The Distribution of Phragmites Surrounding Farmington Bay of Great Salt Lake, Utah

A comparison of Discharge, Non-discharge, Nutrients and Grazing

THE INSTITUTE FOR WATERSHED SCIENCES

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Table of Contents

1. Introduction

Phragmites has expanded its foothold around Farmington Bay fringe wetlands since the floods that occurred during the 1980s, displacing and possibly destroying valuable shorebird and waterbird habitat. Ella Sorenson, a local shorebird specialist who has authored many accounts of the natural history of birds of Great Salt Lake and their environs in the Salt Lake Tribune and in published books, and Manager of Gillmor Audubon Sanctuary and South Shore Preserve; Don Paul, former Sr. wildlife biologist at the Utah Division of Wildlife Resources, former Great Basin Bird Conservation Region Coordinator for the Intermountain West Joint Venture, past president of the Utah Chapter of the Wildlife Society and published in both scientific and popular conservation literature; and Al Trout, former director of the Bear River Migratory Bird Conservation Refuge, distinguished for his significant accomplishment of resorting the Refuge after the floods destroyed existing infrastructure to what it is today, all agreed there was no widespread invasion of non-native Phragmites prior to the 1980s flooding event of Great Salt Lake (personal communication, 2008). The question stands: what stressor(s) define the extent to which Phragmites invades wetland communities?

Our earlier investigation of sheetflow (fringe) wetlands during 2004 and 2005 (Miller and Hoven 2007) and subsequent work in 2011 (Hoven 2012) highlighted extensive Phragmites growth post-flood years followed by extensive invasion in association with a site down-gradient of effluent discharge at Central Davis Sewer District. Analysis presented in Miller and Hoven (2007) showed a negative response by native plant species with increasing nutrients, which included data from two effluent discharge sites: Central Davis Sewer District and North Davis Sewer District. From our earlier work and continued expansion and invasion by Phragmites in practically all fringe wetlands surrounding Farmington Bay, we formulated the following hypotheses for a preliminary study conducted during the summer of 2015.

Hypotheses and Objectives

H1: Phragmites invasion has a greater response in areas down-gradient of effluent discharge than non-discharge sites.

H2: Phragmites invasion has a stronger response to elevated nutrients than lower nutrients.

H3: Biological control of Phragmites by cattle grazing and draw-down (drying to raise surface sediment salinity) can effectively reduce the cover of Phragmites to restore beneficial use for aquatic life and their foodchain.

Objective 1: Conduct a minimum of 3 consecutive monthly assessments at a variety of sites that can be used to describe emergent communities associated with discharge and non-discharge affected flows, grazed and non-grazed areas, freshwater and more saline habitat, as well as low to high sediment toxicity. DWQ has established protocol for evaluating fringe wetland condition once annually during the summer to capture percent cover of plants and species composition within the first 500 m from the discharge point. We challenge that one visit to a site per growing season is inadequate to describe biological response relative to environmental stressors when metrics for condition assessment of emergent plant communities have not yet been fully developed and knowledge of metric sensitivity is unknown. Additionally, in a system where Phragmites and cattail responded to the large-scale disturbance from the Great Salt Lake flooding during the 1980s by outcompeting other wetland emergent plants for newly available barren sediment, identifying additional influences of other environmental stressors (such as nutrients, sediment toxicity, salinity, etc.) that may have also contributed to the extensive distribution of these invasive species cannot be separated from the influence of the flooding disturbance within the spatial scale of 500 m. We documented the expansion of Phragmites well over 500 m beyond the source of discharged water compared to our earlier surveys during 2004 and 2005. We also found significantly higher accumulation of floating plants and algae well outside 500 m from the Central Davis Sewer District discharge during our 2011 survey. We presumed the plants were either sensitive to high flow or washed downgradient where flows dissipated. Assessing such a small proportion of the fringe wetlands would provide inconclusive information relative to describing the influence of discharge on the wetland community (including vegetation, and beneficial uses for shorebirds and waterfowl). Thus our transects extend deeply into the established Phragmites community to capture the full extent of influence of the source water for each site.

Objective 2: Develop a suite of metrics that assess the physical stature and areal cover of Phragmites, the influence of Phragmites on light as a resource (shading effects), taxa richness, and disturbance relative to invasive / non-native species.

Objective 3: Compare differences in the temporal establishment and development of plant communities using a variety of metrics that could be attributed to different environmental effects, including but not limited to salinity, sediment toxicity, cattle grazing, water depth, discharge, and nutrients.

2. Methods

The metrics described below were conducted at each of 10 one m^2 plots (0.5 m by 2.0 m). The plots were located at randomly selected locations along a 100 m transect. There were two transects at each site, which were either matched by GPS position as closely to our historic transect locations or placed at up-gradient and down-gradient locations that would represent a change in plant community, where applicable. At some sites, the stand of Phragmites was so extensive that there was no visible change in species composition or the hydrology precluded us from placing the transects further apart. Field sampling occurred monthly for three months at the discharge / non-discharge sites (eg., KC, CD, OD) and once every four months at the grazed / non-grazed sites (eg., TU, LF).

Site Locations

Five sites, each with two transect locations, were selected from previously established sites and an additional discharge and grazing site. They all drain into Farmington Bay and are located in transitional fringe wetlands between the urban and suburban lands along the Wasatch Front and Great Salt Lake (Figure 2.1). Most years, there is but a thin channel that drains through exposed mudflats of Farmington Bay out to Great Salt Lake. As the freshwater from tributaries, runoff and treated effluent discharge flow through these wetlands, the water becomes more saline as it approaches the Lake. The plant communities respond accordingly changing from freshwater obligates to marginally salt tolerant to salt tolerant species.

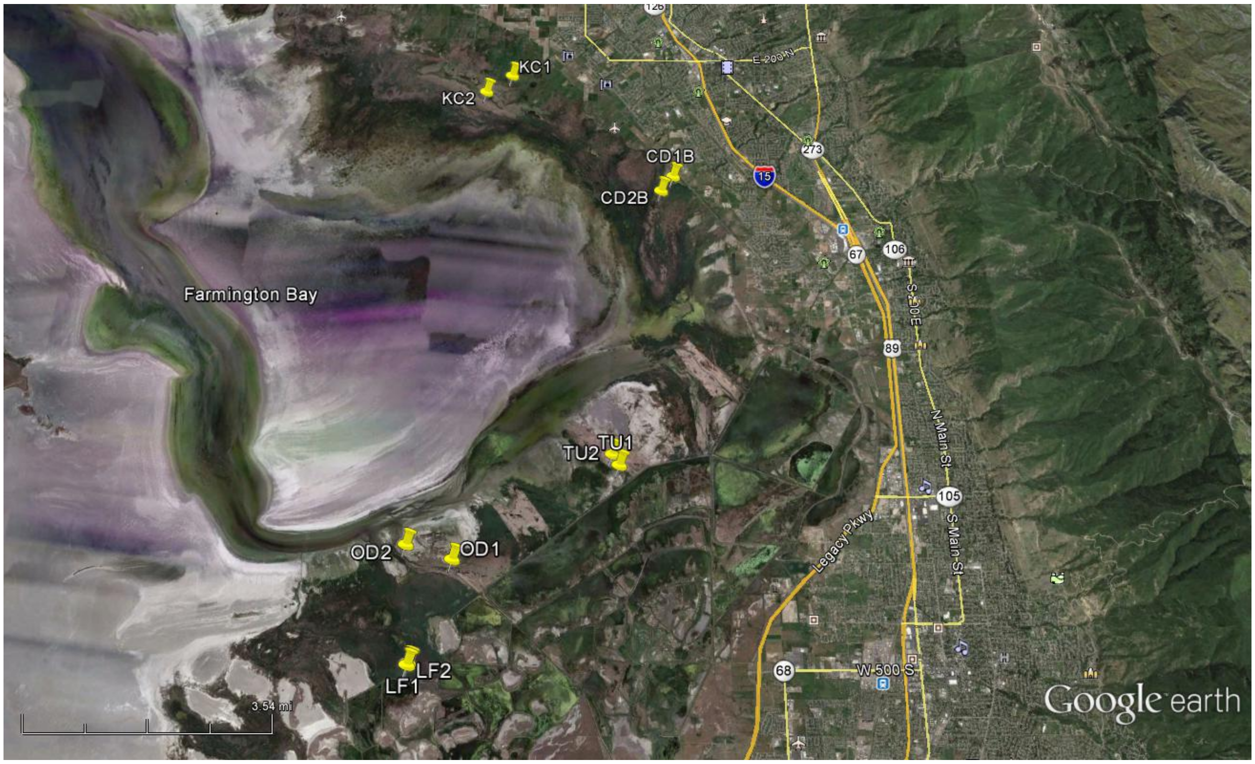


Figure 2.1 Five fringe wetland sites surrounding Farmington Bay, each with two transect locations: Kays Creek (KC), Central Davis Sewer District (CD), Turpin Unit (TU), and the Northwest Oil Drain (OD).

Discharge influenced sites include: the Northwest Oil Drain (OD), effluent discharge from Salt Lake City Public Utility, and down-gradient of Central Davis Sewer District (CD, Figures 2.2 and 2.3).

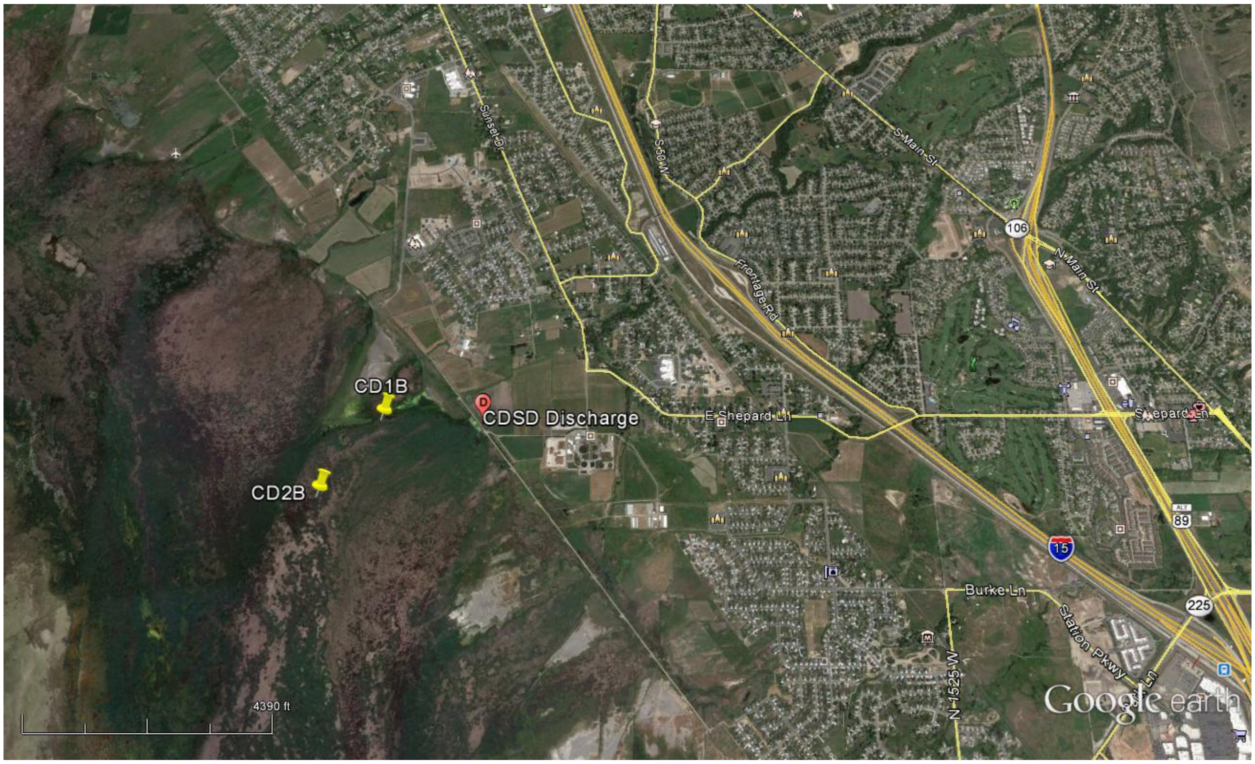


Figure 2. 2 Transect locations at Central Davis Sewer District (CD).

Figure 2..3 Transect locations at the Northwest Oil Drain (OD).

Grazing influenced sites include: Area down-gradient of the Turpin Unit of Farmington Bay Wildlife Management Area (TU, Figure 2.4). The fourth year of high pressure grazing was scheduled for Phragmites control outside of the Turpin dyke during 2015 (2000 cow/calf pairs, R. Hansen, personal communication, 3-31-15). Our second grazed site was located down-gradient of Kays Creek in The Nature Conservancy's Shoreland Preserve (KC, Figure 2.5). A small herd of cattle (lower grazing pressure) have been present at Kays Creek prior to 2004 until the present. Kays Creek has cattle present along the first transect area and is not influenced by effluent discharge. Its water is comprised of groundwater, irrigation return flows and runoff.

Figure 2..4 Transect locations down-gradient of Turpin Unit.

Figure 2.5 Transect locations down-gradient of Kays Creek.

Our control site (non-discharge and non-grazed) is an emergent wetland just outside of the 50s and 60s impounded wetlands at Lakefront Duck Club as it is not influenced directly by effluent discharge and has never had cattle in the vicinity (Figure 2.6). It receives water that originates in the Ambassador cut off the State Canal (Jordan River water), flows through Ambassador Duck Club and Northpoint Duck Club before entering LF and flows through the 50s and 60s impoundments into our control site (LF).

Figure 2.6 Transect locations down-gradient of Lakefront 50s and 60s impoundments. These transects were located fairly close to each other to avoid influences from waters draining from the nearby FB WMA impoundments.

Phragmites Metrics

Within each plot, percent cover of all living plant species and standing dead vegetation were determined and recorded. The following metrics were also recorded or collected:

Average height of the three tallest Phragmites stems.

Standing water depth from where the meter tape cannot penetrate litter or surface of humus soil layer. Average of three maximum Phragmites stem diameters (stem height must be at least 130 cm).

Average of three minimum Phragmites stem diameters (stem height must be at least 130 cm).

Stem density count of Phragmites in a 25 cm 2 sub-plot randomly located within each plot.

Invasive species within plot.

Non-native species within plot.

Litter depth measured from solid ground or impenetrable litter to highest portion of the litter.

Litter score:

0 = full sunlight through the canopy; no shading by litter.
1 = minimal shading by litter; litter is not thick and sunlight penetrates to most of the ground.

2 = plot is shaded by moderate litter but sunlight penetrates through at least 50% of the litter to the ground.
3 = most of the plots is shaded by a thick litter layer, but some sunlight penetrates to the ground, providing diffuse light.
4 = complete shading by thick litter layer; no sunlight penetrates to the ground.

Disturbance score:
0 = No Disturbance, no invasive or non-native species
1 = Minimal to some disturbance (less than 25% of transect contains invasive +/or non-native species)
2 = Disturbed (at least 25% -70% of transect contains invasive +/or non-native species)
3 = Very Disturbed: majority of transect (> 70%) contains invasive +/or non-native species

CNP Phragmites leaf tissue samples at three plots per transect (collection of 1st completely unfurled young leaf from stems in vicinity of plot) during July and August; rinsed in distilled H_20, dried at 34° C for a minimum of three days. CNP samples are archived for analysis at professional lab for total carbon, nitrogen and phosphorous as well as N and C isotopes. Those data will be presented as an addendum when available.

Seed biomass samples (once seeds were formed) of all seeds present within the stem density sub-plots, dried by species at 34° C for a minimum of three days and weighed.

Statistical Analysis

Treatment Effects

Treatment effects models are more appropriate than ANOVAs when estimating experimental-type causal effects that are from collected from observational data and are not results from actual experiments. Unlike experimental data, which are randomly selected into treatment groups, observational data were non-randomly assigned into treatment groups. Of course, these models are based on the scientific rational of the causal (treatment) effects. In addition, if there is more than one treatment (covariables) then these covariables can be controlled for and estimates of individual treatment effects can be made.

