higher in sheltered sites (Table 2). There was strong evidence that the probability of PHAR occurrence differed in exposed versus sheltered sites; however, it varied based on wetland type (Table 2 and Fig. 4, $P < 0.008$). The probability of SPEU occurrence was typically higher in sheltered portions of all wetland types (Table 2). SCAC consistently had higher probability of occurrence in exposed sites across all wetland types (Table 2, interaction between wetland and exposure type, $P > 0.100$). TYLA displayed higher probabilities of occurrence in sheltered sites for all wetland types (Table 2, interaction between wetland and exposure type, $P > 0.100$).

Discussion

Shoreline wetlands in the UKL system are compositionally simple and comprised largely of just five plant species. Wetland type and wave exposure influence the vegetative characteristics of shoreline wetlands of Agency Lake. Generally, deltaic and remnant wetlands contained more species than levee wetlands. SCAC occurred throughout all wetland and exposure type combinations and had relatively high occurrence probabilities. NULU, a species of both biological and cultural significance in the region (Deur 2009), was completely absent from wetlands established on levee shorelines.

In our sampling, PHAR did not occur in remnant wetlands; it was most common in levee wetlands. PHAR may have been intentionally introduced to levees as an attempt to stabilize these artificial shorelines (Lavergne and Molofsky 2004). This species has commonly moved beyond introduction sites and invaded natural habitats. Given that levees sampled were established during the 1950s, it is noteworthy that this species was not detected in remnant wetlands. Since native vegetative diversity of wetlands typically declines following PHAR invasion (Schooler et al. 2006), identifying factors that have limited PHAR invasion in remnant wetlands should be considered in any long-term conservation strategy for fringe wetlands in the UKL system.

In the UKL system exposure to waves appears to be an important factor for describing which species occur in fringe wetlands. Overall, exposed sites had fewer species than sheltered sites within a given wetland type. However, contrary to our expectations, not all species were negatively affected by wave exposure. For example, SCAC had consistently higher probabilities of occurrence in exposed sites regardless of wetland type. Also, we predicted that NULU would be absent from exposed sites, however, this species was relatively common in remnant wetlands that were exposed to waves. Both SPEU and TYLA tended to have higher probabilities of occurrence in portions of wetlands sheltered from wave exposure. Given this understanding of the local species pool and probability of species occurrence, these results offer an understanding of the physical constraints that may limit colonization of emergent and floating species to future restoration projects in UKL (Galatowitsch 2009).

Many efforts underway in the UKB are being implemented to protect or restore lake-fringe habitats that are vital to the conservation of endemic species, improvement of water quality, and restoration of culturally significant wetland plant species (Aldous et al. 2005; Crandall et al. 2008; Elseroad et al. 2009; Wong et al. 2011). Restoration of wetlands in this region has followed the rewetting of former wetland habitat, breaching of existing levees, and small-scale restoration of shoreline habitats. The information described herein reveals how wetland shoreline profiles interact with wave exposure to influence the occurrence probability of common wetland plant species. We believe that this information is a necessary first step to improving the success of future restoration efforts and restoring key ecosystem services to the lakes of the UKB.