We used fractional treatment effects using 'nearest neighbor matching' estimators. Fractional treatment effects were used because Phragmites was measured as a percent. Percent values were transformed to fractional values between 0 and 1. Because fractional values are restricted between 0 and 1, they cannot be normally distributed, therefore fraction treatment effects are the most appropriate method. 'Nearest neighbor matching' pairs the observed outcome in one treatment group with the outcome of the "closest" outcome in the other treatment group. For example, in our data nearest neighbor pairs would be months, years, sites, cattle present/absent, and discharge influenced, etc. The outcome of the closest observation is used as a prediction for the missing potential outcome. The average difference between the observed outcome and the predicted outcome estimates the average treatment effect. We used a Mahalanobis distance metric because it is unit-

less and scale invariant taking into account correlations in the data. We also estimated treatment effect on the treated (atet) outcomes because of potential covariate interactions.

2005 vs. 2015

We estimated the average treatment effects of year, 2005 vs. 2015 on percent Phragmites with site, month, cattle, and discharge as covariates. We could only use 2005 and 2015 data because treatment effects are based on binomial outcomes (i.e. treatment vs. no treatment). Also, the 2011 data only included June samples.

3. Results and Discussion

General observations re: general distribution of Phragmites at FB sites and treatment effects on its distribution. We took the opportunity to review our historic data and compare it with that collected in 2015 to assess change in the extent of cover of Phragmites at sites that were visited both years. We found There was a 20% increase in Phragmites from 2005 to 2015 at two sites that were visited both years: Kays Creek, a non-discharge site, and Central Davis Sewer District a discharge site (Figure 3.1, P =< 0.01, 12.2% to 27.8%, 95% CI's, and Table 3.1).

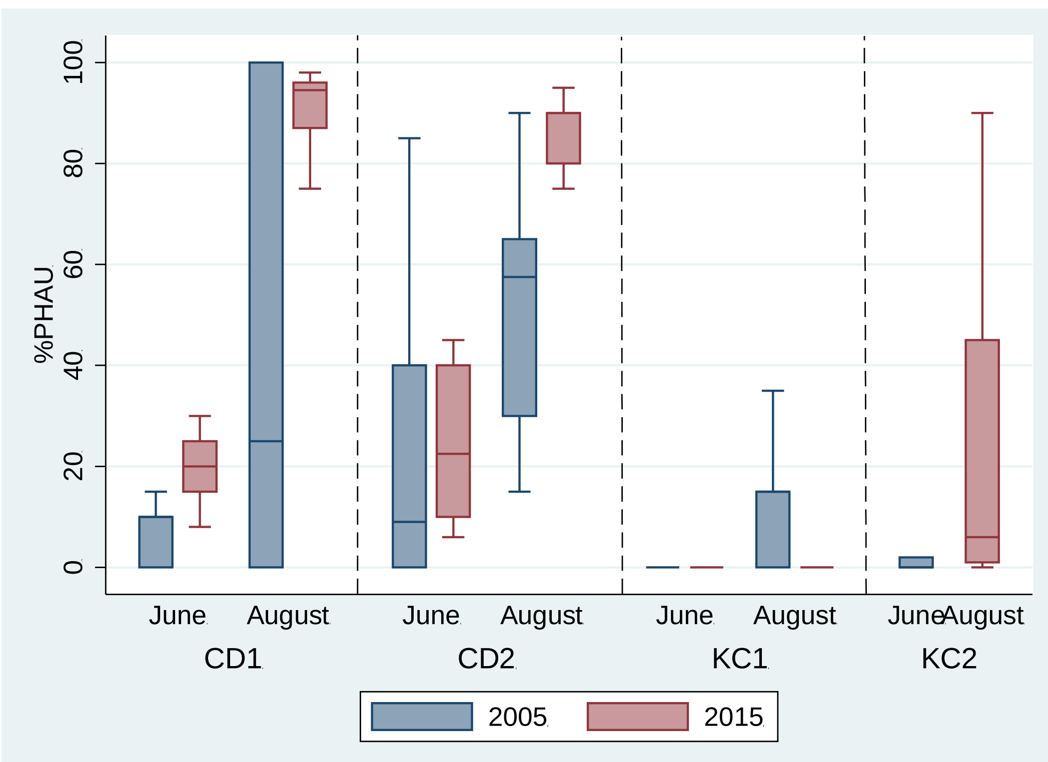


Figure 3.1 Change in percent cover Phragmites (PHAU) at transects 1 and 2 at Central Davis Sewer District (CD) and Kays Creek (KC) from 2005 to 2015.

Table 3.1 Estimation of treatment effects on percent cover PHAU at CD1, CD2, Kc1, and KC2, during June and August, 2015.

```
. teffects nnmatch (Phau Site Month Cattle Discharge) (Year)

Treatment-effects estimation                   Number of obs      =        397
Estimator      : nearest-neighbor matching     Matches: requested =          1
Outcome model  : matching                                     min =          1
Distance metric: Mahalanobis                                  max =         11
```

Phau	Coef.	AI Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
ATE						
Year (2015 vs 2005)	.2000719	.0398627	5.02	0.000	.1219424	.2782014

General Descriptive Metrics, 2015

Samples from each quadrat location varied enough to justify treating them separately, thus all samples from both transects at a site would represent the entire site. Bare ground / open water within the sample plots shows a decrease in open space as the summer progressed at both CD and LF. KC, OD, and TU remain somewhat open as the summer progressed (Figure 3.2).

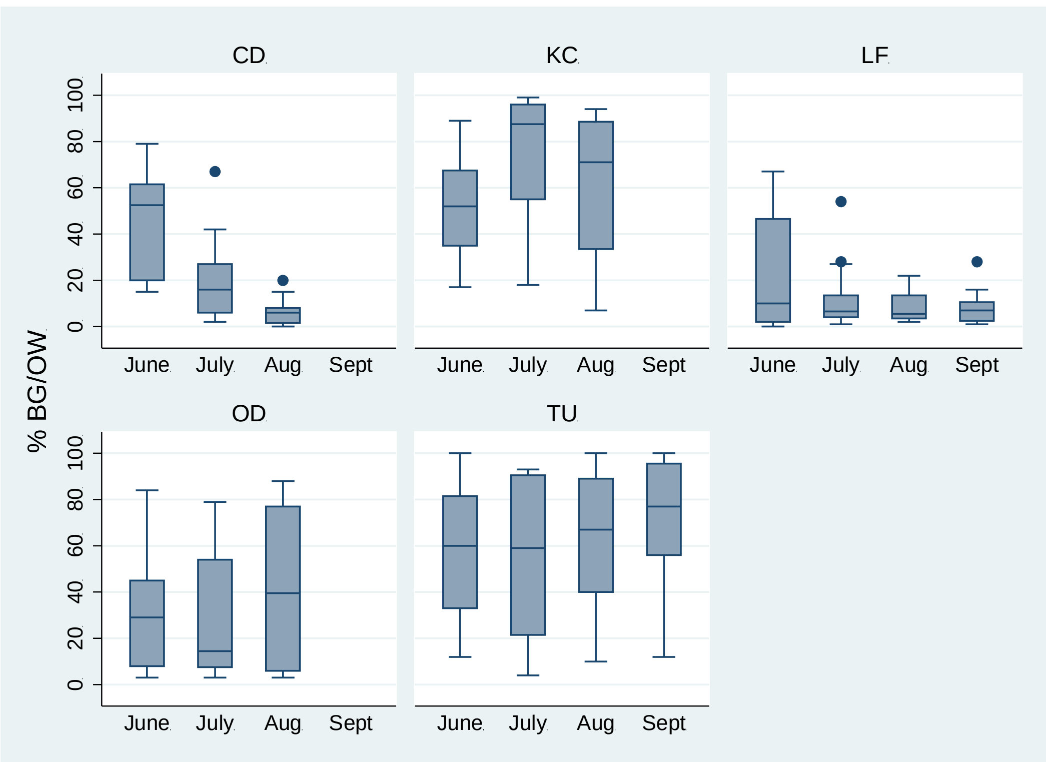


Figure 3.2 Average bare ground / open water at each fringe wetland site during 2015.

Average percent cover standing dead vegetation (DV) was highest at CD, LF, and OD during June or June and July (Figure 3.3).

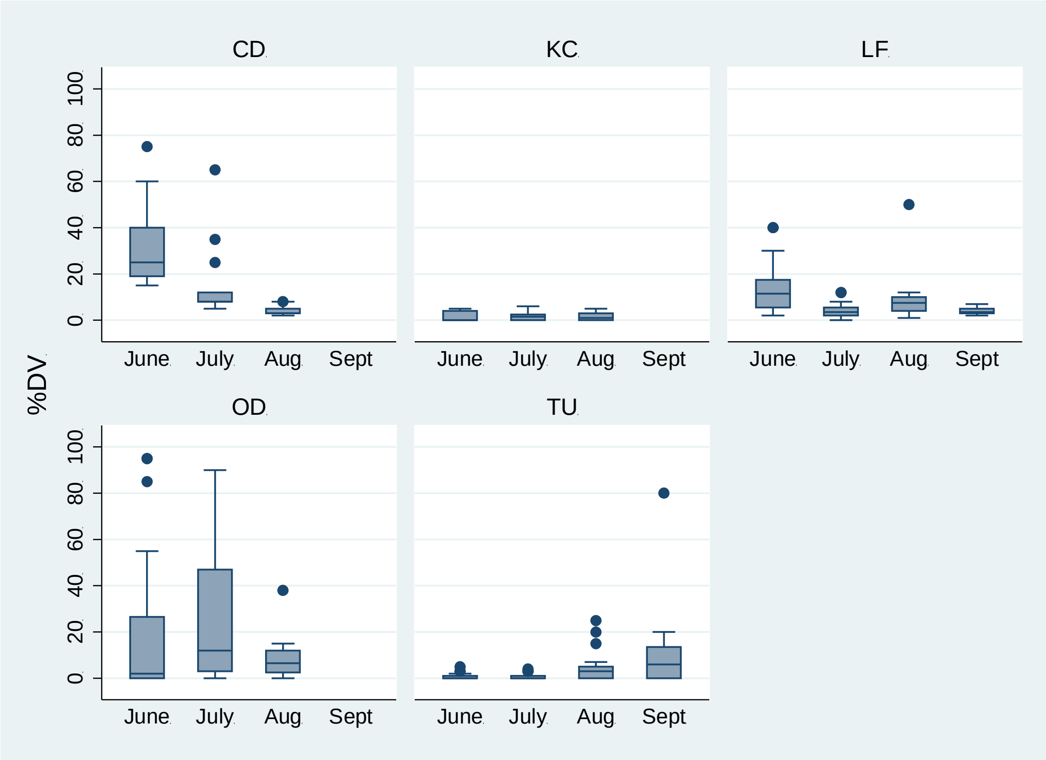


Figure 3.3 Average percent cover standing dead vegetation at each fringe wetland site during 2015.

Average percent cover DW (LEMI) was most prevalent at KC and TU, however the percent cover was typically low (Figure 3.4).

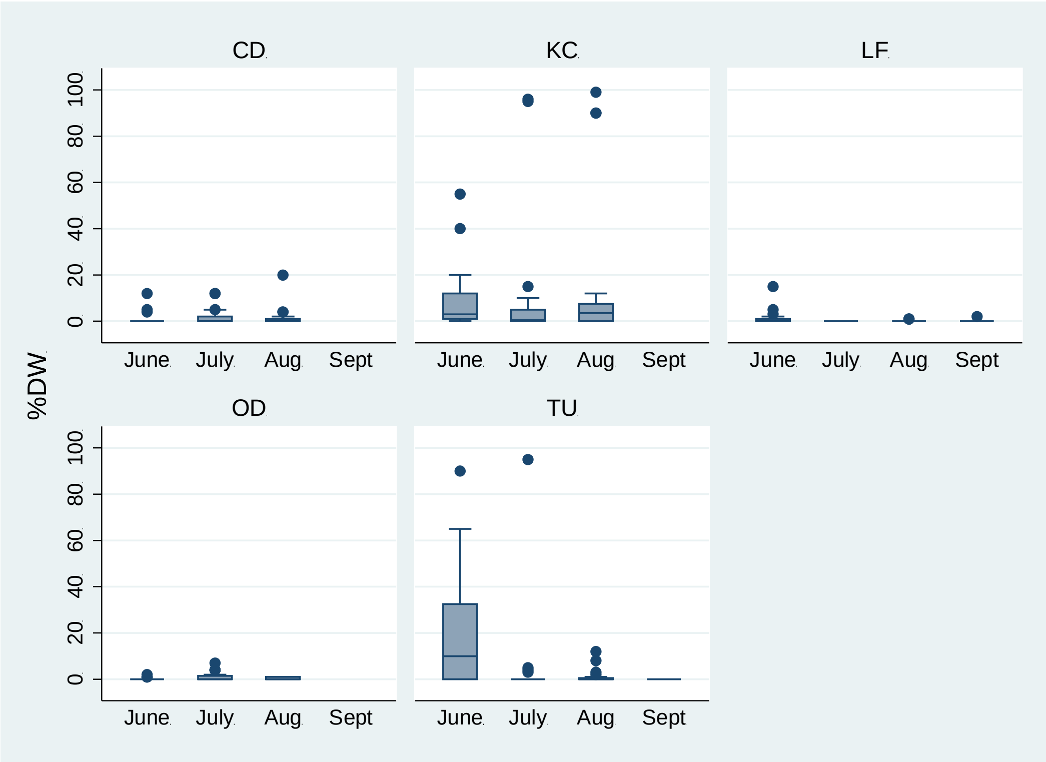


Figure 3.4 Average percent cover DW (LEMI) at each fringe wetland site during 2015.

Average percent cover Phragmites (PHAU) at CD (discharge) and LF (non-discharge, control) increase in cover and remain high throughout the summer (Figure 3.5). TU cover actually declined as the summer progressed, likely related to the active grazing at that site and drying condition resultant from closing of the Turpin Unit culverts during June. KC also had cattle present in the vicinity of the first transect and was low in Phragmites cover. The second KC transect was not accessible to the cattle but had very dense litter cover, which likely negatively affected new Phragmites growth due to shading (see litter depth and litter score below).

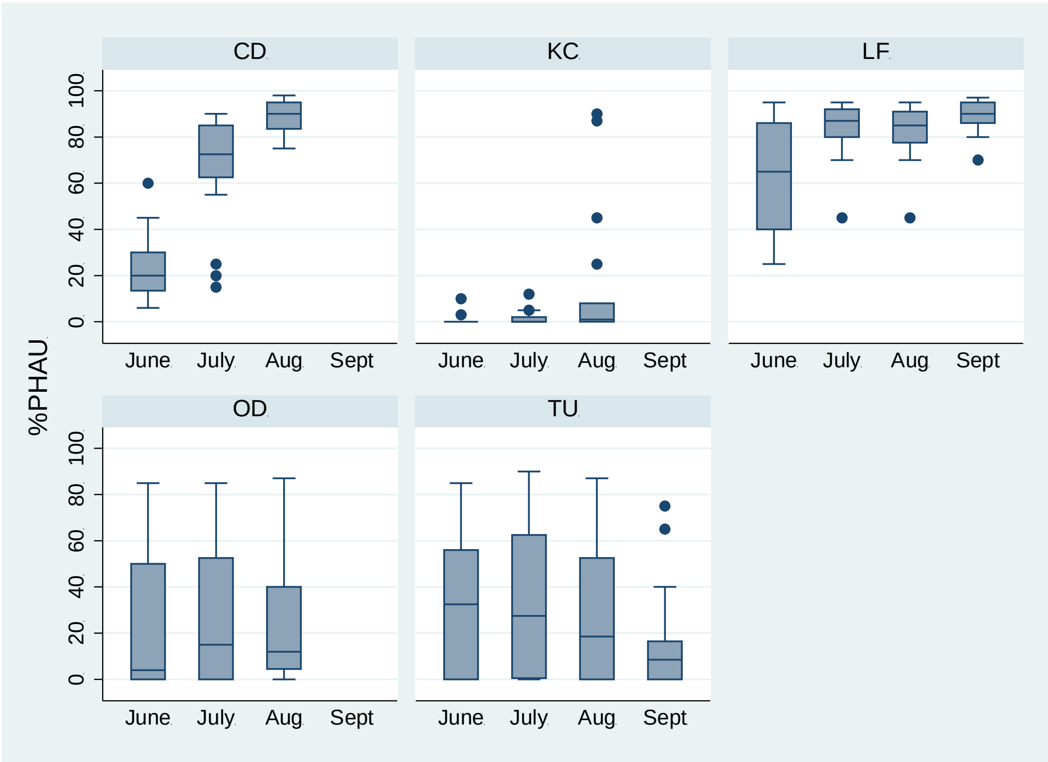


Figure 3.5 Average percent cover Phragmites (PHAU) at each fringe wetland site during 2015.

Cattail (TYLA) was the second most dominant species at all sites, but was only prevalent at KC (Figure 3.6).

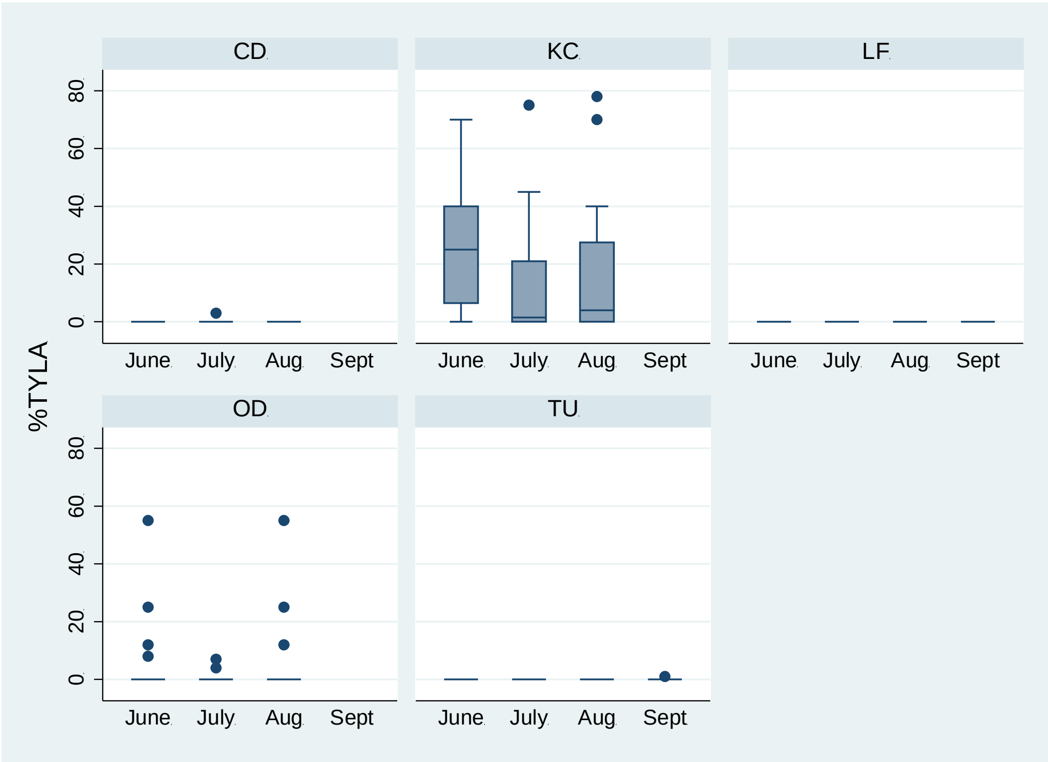


Figure 3.6 Average percent cover cattail (TYLA) at each fringe wetland site during 2015.

Litter Depth revealed a substantial litter build-up at CD, KC, LF, and to some extent at OD. Litter build-up at TU was minimal (Figure 3.7).

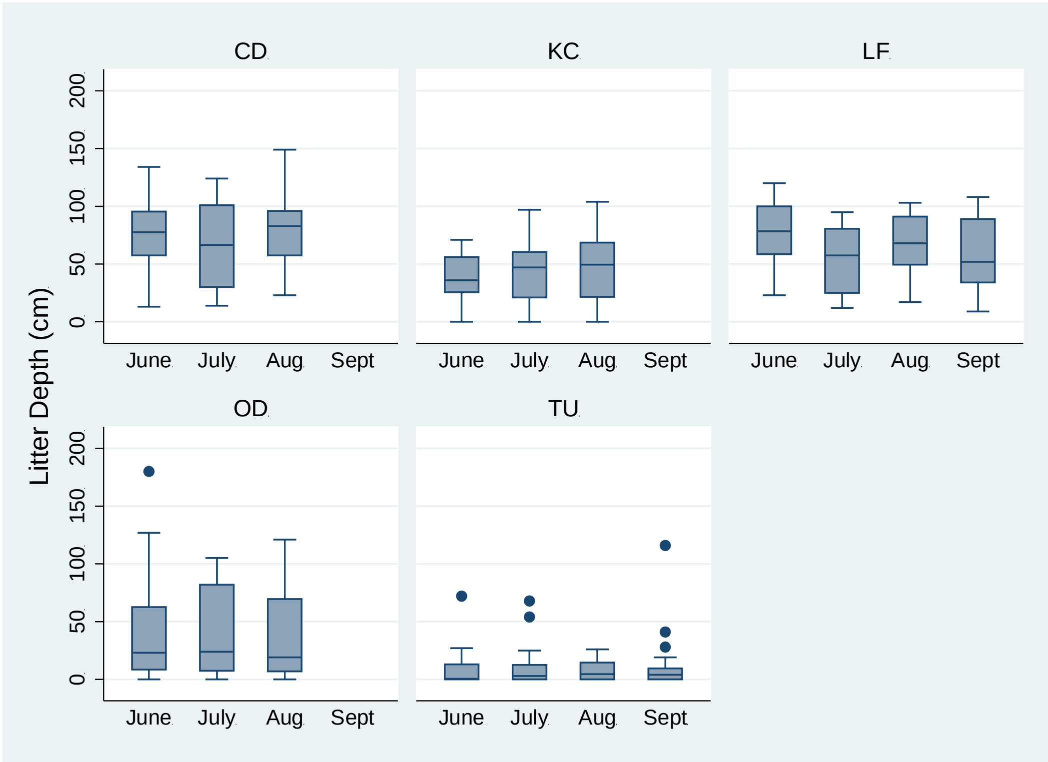


Figure 3.7 Average litter depth (cm) at each fringe wetland site during 2015.

Litter Score was developed during the August sampling period so data were not available at all sites, all months. The available litter score data show that shading was most extreme at CD, probably precluding other species from becoming established (Figure 3.8). Other sites with moderately high shading were KC and LF. Shading from litter build-up were very low and low at OD and TU, respectively.

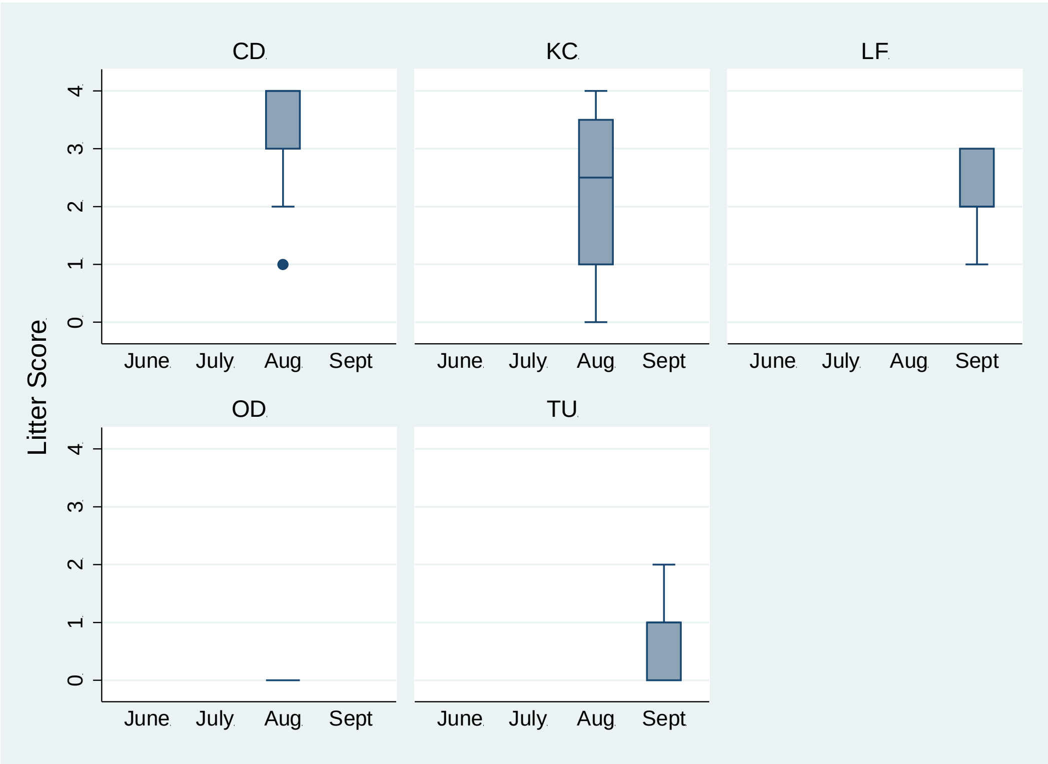


Figure 3.8 Average litter score, 0 being zero litter build-up and thus zero shading of the subcanopy and sediment surface; 4 being the most dense with complete blockage of sunlight penetration to the wetland floor.

Water depth (H2O Depth cm) was greatest at KC, LF, and OD during June (Figure 3.9). KC and OD1 have many braided channels accounting for the high variability at those sites. Additionally, OD2 was adjacent to a playa, which was an inherently dry site after spring runoff subsided. Median depth remained stable during the three months of sampling at the two discharge sites, CD and OD, while water depth was more variable from month to month at the other sites. Water depth measurements during July and September (when measured) were notably lower at KC, LF, and TU.

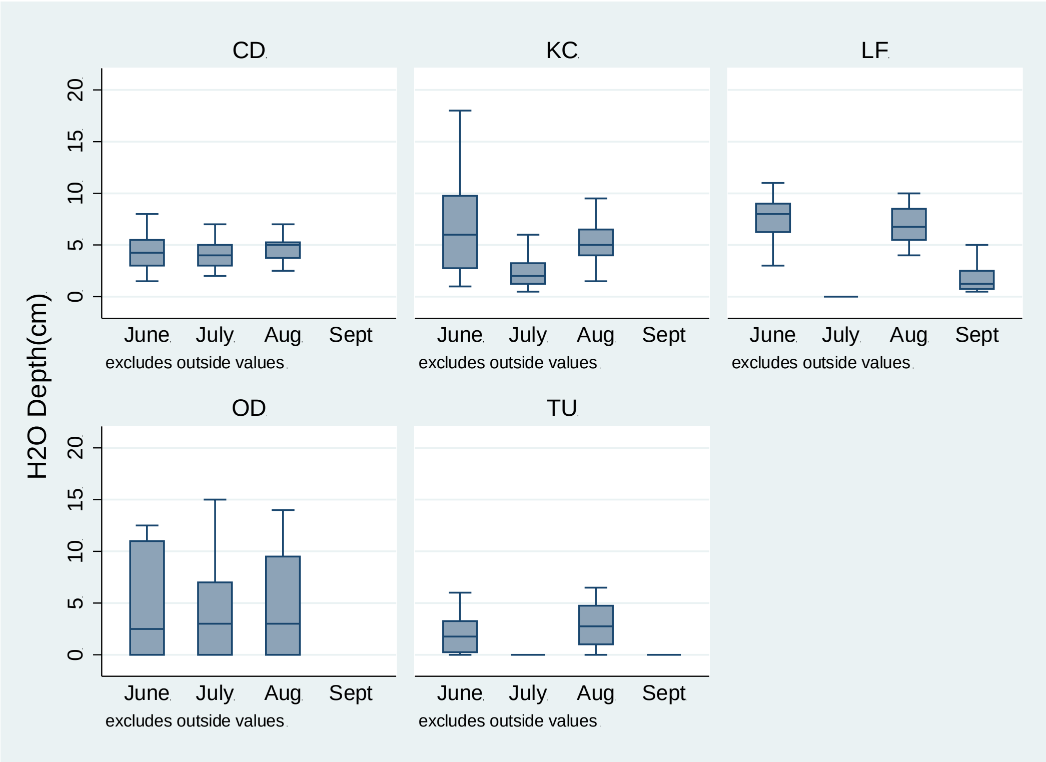


Figure 3.9 Average water depth (H2O Depth cm) at each fringe wetland site during 2015.

Phragmites at CD (discharge) and LF (control) had comparable maximum height, while Phragmites at KC, OD and TU were notably shorter (Figure 3.10).

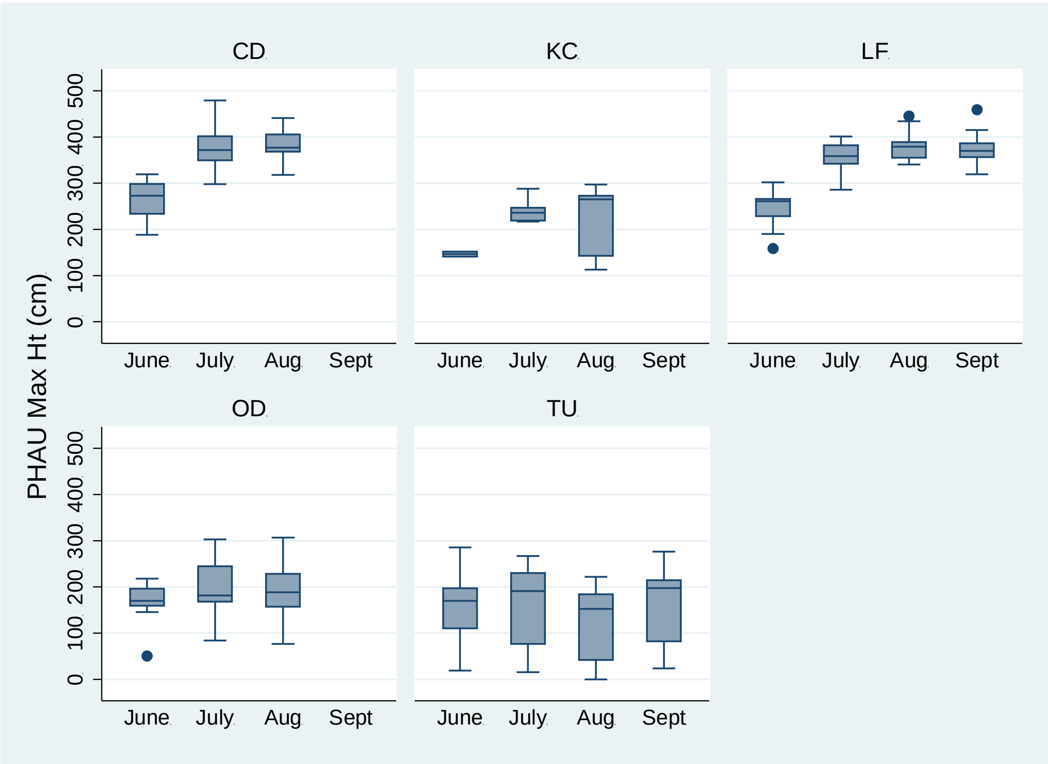


Figure 3.10 Average maximum height of Phragmites at fringe wetland sites during 2015.

Average stem density / m^2 (PHAU) was highest at TU, perhaps showing the tenacity of Phragmites when grazed (many new shoots produced as stimulated by grazing, Figure 3.11). By September, decreased stem density at TU may have been resultant of grazing and increased salinity – both related to management actions, however, stem density declined at the control site, LF, as well. OD and CD, both down-gradient of discharges, had comparable PHAU stem density with medians being fairly low. LF had somewhat higher stem densities during June and July than CD and KC. Stem density at KC was low all months.