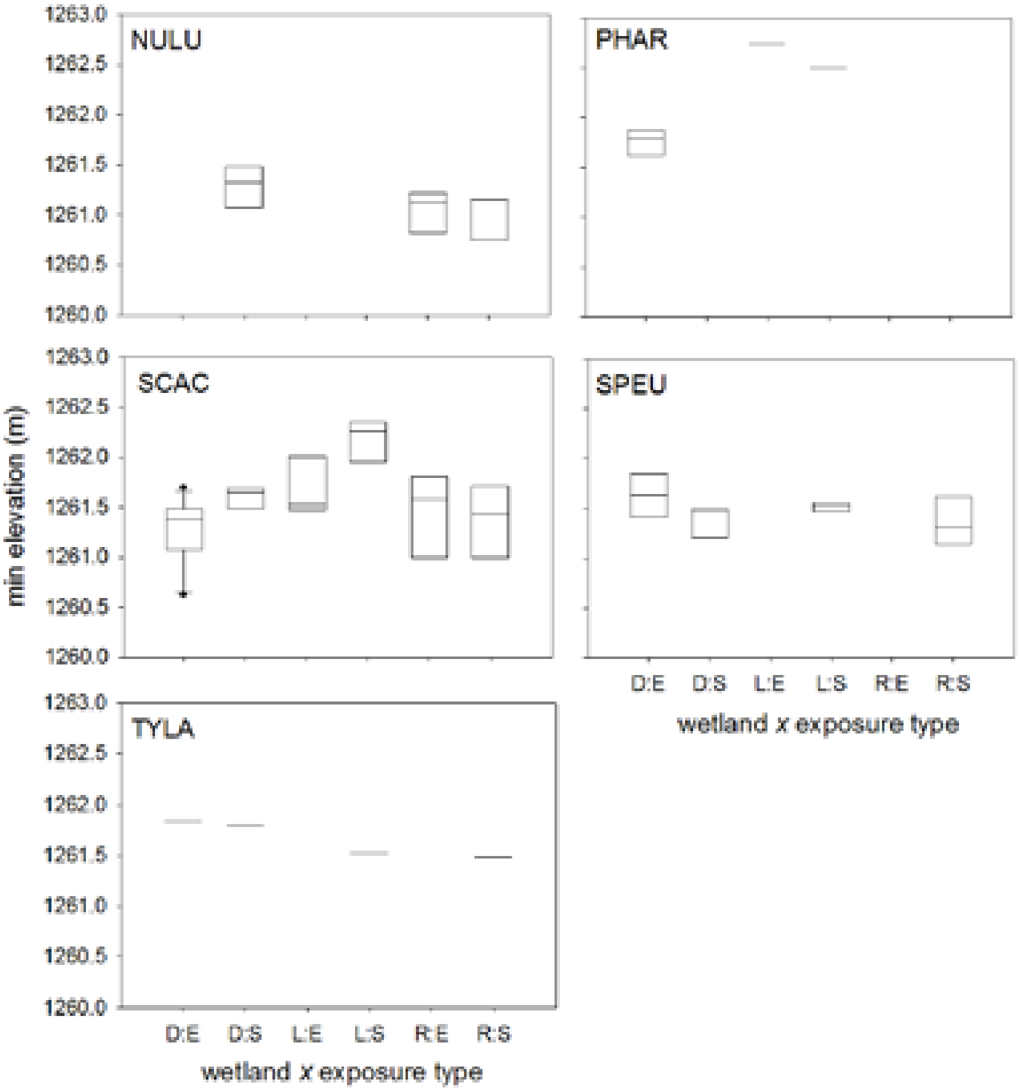

Figure 3: Minimum elevation (m) that each vegetative species was detected. Species codes are as follows: *Nuphar lutea* (NULU), *Phalaris arundinacea* (PHAR), *Schoenoplectus acutus* (SCAC), *Sparganium eurycarpum* (SPEU), and *Typha latifolia* (TYLA). Detections are summarized by transect for each wetland and exposure type. The total number of transects in each wetland X exposure combination is summarized in Table 1. Boxes represent the upper and lower quartiles of the dataset; internal lines indicate the medians. Boxed summaries represent a minimum of three observations. Whiskers are produced when there was a minimum of seven observations and represent the 10th and 90th percentiles. The absence of a box plot indicates that the vegetative species was not detected on transects within the wetland X exposure combination. Elevations are based on the Upper Klamath Lake Vertical Datum used by U.S. Bureau of Reclamation in reporting elevation in Upper Klamath Lake.

Species	Wetland Type	Exposure Type	Probability	SE
PHAR	D	S	0.00	0.000
	D	E	0.054	0.019
	L	S	0.089	0.038
	L	E	0.013	0.013
	R	S	0.000	0.000
	R	E	0.000	0.000
NULU	D	S	0.209	0.056
	D	E	0.000	0.000
	L	S	0.000	0.000
	L	E	0.000	0.000
	R	S	0.145	0.053
	R	E	0.538	0.082
SPEU	D	S	0.157	0.053
	D	E	0.142	0.037
	L	S	0.254	0.075
	L	E	0.000	0.000
	R	S	0.333	0.075
	R	E	0.000	0.000
SCAC	D	S	0.412	0.068
	D	E	0.460	0.054
	L	S	0.079	0.034
	L	E	0.094	0.038
	R	S	0.201	0.056
	R	E	0.234	0.063
TYLA	D	S	0.081	0.040
	D	E	0.020	0.014
	L	S	0.018	0.021
	L	E	0.004	0.006
	R	S	0.030	0.026
	R	E	0.007	0.008

Table 2: Estimated probability of occurrence for each species within deltaic (D), levee (L), and remnant (R) wetland types and sheltered (S) versus exposed (E) sites using quasi-binomial likelihood estimation. *Phalaris arundinacea* (PHAR), *Nuphar lutea* (NULU), *Sparganium eurycarpum* (SPEU) models include interaction between wetland type and exposure type and *Schoenoplectus acutus* (SCAC) and *Typha latifolia* (TYLA) models are additive (no interaction of wetland type and exposure type). The SE estimates of zero are because of rounding to only 3 significant digits.