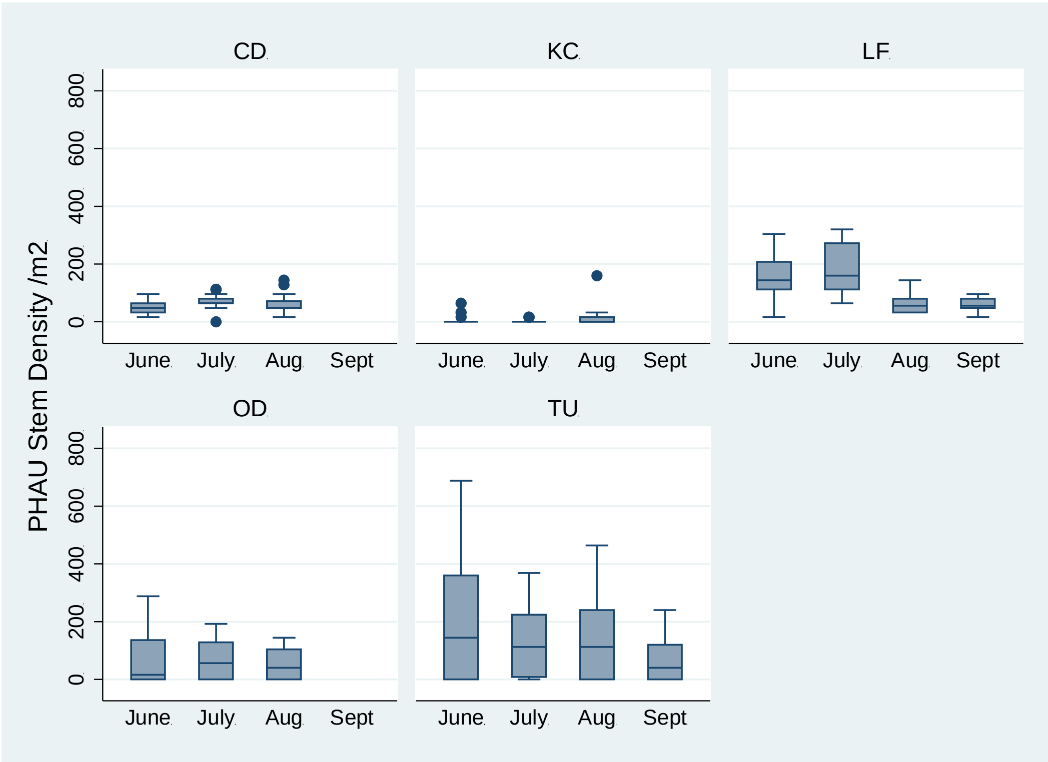


Figure 3.11 Phragmites average stem density / m² at each fringe wetland site during 2015.

Sites with the highest taxa richness were KC, OD, and TU (Figure 3.12). KC1 had similar hydrology to OD1, both with braded channels and fairly open areas throughout the vegetation. Both OD2 and TU1 were adjacent to playas, which contributed to the addition of salt tolerant wetland species. TU1, TU2 and KC1 were grazed by cattle.

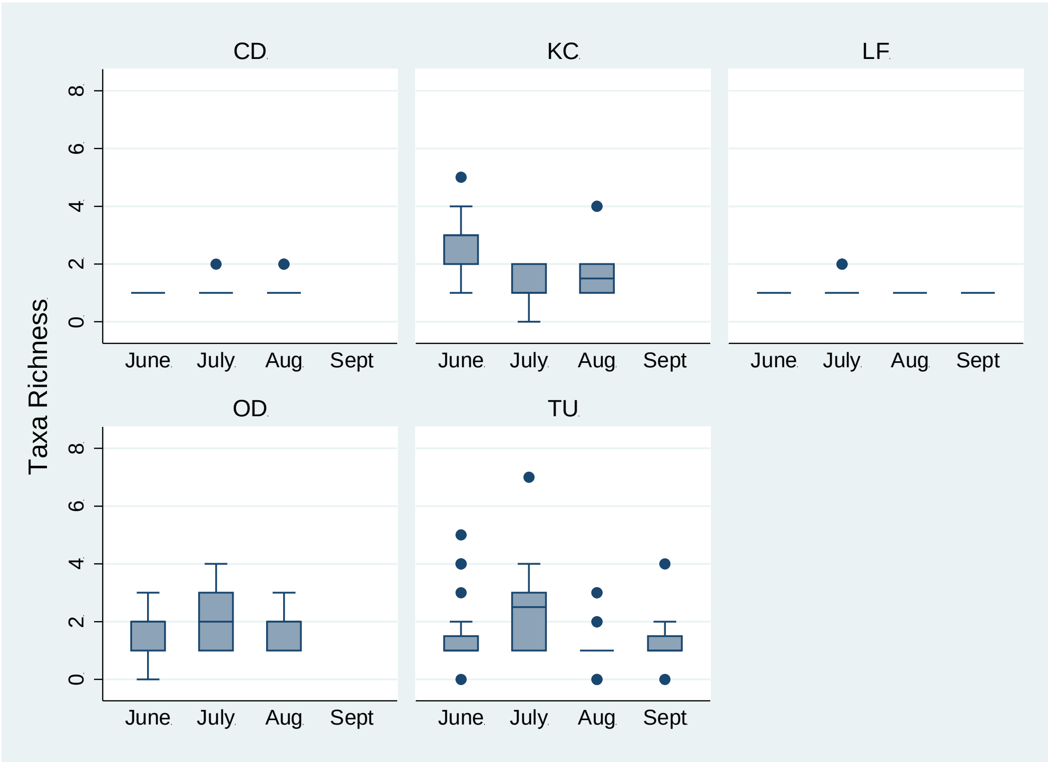


Figure 3.12 Taxa richness at each fringe wetland site during 2015.

Water Chemistry at Farmington Bay Fringe Wetland Sites

Summary water chemistry statistics and correlations are provided in Tables 3.2 and 3.3. Maximum values illustrate the elevated levels found at some of the sites described in more detail below.

Table 3.2 *Error! Use the Home tab to apply 0 to the text that you want to appear here.**Summary statistics of nutrients and sulfide from all sites, 2005 (DWQ), 2011 (Carling et al. 2013), and 2015 (JR/FB WQ Council).***

Variable	Mean	Std. Dev.	Min	Max
ammonia	1.78	1.53102	0.59	5.61
sulfide	0.1522222	0.2242479	0.05	0.78
sulfate	143.4411	104.8023	38.98	322
nitrite	0.0777778	0.1017573	0.02	0.36
nitrate	0.1677778	0.1990301	0.03	0.55
phosphate2	0.8877778	0.8303211	0.18	2.58

Table 3.3 **Water chemistry correlations and** ***P values (N = 90)***

	ammonia	sulfide	sulfate	nitrite	nitrate	phosph~2
ammonia	1					
sulfide	0.8916	1				
	0					
sulfate	-0.1074	-0.2904	1			
	0.3136	0.0055				
nitrite	0.9299	0.9899	-0.2792	1		
	0	0	0.0077			
nitrate	0.5188	0.6962	-0.4493	0.6799	1	
	0	0	0	0		
phosphate2	0.3687	0.0907	-0.241	0.1702	-0.1359	1
	0.0003	0.3951	0.0221	0.1088	0.2016	

Sulfide was elevated at KC (Figure 3.13). Phytotoxic levels of sulfide may accumulate in wetland sediment as a result of microbial reduction of sulfate during anaerobiosis, particularly in the rhizosphere (Lamers et. al 2013).

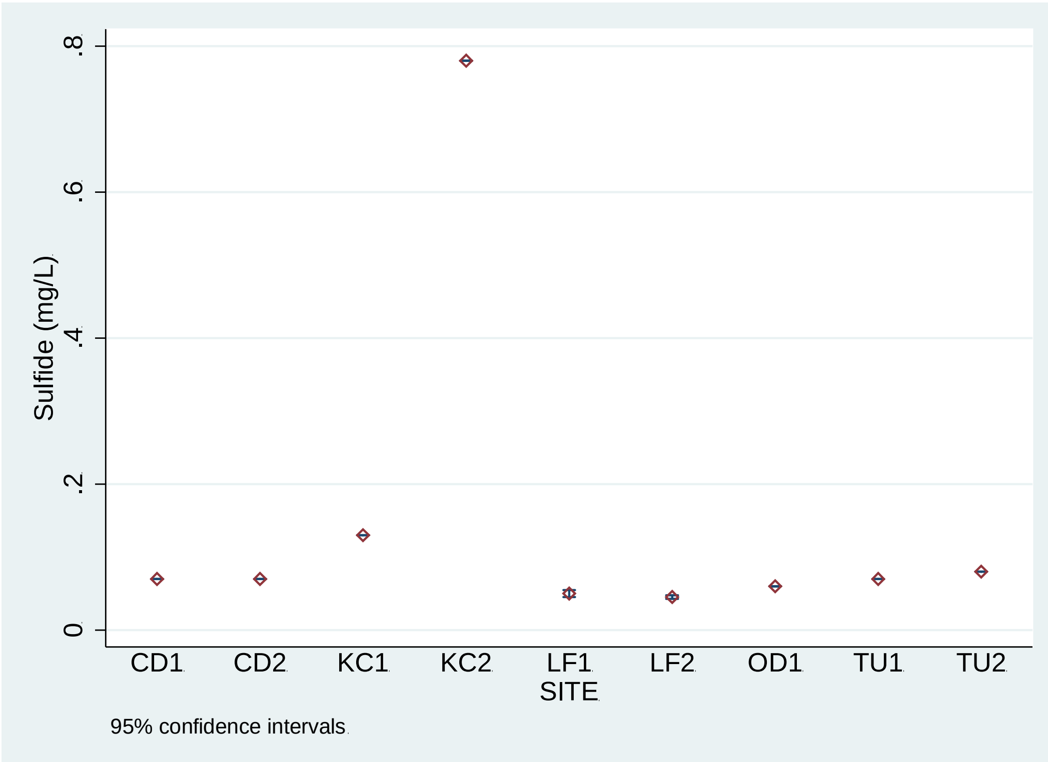


Figure 3.13 Sulfide at each fringe wetland site during 2015. N = 1

Sulfate was elevated at OD1, TU1 and TU2 compared to the other sites (Figure 3.14).

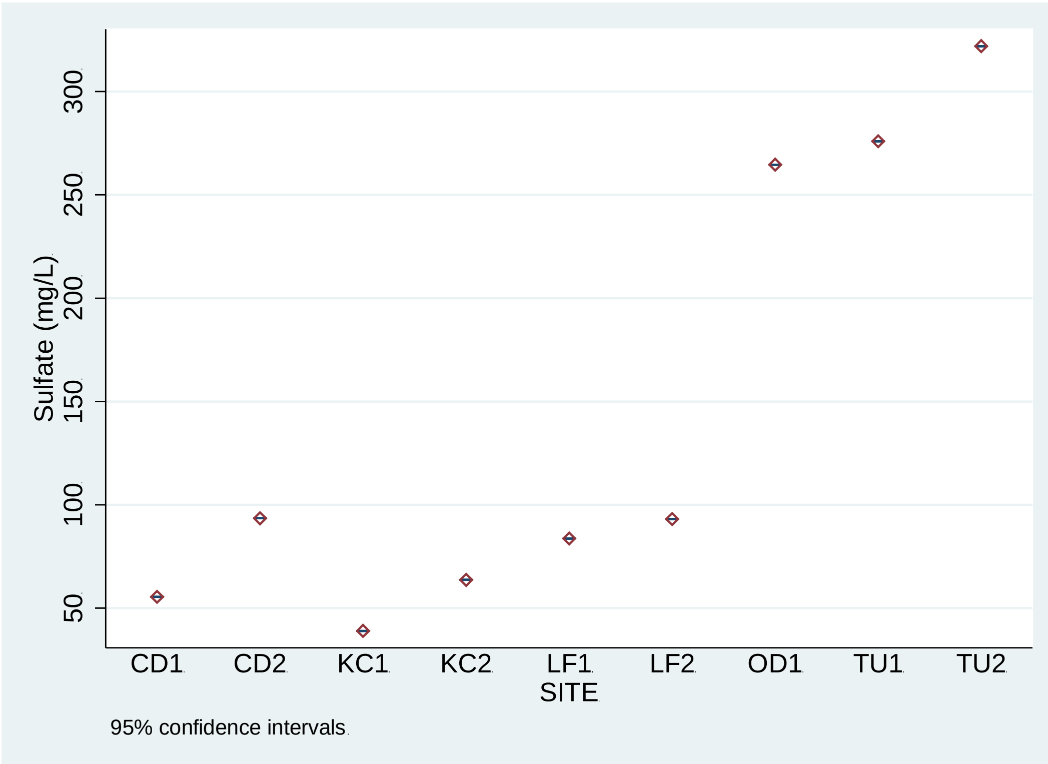


Figure 3.14 Sulfate at each fringe wetland site during 2015. N = 1

Phosphate levels varied among sites with highest levels at CD1, followed by CD2 and OD2 (Figure 3.15).

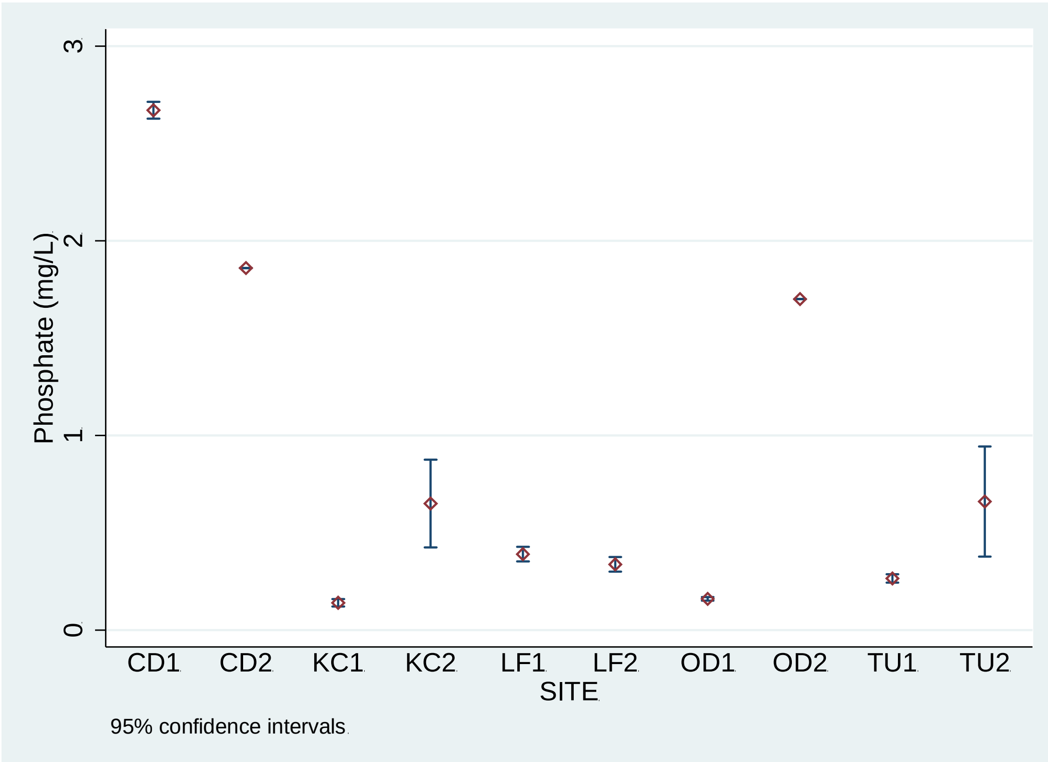


Figure 3.15 Phosphate at each fringe wetland site during 2015. N = 1

Nitrite levels were highest at KC2, while all other sites had comparably low levels of nitrite (Figure 3.16).

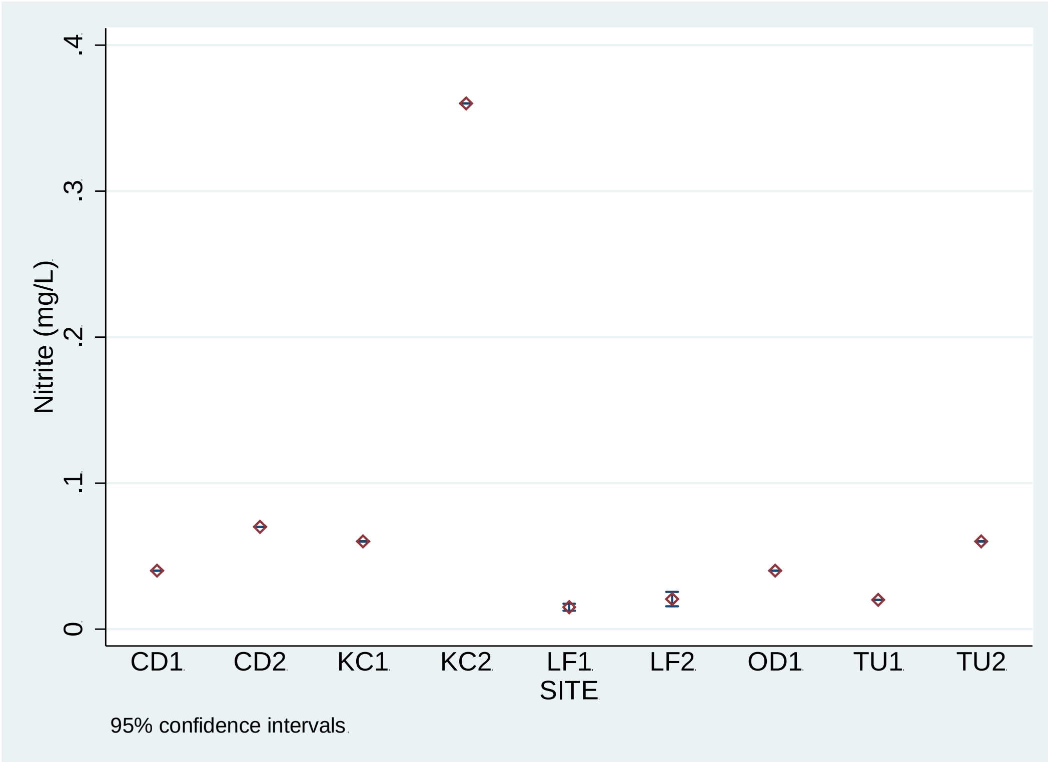


Figure 3.16 Nitrite at each fringe wetland site during 2015. N = 1

Nitrate was highest at KC1 and KC2 (Figure 3.17).

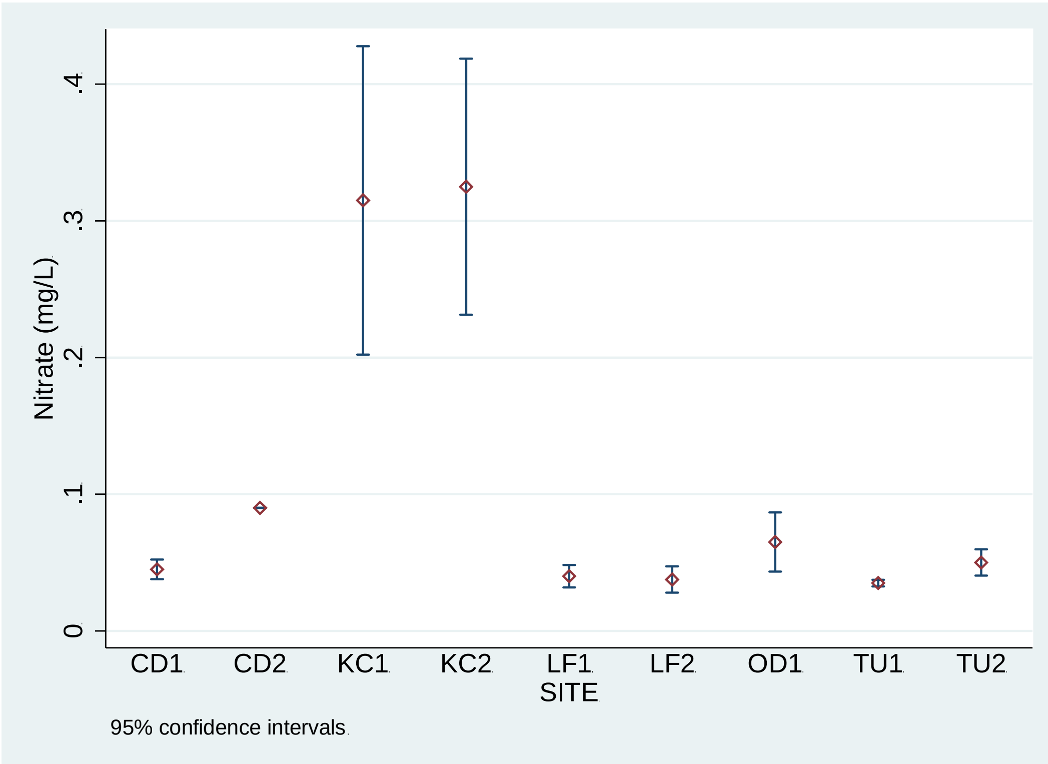


Figure 3.17 Nitrate at each fringe wetland site during 2015. N = 1

Ammonia was highest at OD2 and variable at the other sites (Figure 3.18).

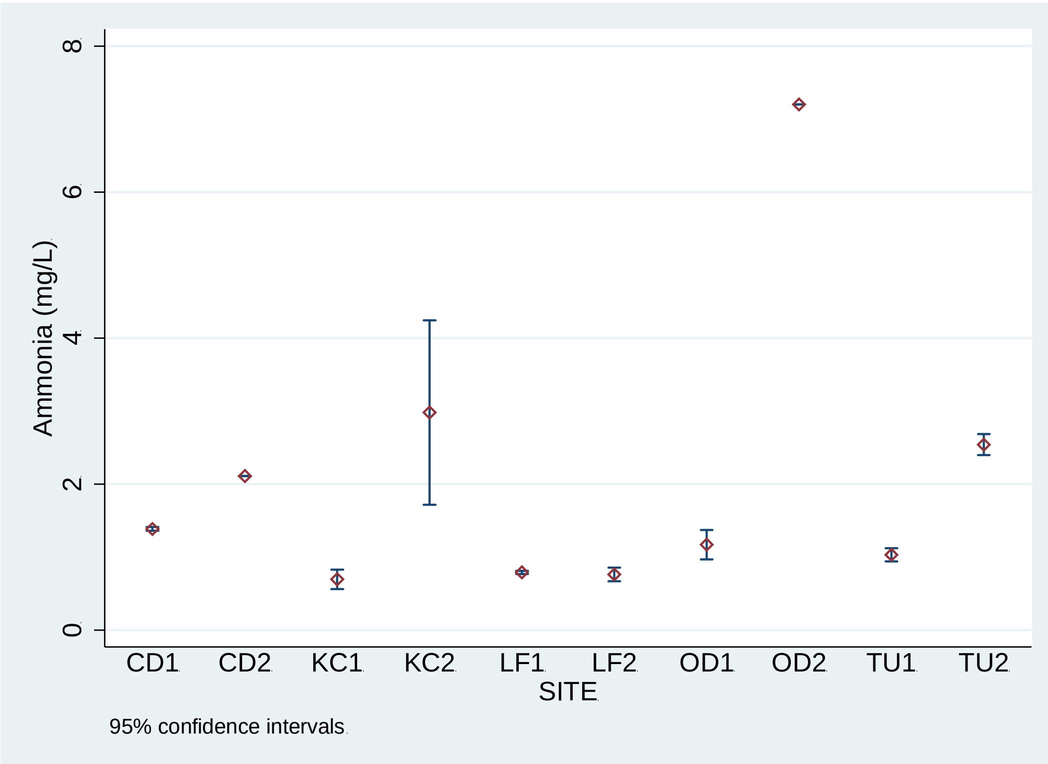


Figure 3.18 Ammonia at each fringe wetland site during 2015. N = 1

Treatment effects on Phragmites

Covariates of treatment effects are shown in Appendix 1 to illustrate the many lines of co-linearity and complexities of modeling the system (Appendix 1).

Nutrients

Margins dy/dx are helpful estimates for interpreting fractional regression coefficients. For the continuous variables (all except salinity and SedTox) margins is the estimate of the marginal change which is the partial derivative or instantaneous rate of change in the estimated quantity with respect to a given variable holding other variables constant. For example, a 1% increase in nitrite is estimated to result in a 5.46% decrease in percent cover Phragmites (Table 3.4). A 1% increase in nitrate is estimated to result in a 2.94% decrease in percent cover Phragmites as well. Although an inverse relationship between percent cover PHAU and nitrite or nitrate may seem counter-intuitive, other factors must be considered, such as competition for light from the canopy and litter build up in monotypic stands of PHAU or other limiting factors. It is interesting, however, that the nutrients considered essential for growth and often associated with stimulated growth (N and P) have inverse relationships with proportion PHAU or no significant relationship at all when Phragmites is a known to assimilate nutrients competitively (Kadlec and Wallace 2009). A 1% increase in sulfide on the other hand, is estimated to result in a 2.62% increase in proportion PHAU.

Table 3.4 Average marginal effects of nutrients and sulfide on percent cover Phragmites

```
. margins ,dydx(*)

Average marginal effects                        Number of obs     =         90
Model VCE    : Robust

Expression   : Conditional mean of Phragmites, predict()
dy/dx w.r.t. : ammonia nitrite phosphate2 sulfide sulfate nitrate 2.Salinity1 3.Salinity1 2.SedTox1 3.SedTox1
```

	dy/dx	Delta-method Std. Err.	z	P>|z|	[95% Conf.	Interval]
ammonia	.1401139	.0777826	1.80	0.072	-.0123372	.2925649
nitrite	-5.455463	2.156885	-2.53	0.011	-9.68288	-1.228047
phosphate2	-.0237794	.0224524	-1.06	0.290	-.0677853	.0202265
sulfide	2.629658	.6911068	3.80	0.000	1.275113	3.984202
sulfate	-.0007566	.0003751	-2.02	0.044	-.0014918	-.0000214
nitrate	-2.944625	.1303825	-22.58	0.000	-3.20017	-2.68908
Salinity1						
Moderate	.	(not estimable)				
None	.	(not estimable)				
SedTox1						
2	.	(not estimable)				
3	.	(not estimable)				

Note: dy/dx for factor levels is the discrete change from the base level.

There was no significant effect of surface water nutrients or sulfide on average maximum height of PHAU (Table 3.5).

Table 3.5 Generalized linear model of nutrients and sulfide and average maximum height of Phragmites (PHAU).

```
. glm avgphaumaxhtcm ammonia sulfide sulfate nitrite nitrate phosphate, family(gaussian) link(identity)
note: phosphate omitted because of collinearity

Iteration 0:   log likelihood = -337.63427

Generalized linear models                         No. of obs      =         60
Optimization     : ML                             Residual df     =         54
                                                  Scale parameter =   5023.887
Deviance         =   271289.886                   (1/df) Deviance =   5023.887
Pearson          =   271289.886                   (1/df) Pearson  =   5023.887

Variance function: V(u) = 1                       [Gaussian]
Link function    : g(u) = u                       [Identity]

                                                  AIC             =   11.45448
Log likelihood   = -337.6342717                   BIC             =   271068.8

--------------------------------------------------------------------------------
               |                 OIM
avgphaumaxhtcm |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
---------------+----------------------------------------------------------------
       ammonia |  -491.5969    2903.21    -0.17   0.866    -6181.783    5198.589
       sulfide |  -7194.723   39509.14    -0.18   0.856    -84631.22    70241.78
       sulfate |  -5.668222   26.85187    -0.21   0.833    -58.29692    46.96048
       nitrite |   5734.951   33998.25     0.17   0.866     -60900.4     72370.3
       nitrate |   11073.46   64106.79     0.17   0.863    -114573.5    136720.5
     phosphate |          0  (omitted)
         _cons |   1025.161   3246.307     0.32   0.752    -5337.483    7387.805
--------------------------------------------------------------------------------

.
```

The presence of cattle had a significant negative effect on proportion of Phragmites (Kruskal Wallis rank test $\chi^2 = 81.4$, $p < 0.01$, Figure 3.19). Two additional analyses were run, cattle being absent, 1 and cattle present, 2: ATE, which is the total sampled population and showed and estimated 24% reduction in proportion PHAU, and ATET, which is the treated population showing an estimated 27% reduction (Tables 3.6 and 3.7).

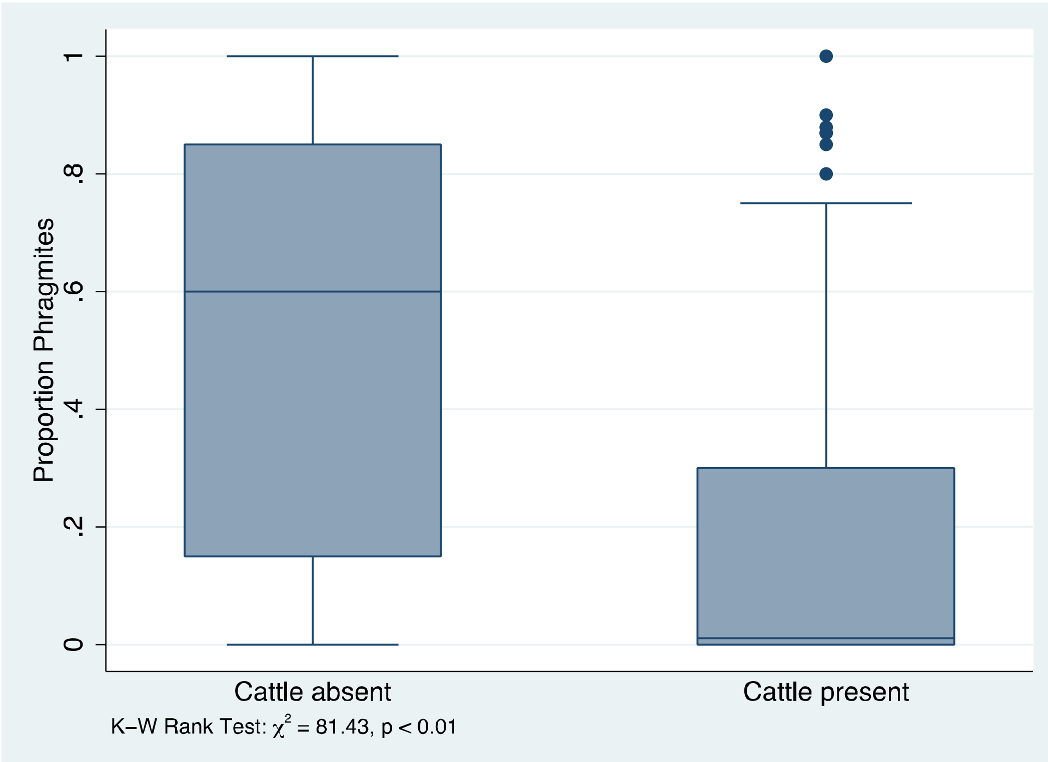


Figure 3.19 Effect of presence of cattle on proportion Phragmites at wetland sites surrounding Farmington Bay during 2015.

Table 3.6 **ATE estimation of the effect of presence of cattle (1 being absent, 2 present)**

```
. teffects nnmatch (Phragmites Site Month Year Salinity SedTox Disturbance Discharge) (Cattle)

Treatment-effects estimation                   Number of obs      =        357
Estimator      : nearest-neighbor matching     Matches: requested =          1
Outcome model  : matching                                     min =          1
Distance metric: Mahalanobis                                  max =         10
```

Phragmites	Coef.	AI Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
ATE						
Cattle (2 vs 1)	-.2437414	.036327	-6.71	0.000	-.3149409	-.1725418

Table 3.7 **ATET estimation of the effect of presence of cattle (1 being absent, 2 present)**

```
. teffects nnmatch (Phragmites Site Month Year Salinity SedTox Disturbance Discharge) (Cattle), atet

Treatment-effects estimation                    Number of obs      =        357
Estimator      : nearest-neighbor matching      Matches: requested =          1
Outcome model  : matching                                      min =          1
Distance metric: Mahalanobis                                   max =         10

------------------------------------------------------------------------------
             |              AI Robust
  Phragmites |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
ATET         |
      Cattle |
    (2 vs 1) |  -.2735294   .0742971    -3.68   0.000     -.419149   -.1279098
------------------------------------------------------------------------------
```

One of the most noticeable effects of cattle was on average maximum height of Phragmites (Figure 3.20). When cattle were present and had access to the Phragmites, average maximum height was well below 100 cm.