Acknowledgements

The U.S. Bureau of Land Management (L10PG00839) and U.S. Bureau of Reclamation (R10AP20603 and 08FG200155) provided funding for this work. We would especially like to thank C. Aquino, C. Fujishin, E. Duffy, and J. Litts for help in the field. We thank C. Aquino for assistance with Figure 1, assembling the field data, and for her thoughtful review of an earlier version of this manuscript. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

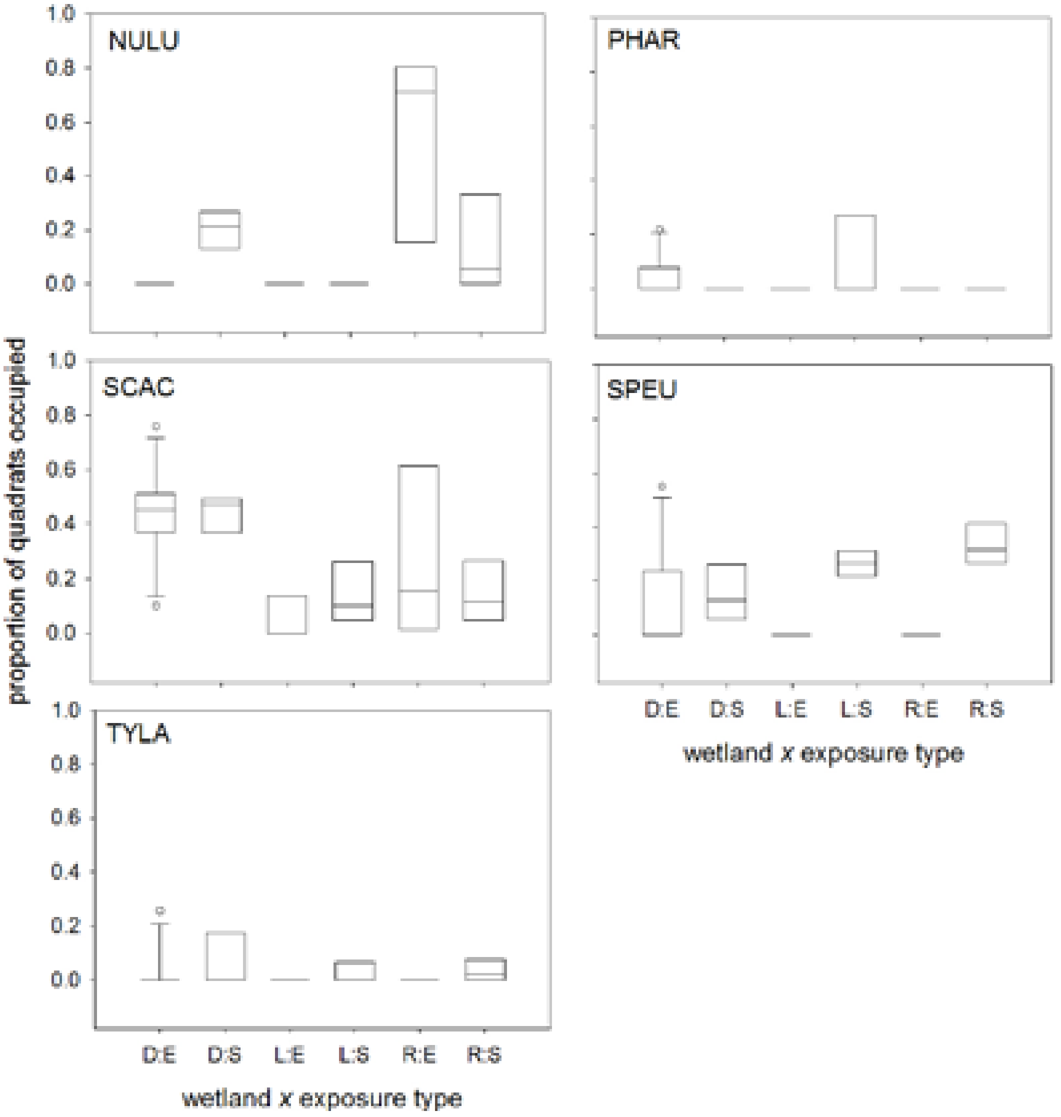

Figure 4: Comparison of the proportion of plots occupied by each species and summarized by transect for each wetland and exposure type. Species codes are as follows: *Nuphar lutea* (NULU), *Phalaris arundinacea* (PHAR), *Schoenoplectus acutus* (SCAC), *Sparganium eurycarpum* (SPEU), and *Typha latifolia* (TYLA). Boxes represent the upper and lower quartiles of the dataset; internal lines indicate the medians. Boxed summaries represent a minimum of three observations. Whiskers are produced when there was a minimum of seven observations and represent the 10th and 90th percentiles.