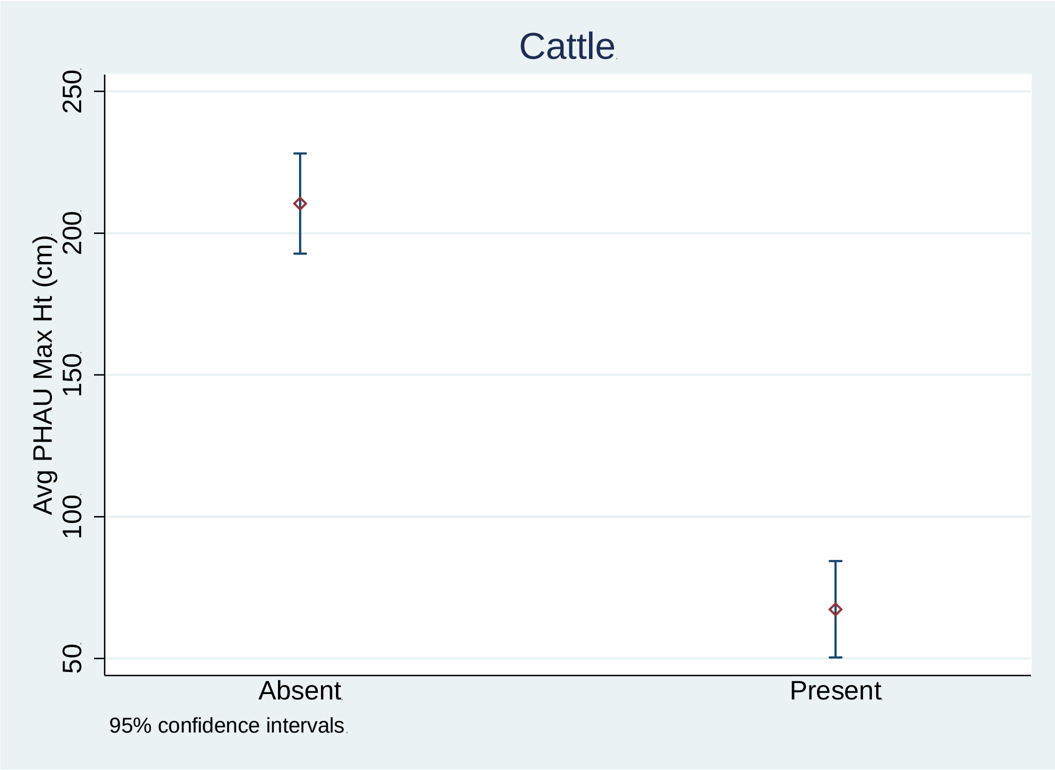


Figure 3.20 Effect of presence of cattle on average maximum height of Phragmites at wetland sites surrounding Farmington Bay during 2015.

Salinity (as qualitatively assigned using available water quality data from DWQ, Carling et al. 2013, and JR/FB WQCouncil) also had a significant negative effect on the proportion of PHAU

(Figure 3.21). Sites with high salinity had the lowest proportion of PHAU, which was significantly lower than that at sites with moderate or low salinity. There may have been an additional negative relationship with the proportion of duckweed (LEMI). Salinity had an even stronger effect on maximum height of Phragmites (Figure 3.22).

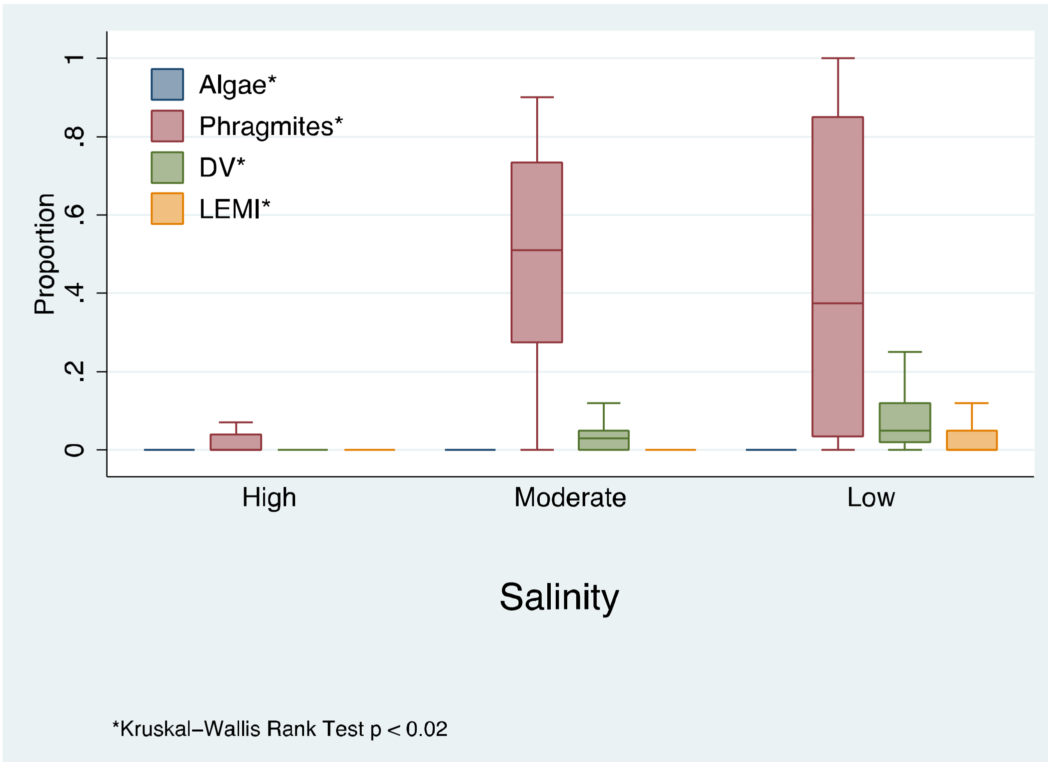


Figure 3.21 The effect of salinity on the proportion of algae, Phragmites, dead vegetation (DV) and duckweed (LEMI) at fringe wetland sites surrounding Farmington Bay during 2015.

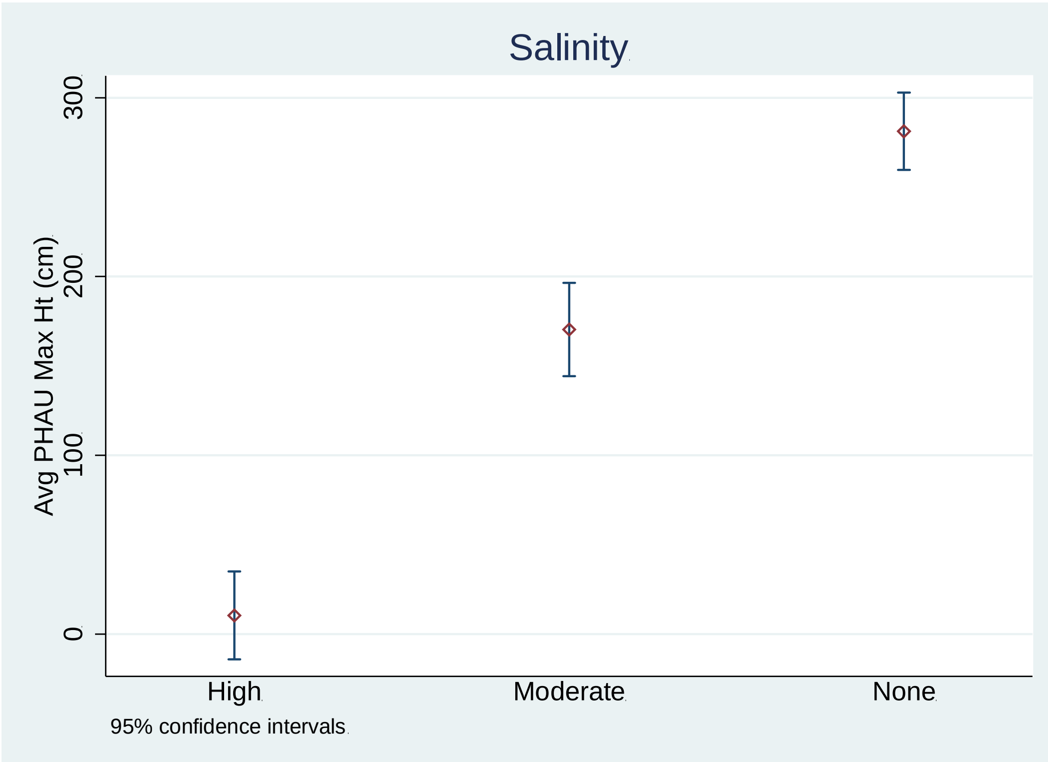


Figure 3.22 The effect of salinity on average maximum height of Phragmites (PHAU) at fringe wetland sites surrounding Farmington Bay during 2015.

Sites considered to have high sediment toxicity (as qualitatively assigned using available water quality data from DWQ, Carling et al. 2013, and JR/FB WQCouncil) *was important for percent cover (as proportion) PHAU, LEMI and DV when sediment toxicity was high (Kruskal Wallis Rank Test $p < 0.01$, Figure 3.23).*

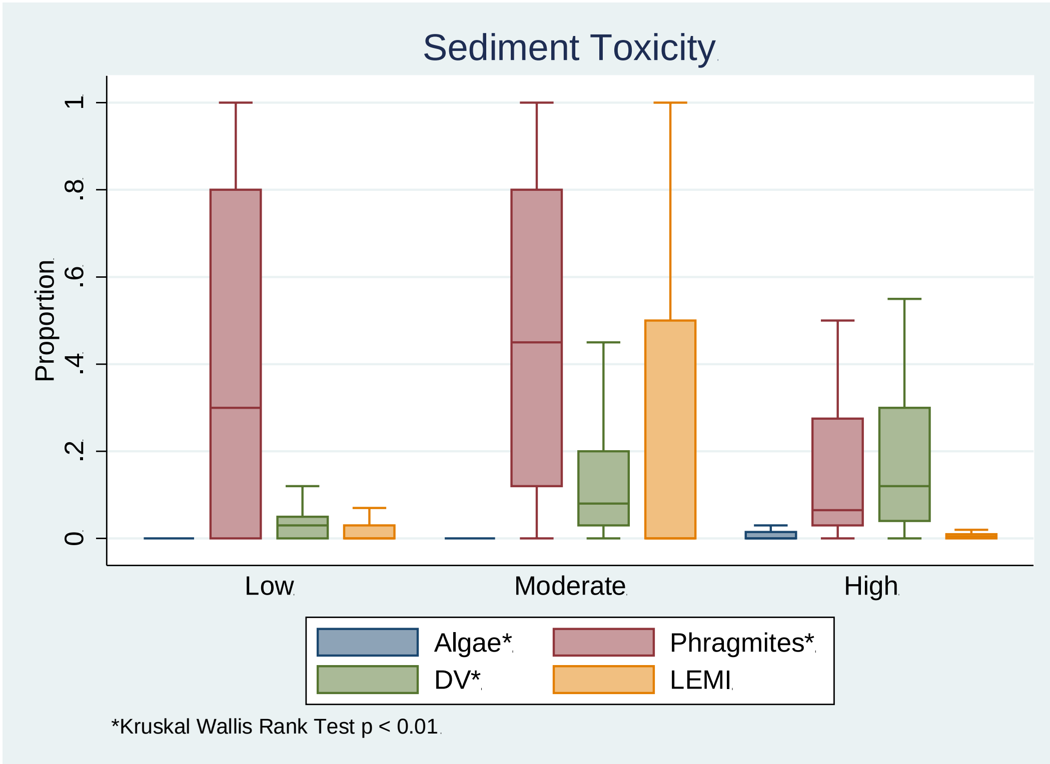


Figure 3.23* The effect of sediment toxicity on proportion of Phragmites (PHAU) *at fringe wetland sites surrounding Farmington Bay during 2015.

Sediment toxicity also had a strong effect on average maximum height of Phragmites (Figure 3.24).

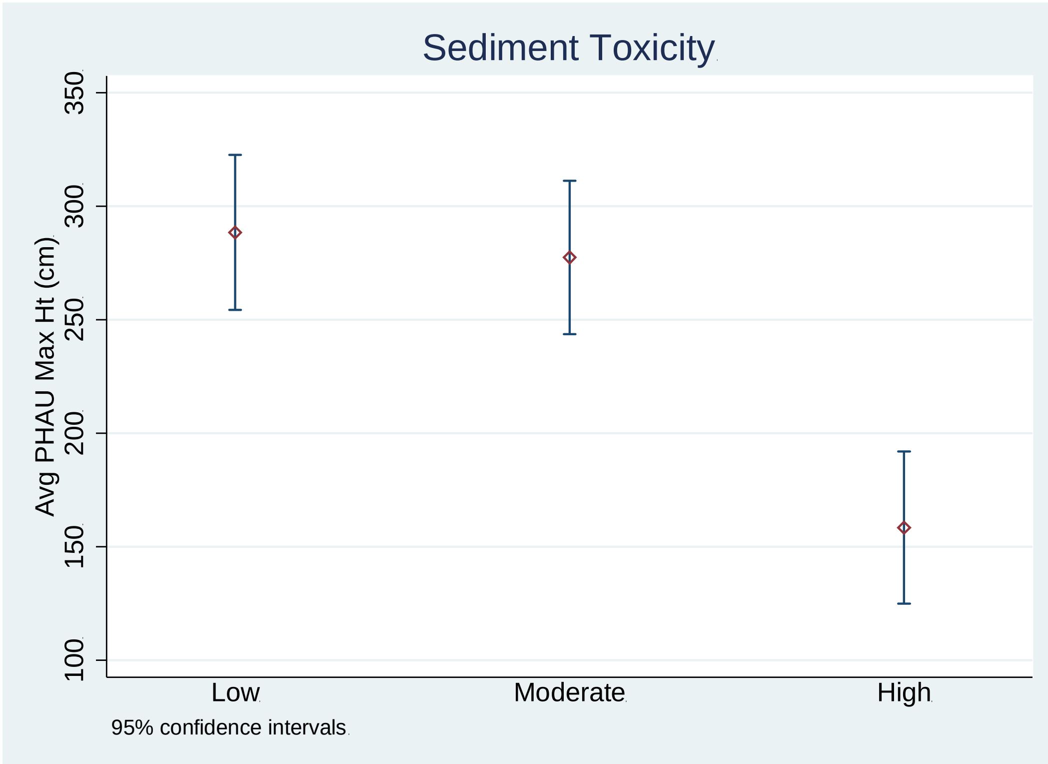


Figure 3.24* The effect of sediment toxicity on average maximum height of Phragmites (PHAU) *at fringe wetland sites surrounding Farmington Bay during 2015.

Disturbance scores were determined from the percentage of the transect that was dominated by invasive and non-native species. Sites that were highly disturbed were commonly dominated by a high proportion of Phragmites (Figure 3.25, Table 3.8). Sites that were least disturbed had the highest proportion of duckweed (LEMI, Table 3.9).

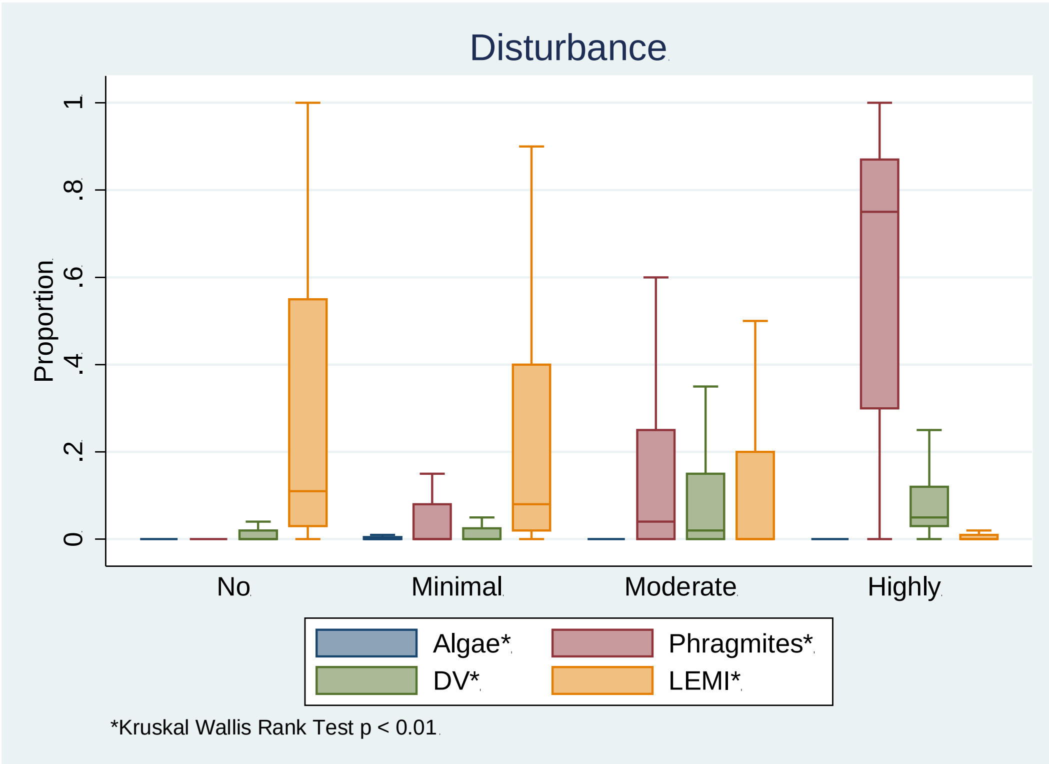


Figure 3.25 Proportion Phragmites versus disturbance at fringe wetland sites surrounding Farmington Bay during 2015.

Table 3.8 Kruskal-Wallis equality-of-populations rank test of proportion Phragmites by disturbance

Distur~e	Obs	Rank Sum
0	27	1282.50
1	25	2042.00
2	109	13237.50
3	225	58129.00

chi-squared = 192.820 with 3 d.f.
probability = 0.0001

chi-squared with ties = 195.803 with 3 d.f.
probability = 0.0001

Table 3.9 Kruskal-Wallis equality-of-populations rank test of proportion LEMI (duckweed) by disturbance

Distur~e	Obs	Rank Sum
0	26	7823.50
1	25	7321.00
2	107	21097.00
3	223	36529.50

chi-squared = 61.201 with 3 d.f.
probability = 0.0001

chi-squared with ties = 78.857 with 3 d.f.
probability = 0.0001

Since highly disturbed sites were dominated by PHAU, it follows that those sites also had a high occurrence of tall Phragmites and low variability (Figure 3.26). Although the introduction and use of cattle as a control on Phragmites is in itself a disturbance, as is drying the portion of a wetland that is being treated by cattle, the overall effect at both TU and KC was an increase in taxa richness and decrease in invasive, non-native species and they scored moderate (TU) to minimally (KC1) disturbed. Average maximum PHAU height was short at TU due to grazing and drying, which was represented within the moderate disturbance heights and although sparse, PHAU at KC was highly variable in height.

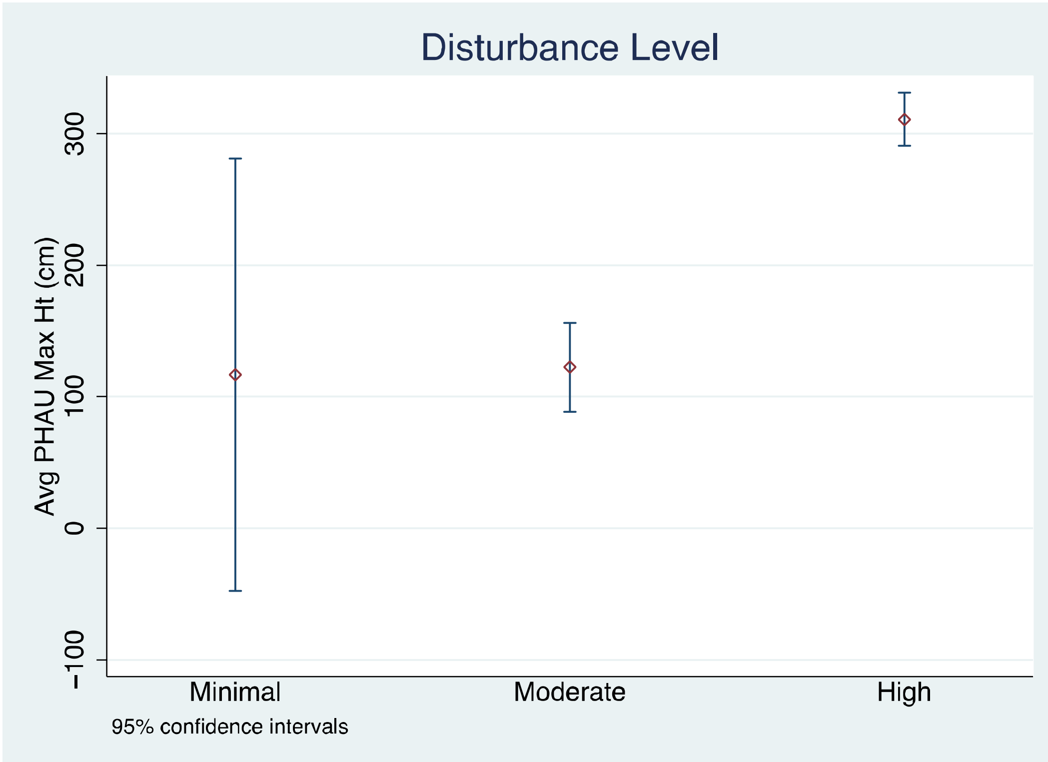


Figure 3.26 Disturbance level and average maximum height of Phragmites.

We then tested for effects of discharge on proportion Phragmites during 2015 (Figure 3.27) and found no significant difference between the two treatments (Table 3.10).

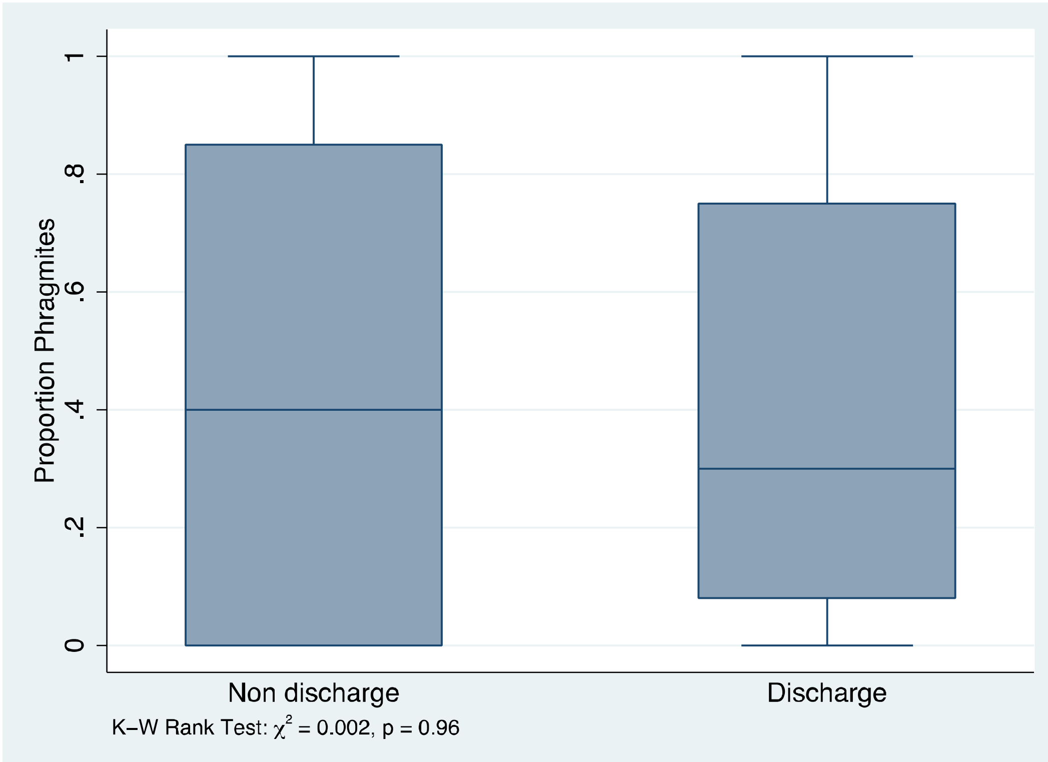


Figure 3.27 Proportion Phragmites at non-discharge versus discharge sites during 2015.

Table 3.10 Kruskal-Wallis Equality of Populations Rank Test for proportion Phragmites (PHAU) by discharge water (1 being non-discharge, 2 being discharge), 2015

```
. kwallis Phau, by(Discharge)

Kruskal-Wallis equality-of-populations rank test
```

Discha~e	Obs	Rank Sum
1	211	39828.50
2	166	31424.50

```
chi-squared =     0.002 with 1 d.f.
probability =     0.9620

chi-squared with ties =     0.002 with 1 d.f.
probability =     0.9617
```

If we consider all sites and years, the model improves a little, but there is still no significant difference in proportion PHAU at sites influenced by discharge water and site that are not (Table 3.11).

Table 3.11 ATE estimation of the effect of discharge water on proportion Phragmites (all sites and years)

```
. teffects nnmatch (Phragmites Site Month Year Salinity SedTox Disturbance Cattle) (Discharge), ate

Treatment-effects estimation                   Number of obs      =        357
Estimator      : nearest-neighbor matching     Matches: requested =          1
Outcome model  : matching                                     min =          1
Distance metric: Mahalanobis                                  max =         10

------------------------------------------------------------------------------
             |              AI Robust
  Phragmites |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
ATE          |
   Discharge |
   (2 vs 1)  |   .0223024   .0352483     0.63   0.527    -.0467831    .0913879
------------------------------------------------------------------------------
```

However, if we just use 2015 data excluding June (pre-mature heights) and KC2 data (because cattle cannot access that area and the site is labeled as a cattle affected area), there is a positive effect of discharge on average maximum height of Phragmites (Table 3.12). But suffice it to say, we have very limited data and there are so many other covariables that it is difficult to draw a definitive conclusion of the total effect of discharge water on Phragmites. We use a Generalized Structural Equation Model (GSEM) later in this section to summarize some of the important relationships.

Table 3.12 ATE estimation of the effect of discharge water on average maximum height of Phragmites

```
. teffects nnmatch (avgphaumaxhtcm h2odepthcm phaustemdensitym2 Phragmites i.Salinity i.SedTox i.Disturbance i.Cattle) (Discharge)

Treatment-effects estimation                   Number of obs      =        175
Estimator      : nearest-neighbor matching     Matches: requested =          1
Outcome model  : matching                                     min =          1
Distance metric: Mahalanobis                                  max =          2

------------------------------------------------------------------------------
             |              AI Robust
avgphaumax~m |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
ATE          |
   Discharge |
   (2 vs 1)  |   35.97543   11.56218     3.11   0.002     13.31398    58.63688
------------------------------------------------------------------------------

. teffects nnmatch (avgphaumaxhtcm h2odepthcm phaustemdensitym2 Phragmites Salinity SedTox Disturbance Cattle) (Discharge), atet

Treatment-effects estimation                   Number of obs      =        175
Estimator      : nearest-neighbor matching     Matches: requested =          1
Outcome model  : matching                                     min =          1
Distance metric: Mahalanobis                                  max =          2

------------------------------------------------------------------------------
             |              AI Robust
avgphaumax~m |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
ATET         |
   Discharge |
   (2 vs 1)  |  -62.26972   13.87471    -4.49   0.000    -89.46365   -35.07578
------------------------------------------------------------------------------
```

Covariates with Phragmites Metrics

Disturbance scores were negatively co-varied with LEMI and also co-varied with salinity and were excluded from the following analyses because they were intended as an implication of the level of disturbance as derived from the amount of invasive and non-native species present rather than a measure of a particular stressor. The following Fractional probit regression results for proportion Phragmites (excluding disturbance) show many significant effects (Table 3.13). From this analysis, we show:

1. *2015 had significantly more PHAU than 2005.*
2. *The highest proportion of PHAU was encountered during August versus other months.*
3. *Significantly more PHAU at moderately salt affected sites than salt affected sites; and more PHAU occurred at not salt affected sites than salt affected sites. Most PHAU occurred at moderately salt affected sites.*
4. *Significantly decreasing proportion PHAU with increasing sediment toxicity.*
5. *Significantly less PHAU with cattle.*
6. *No significant effect of discharge on proportion PHAU.*
7. *Cattle, moderate salinity, and high sediment toxicity had the greatest effects.*

Table 3.13 Fractional probit regression of treatment effects on proportion Phragmites

```
Fractional probit regression                    Number of obs     =        357
                                                Wald chi2(16)     =     406.45
                                                Prob > chi2       =     0.0000
Log pseudolikelihood = -172.28922               Pseudo R2         =     0.2909
```

Phragmites	Coef.	Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
Month						
July	.5593736	.1187737	4.71	0.000	.3265814	.7921659
Aug	.8577183	.1056454	8.12	0.000	.650657	1.06478
Sept	.5354366	.1423376	3.76	0.000	.2564601	.8144131
Year						
2015	.5458122	.1691019	3.23	0.001	.2143786	.8772458
Salinity						
2	1.692042	.2061034	8.21	0.000	1.288087	2.095998
3	.7212292	.2104579	3.43	0.001	.3087393	1.133719
SedTox						
2	-.6612503	.1948873	-3.39	0.001	-1.043222	-.2792783
3	-1.951452	.2437301	-8.01	0.000	-2.429154	-1.47375
Cattle						
2	-2.021185	.151637	-13.33	0.000	-2.318388	-1.723982
Discharge						
2	-.0559933	.1588846	-0.35	0.725	-.3674013	.2554147
_cons	-.9176972	.2982889	-3.08	0.002	-1.502333	-.3330616

Cattle, sediment toxicity and salinity all having negative effects on Phragmites maximum height in the following GSEM (Figure 3.28). Whereas, in this model, discharge, proportion Phragmites and water depth have a positive effect. Indirect negative effects on proportion PHAU are also shown. As we alluded to previously, the limited data made it difficult to make a case as to whether a single covariable (discharge) had an effect on maximum height of Phragmites. The treatment effects model of average maximum height by discharge included site and month and year as predictors. The GLM omitted discharge because it covaried with site and possibly month. We omitted these in the PHAU maximum height GSEM. Discharge is one of the response variables that seemed to change depending on what predictors and models were used and the presented GSEM seemed to have the best fit (Table 3.14a)followed by an additional model with discharge omitted, Table 3.14b for comparison). We should consider obtaining more data to explore these relationships in more detail.

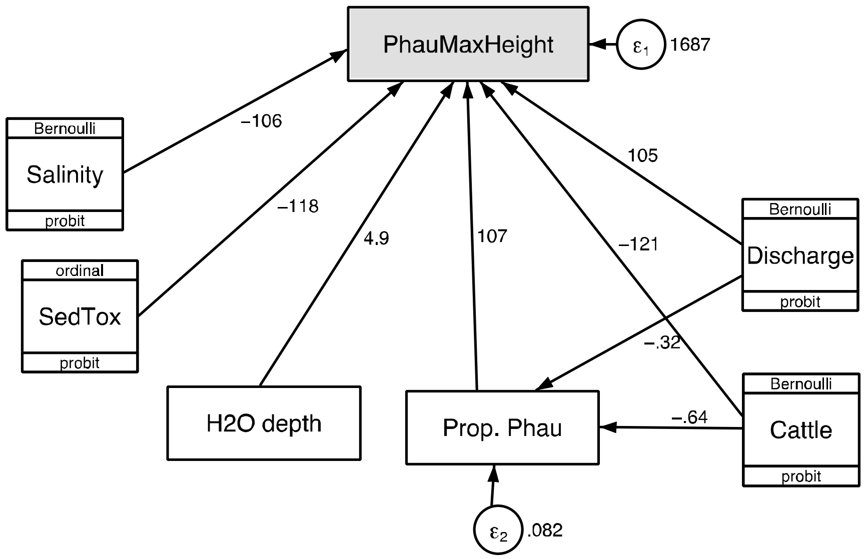


Figure 3.28 GSEM of Phragmites Maximum Height

Table 3.14a GSEM for average maximum height of Phragmites

```
. gsem (Salinity -> avgphaumaxhtcm, ) (SedTox -> avgphaumaxhtcm, ) (Cattle -> avgphaumaxhtcm, ) (Cattle -> Phragmites, ) (Discharge -> avgphaumaxht
> cm, ) (Discharge -> Phragmites, ) (h2odepthcm -> avgphaumaxhtcm, ) (Phragmites -> avgphaumaxhtcm, ), nocapslatent

Iteration 0:   log likelihood = -940.04825
Iteration 1:   log likelihood = -940.04825

Generalized structural equation model           Number of obs     =        245

Response       : avgphaumaxhtcm                 Number of obs     =        175
Family         : Gaussian
Link           : identity

Response       : Phragmites                     Number of obs     =        245
Family         : Gaussian
Link           : identity

Log likelihood = -940.04825

------------------------------------------------------------------------------------------
                      |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
----------------------+-------------------------------------------------------------------
avgphaumaxhtcm <-     |
           Phragmites |   106.9748   15.15862     7.06   0.000     77.26444    136.6851
             Salinity |  -105.5829   14.12146    -7.48   0.000    -133.2605   -77.90538
               SedTox |  -118.1977   12.48431    -9.47   0.000    -142.6665   -93.72889
               Cattle |  -121.0436    10.8113   -11.20   0.000    -142.2333   -99.85382
            Discharge |   104.6859   16.58262     6.31   0.000     72.18457    137.1873
           h2odepthcm |   4.899684   .9886954     4.96   0.000     2.961876    6.837491
                _cons |   502.3638   32.44973    15.48   0.000     438.7635    565.9641
----------------------+-------------------------------------------------------------------
Phragmites <-         |
               Cattle |  -.6368335   .0476487   -13.37   0.000    -.7302232   -.5434438
            Discharge |  -.3154973     .04671    -6.75   0.000    -.4070473   -.2239473
                _cons |   1.784911   .1171832    15.23   0.000     1.555237    2.014586
----------------------+-------------------------------------------------------------------
var(e.avgphaumaxhtcm) |   1686.971   180.3448                      1368.076    2080.199
    var(e.Phragmites) |   .0821914   .0074261                      .0688525    .0981145
------------------------------------------------------------------------------------------
```