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Wetlands One-Stop Mapping: Providing Easy Online Access to Geospatial Data on Wetlands and Soils and Related Information

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The Association of State Wetland Managers (ASWM) in collaboration with Virginia Tech's Conservation Management Institute (CMI) and the U.S. Fish and Wildlife Service's Northeast Region have created "*Wetlands One-Stop Mapping*" (http://www.aswm.org/wetland-science/wetlands-one-stop-mapping) – a new website designed mainly to provide easy online access to geospatial data on wetlands and soils produced by federal and state agencies. Because different agencies post data on their own sites, there is not a single place to go for this information. *Wetlands One-Stop Mapping* provides links to these and other websites of interest to people interested in learning about the presence and diversity of wetlands in a given locale as well as learning more about the nature and societal and environmental values of wetlands (Table 1). It provides online access to classification tools for adding hydrogeomorphic (hgm) properties to wetland inventory data along with the results of National Wetlands Inventory special projects, especially maps showing wetlands grouped by hgm features and predicted significance for performing numerous wetland functions via the NWI+ Web Mapper. Access to the NWI+ Web Mapper is a focal point of the website as this provides additional classification of wetlands along with preliminary landscape-level assessments of wetland functions for rather large geographic areas including some states. The new website also provides links to other federal and state websites that contain vital information on wetlands (e.g., regulatory programs, wetland delineation manuals, and other publications) and geospatial wetland data. Links to NatureServe Explorer and the U.S. National Vegetation Classification Hierarchy Explorer allow users to extract descriptions of wetland plant communities from those sites for specific areas of interest. Among the national datasets accessible via *Wetlands One-Stop Mapping* are the NWI's wetlands mapper and U.S. Department of Agriculture's web soil survey while U.S. Geological Survey's national hydrography data and watershed boundaries (hydrologic units; HUCs) can easily be added to the NWI+ Web Mapper. The site also provides information about the activities of the Wetland Mapping Consortium (including recorded webinars), Coastal Mapping Resources, and a summary of the status of state wetland mapping. This website greatly expands the amount of information ASWM serves up to the public and thereby further aids its mission to provide useful information for improving wetland management, conservation, and resource decision-making.

1. Introduction to Wetlands One-Stop Mapping
2. Primer
3. National Wetlands Inventory (NWI)
4. LLWW
5. NWI+ Data and Web Mapper
6. Vegetation Types
7. National Data
8. State Data
9. Other Resources
10. Online Wetlands Mapping Training
11. Wetland Subcommittee of the Federal Geographic Data Committee
12. 2010 Wetland Mapping Summary
13. Wetland Mapping Consortium
14. Future Wetland Mapping Consortium
15. Past Wetland Mapping Consortium
16. Coastal Wetland Mapping
17. Wetland Classification Image Gallery
18. Detailed U.S. Vegetation Maps
19. Resources, Publications and Links of Interest
20. Coastal Barrier Resources System Mapper – NWI Program
21. Coastal & Marine Ecological Classification Standard Gets Federal Approval

Table 1: List of topics included in "*Wetlands One-Stop Mapping*."

Wetland Maps

Pre-published hardcopy maps are largely a thing of the past as color printing and maintaining an inventory of these maps and a distribution system are too expensive for current agency budgets. Furthermore, mapping technology has advanced to the point where geospatial databases are created, thereby allowing people to print custom maps of specific areas of interest from their personal computers. In the mid-1990s, the U.S. Fish and Wildlife Service (FWS) discontinued hardcopy map production and since then posts its National Wetlands Inventory (NWI) data for public use on its "Wetlands Mapper." The data posted are standard NWI "map" data and not data from special projects which generate more detailed information. Virginia Tech's CMI has worked closely with the FWS Northeast Region to enhance NWI data by adding hydrogeomorphic-type attributes (landscape position, landform, and water flow path = LLWW descriptors) to mapped wetlands (Tiner 2011a). The expanded database now called "NWI+ data" is used to better characterize wetlands and to predict wetland functions at the landscape-level. NWI+ data may be further expanded to include other geospatial layers showing: 1) wetlands that are likely to perform various functions at significant levels, 2) land that was not detected as wetland by NWI but may support wetland due to soil mapping ("P-wet areas") and 3) potential wetland restoration sites. These special projects have produced geospatial data, maps and technical reports on study findings for specific watersheds or, in a few cases, entire states.