Table 3.14b Subsequent GSEM for average maximum height of Phragmites with discharge omitted

```
. gsem (i.Salinity -> avgphaumaxhtcm, ) (i.SedTox -> avgphaumaxhtcm, ) (i.Cattle -> avgphaumaxhtcm, ) (i.Cattle -> Phragmites, ) (i.i.Discharge ->
> avgphaumaxhtcm, ) (i.Discharge -> Phragmites, ) (h2odepthcm -> avgphaumaxhtcm, ) (Phragmites -> avgphaumaxhtcm, ), nocapslatent
note: 2.Discharge omitted because of collinearity

Iteration 0:   log likelihood = -940.04825
Iteration 1:   log likelihood = -940.04825

Generalized structural equation model          Number of obs     =        245

Response       : avgphaumaxhtcm                Number of obs     =        175
Family         : Gaussian
Link           : identity

Response       : Phragmites                    Number of obs     =        245
Family         : Gaussian
Link           : identity

Log likelihood = -940.04825
```

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
avgphaumaxhtcm <-						
Phragmites	106.9748	15.15862	7.06	0.000	77.26444	136.6851
Salinity						
2	-105.5829	14.12146	-7.48	0.000	-133.2605	-77.90538
SedTox						
2	-13.51178	8.190336	-1.65	0.099	-29.56454	2.540985
3	-131.7095	13.07272	-10.08	0.000	-157.3315	-106.0874
Cattle						
2	-121.0436	10.8113	-11.20	0.000	-142.2333	-99.85382
Discharge						
2	0	(omitted)				
h2odepthcm	4.899684	.9886954	4.96	0.000	2.961876	6.837491
_cons	262.2255	14.17498	18.50	0.000	234.4431	290.0079
Phragmites <-						
Cattle						
2	-.6368335	.0476487	-13.37	0.000	-.7302232	-.5434438
Discharge						
2	-.3154973	.04671	-6.75	0.000	-.4070473	-.2239473
_cons	.8325806	.0364097	22.87	0.000	.7612189	.9039424
var(e.avgphaumaxhtcm)	1686.971	180.3448			1368.076	2080.199
var(e.Phragmites)	.0821914	.0074261			.0688525	.0981145

In the following GSEM regarding PHAU stem density and minimum stem diameter, all effects are significant (Figure 3.29). Cattle, high sediment toxicity, and discharge have a strong effect on minimum stem diameter. Cattle and sediment toxicity (high level) have negative effects on minimum stem diameter, whereas discharge has a positive effect.

This GSEM may be showing us a very slight but significant intraspecific competition (related to crowding) effect of stem density on minimum stem diameter. Cattle and proportion Phragmites have a direct positive effect on stem density which increases the negative effect of stem density on minimum stem diameter (i.e., stem diameter becomes diminished). However, cattle have a negative effect on proportion Phragmites which decreases its effect on stem density which increases min stem diameter. Thus cattle have a three way direct and indirect effect on minimum stem diameter. This model exhibits the tenacity of PHAU as a competitive plant and the need for multi-year application of grazing with other control mechanisms (eg., drying) to gain control of the spread of PHAU in an area. The GSEM results are shown in Table 3.15.

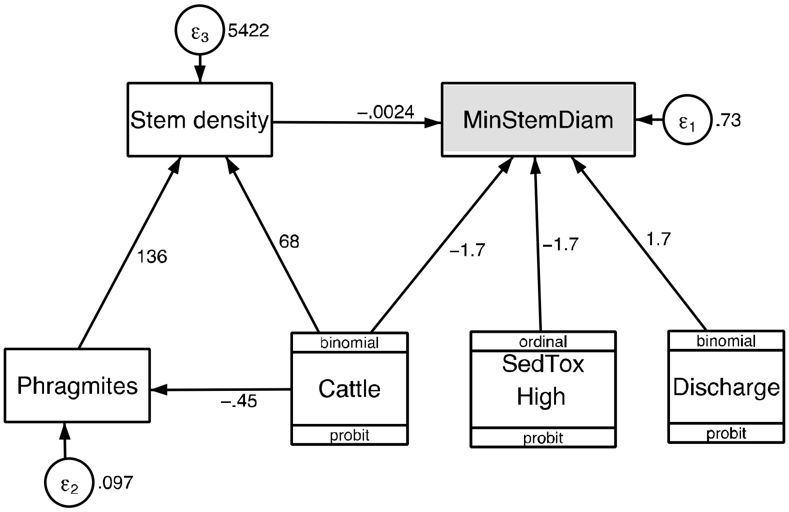


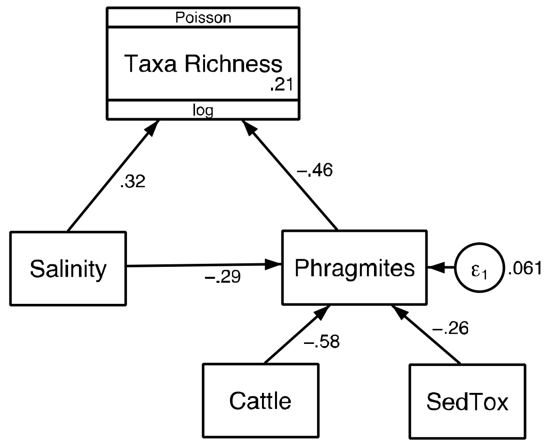
Figure 3.29 GSEM of treatment effects on minimum PHAU stem diameter

Table 3.15 Generalized structural equation model of treatment effects on minimum stem diameter

```
. . gsem (Phragmites -> phaustemdensitym2, ) (i.SedTox -> avgminstemdiametermm, ) (i.Cattle -> avgminstemdiametermm, ) (i.Cattle -> Phragmites, ) (
> i.Cattle -> phaustemdensitym2, ) (i.Discharge -> avgminstemdiametermm, ) (phaustemdensitym2 -> avgminstemdiametermm, ), nocapslatent
note: 2.Discharge omitted because of collinearity

Iteration 0:   log likelihood =  -1527.622
Iteration 1:   log likelihood =  -1527.622

Generalized structural equation model          Number of obs     =        245

Response       : phaustemdensitym2             Number of obs     =        219
Family         : Gaussian
Link           : identity

Response       : avgminstemdiametermm          Number of obs     =        169
Family         : Gaussian
Link           : identity

Response       : Phragmites                    Number of obs     =        245
Family         : Gaussian
Link           : identity

Log likelihood =  -1527.622
```

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
phaustemdensitym2 <-						
Phragmites	136.242	16.24407	8.39	0.000	104.4042	168.0798
Cattle						
2	67.93728	12.86732	5.28	0.000	42.71779	93.15676
_cons	-11.05222	12.42019	-0.89	0.374	-35.39535	13.29092
avgminstemdiametermm <-						
phaustemdensitym2	-.0023886	.0008743	-2.73	0.006	-.0041022	-.000675
SedTox						
2	-.0056833	.1681214	-0.03	0.973	-.3351953	.3238286
3	-1.669589	.2043604	-8.17	0.000	-2.070128	-1.26905
Cattle						
2	-1.741685	.1863751	-9.35	0.000	-2.106973	-1.376396
Discharge						
2	0	(omitted)				
_cons	4.633162	.1397076	33.16	0.000	4.35934	4.906984
Phragmites <-						
Cattle						
2	-.4451389	.0416859	-10.68	0.000	-.5268418	-.3634361
_cons	.6408861	.0248408	25.80	0.000	.592199	.6895732
var(e.phaustemdensitym2)	5421.922	518.1389			4495.824	6538.788
var(e.avgminstemdiametermm)	.7273797	.0791763			.5876337	.9003589
var(e.Phragmites)	.0974963	.0088145			.0816644	.1163975

Taxa richness is one of the most widely used ecosystem health measures. The following analyses and results suggest how plant taxa richness in the fringe wetlands may be affected by environmental conditions, e.g., salinity, sediment toxicity, invasive species, e.g., Phragmites, and management practices, e.g., cattle grazing, drying (Figure 3.30 and Table 3.16).



Direct effects on Taxa Richness
  Salinity = 0.32
  Phragmites = −0.46
Direct effects on Phragmites
  Salinity = −0.29
  Cattle = −0.58
  Sed.Tox. = −0.26
Indirect effects on Taxa Richness via Phragmites
  Salinity = 0.13
  Cattle = 0.27
  Sed.Tox. = 0.12
Total effects on Taxa Richness
Salinity = 0.45

Figure 3.30 GSEM of treatment effects on taxa richness in fringe wetlands surrounding Farmington Bay

This model used the following data:

1. Removed: 2005/2011, June, and KC2

2. Modified salinity metric by reversing scores and then combining values 1 and 2 into 1 (low) and value 3 into a score of 2 (high). This new scoring was based on many preliminary regression results that showed moderate (2) was not significantly different than low (1) and 3 (high) was significantly different than 1 (low).

Taxa Richness was reported as count data, therefore it was modeled as a probit (log) response.

Many GSEMs were evaluated prior to this model and this appears to be the 'best' model to date.

Table 3.16 GSEM of taxa richness in fringe wetlands surrounding Farmington Bay

```
. gsem (Phragmites -> taxarichness, family(poisson) link(log)) (i.Cattle -> Phragmites, ) (i.SedTox -> Phragmites, ) (i.Salinity -> Phragmites, ) (
> i.Salinity -> taxarichness, family(poisson) link(log)), nocapslatent

Iteration 0:   log likelihood = -318.07345
Iteration 1:   log likelihood = -312.71451
Iteration 2:   log likelihood = -312.70689
Iteration 3:   log likelihood = -312.70689

Generalized structural equation model           Number of obs     =        245

Response       : taxarichness
Family         : Poisson
Link           : log

Response       : Phragmites
Family         : Gaussian
Link           : identity

Log likelihood = -312.70689
```

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
taxarichness <-						
Phragmites	-.4577201	.1624328	-2.82	0.005	-.7760826	-.1393576
Salinity						
2	.3228159	.1456346	2.22	0.027	.0373773	.6082546
_cons	.5310277	.1007387	5.27	0.000	.3335834	.7284719
Phragmites <-						
Cattle						
2	-.5501365	.043666	-12.60	0.000	-.6357203	-.4645528
SedTox						
2	-.1824316	.0434019	-4.20	0.000	-.2674978	-.0973653
3	-.5545234	.0549417	-10.09	0.000	-.6622072	-.4468396
Salinity						
2	-.2863205	.0477947	-5.99	0.000	-.3799963	-.1926446
_cons	.8380328	.0313329	26.75	0.000	.7766214	.8994442
var(e.Phragmites)	.0598869	.0054108			.0501678	.0714889

This GSEM shows that based on the data used, taxa richness is directly positively affected by salinity and significantly negatively affected by proportion Phragmites. There are several indirect effects on taxa richness via negative effects on Phragmites from salinity, cattle grazing, and sediment toxicity. Finally, total positive effects of salinity on taxa richness is equivalent to the negative effects from Phragmites. (ε_1 is the error term for PHAU: Approximately 6% of PHAU variability wasn't explained by salinity, cattle, sediment toxicity)

We can generally conclude that of the sites we sampled, more saline locations have greater plant diversity than more freshwater locations because Phragmites and to some extent Typha sp. (cattail) are now often the only remaining taxa in less saline areas. We should point out that salinity has a positive effect on taxa richness to a degree. In areas that are more saline than where we sampled, salinity becomes a limiting factor and taxa richness diminishes to just pickleweed (*Salicornia sp.*) or no salt tolerant species at all. Both Phragmites and cattail are known to have high assimilation capacity and tolerance of nutrients and metals (Kadlec and Wallace 2009), which would predispose the two emergent species to a competitive edge over other less tolerant species. It is interesting that even with the negative effects of cattle, salinity and sediment toxicity upon Phragmites that Phragmites still presents a strongly negative effect on taxa richness.

If the goal of a manager is to increase or maintain plant diversity, then increasing salinity via drying the wetland and using cattle grazing to control the spread of Phragmites appears to be very beneficial. If the goal of a manager is to open up and restore nesting grounds for shorebirds, and thereby beneficial use for aquatic life, increasing salinity and continued grazing would also be beneficial. (We observed many active nests and fledglings within the grazed area at TU that was more saline.) Finally, all of these analyses are based on limited data including categorical data. With more data measurements, we can begin to include continuous data for salinity, sediment toxicity, etc., to better understand the ecological interactions and relationships that determine the presence and extent of invasive Phragmites.

Summary and Recommendations

Our major findings show a significant increase in proportion Phragmites from 2005 to 2015 in fringe wetlands surrounding Farmington Bay, regardless of association with discharge water. Contrary to our original hypothesis, discharge water had no effect on proportion of Phragmites at the sites we sampled and no effects of nutrients on proportion or maximum height were identified (initially disproving Hypotheses 1 and 2). However, more data is necessary to conclusively determine the effects of discharge water on Phragmites since our models demonstrated the results changed depending on the predictors that were selected. While it is true that Phragmites that has established down-gradient of CDSD is dense and very tall, there are likely other factors not included in our analyses that make for a perfect setting for Phragmites invasion. Results from our metrics show that Phragmites at CD was very comparable to that at LF, our control site, both of which were true sheetflow sites; and Phragmites at OD was comparable to that at KC, both influenced by braided channels and sheetflow, implicating that differences occurring by site may be related to a number of effects aside from or in addition to discharge. It may be that hydrology is an important factor and that more hydrologic metrics should be included in further studies as it may play a central role in the status of Phragmites. This hypothesis was presented by Miller and Hoven (2007) as illustrated by differences in hydrology and emergent species distribution at two discharge sites: Central Davis Sewer District and North Davis Sewer District.

Our analyses suggest that cattle, salinity and (high) sediment toxicity all have strong negative effects on Phragmites (in agreement with Hypothesis 3) as has been shown in many other studies (Kadlec and Wallace 2009). However, as was the case in other studies, once Phragmites establishes a foothold, it quickly out-competes other species for resources such as light and nutrients and with its tolerance to toxic sediment.

We recommend a continued monitoring effort with emphasis on developing metrics at the established fringe wetland sites and possibly the addition of another discharge site where we have previously collected data (e.g., North Davis Sewer District). There is a need for more robust data to confirm and *refine or disprove our initial findings. With a more robust data set, we would continue to test for applicability and feasibility of metrics for use as an assessment tool of fringe wetlands associated with drainages into Farmington Bay.*

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Appendix

Appendix 1. Covariates of treatment effects

	Salinity	SedTox	Distur~e	Cattle	Discha~e	Site	Month	Year
Salinity	1.0000							
SedTox	0.1334	1.0000						
Disturbance	0.0228	0.1362	1.0000					
Cattle	-0.5360	-0.5039	-0.4118	1.0000				
Discharge	0.1615	0.9087	0.1609	-0.5498	1.0000			
Site	-0.7287	-0.1942	0.1930	0.4704	-0.4003	1.0000		
Month	-0.0965	-0.1418	0.1271	0.1263	-0.2049	0.1487	1.0000	
Year	-0.2152	-0.1599	0.2835	0.0897	-0.2837	0.4249	0.0329	1.0000