Photo: K.M. Kettenring

Final report to
Utah Department of Natural Resources
Division of Forestry, Fire & State Lands

Assessing approaches to manage *Phragmites* in the Great Salt Lake watershed

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Problem statement and report overview

Phragmites australis (common reed; hereafter *Phragmites*) is an invasive grass that has rapidly invaded wetlands across North America (Marks et al. 1994) and is widespread and dominant in wetlands and disturbed habitats in northern Utah (Kulmatiski et al. 2011, Kettenring et al. 2012a, Kettenring and Mock 2012). This plant is undesirable because it crowds out native vegetation and profoundly alters habitat quality for wildlife including waterfowl and other migratory birds by creating large monotypic stands (Marks et al. 1994). Great Salt Lake (GSL) wetlands are the most important wetland habitat for migratory birds in the region and are continentally significant (Evans and Martinson 2008). Unfortunately, tens of thousands of acres of diverse native wetland vegetation have been replaced by invasive *Phragmites*, reducing the availability and quality of habitat in GSL wetlands.

Given the extent of the *Phragmites* problem in Utah and elsewhere, managers need to understand what techniques are most effective for killing *Phragmites* while fostering native plant recovery. A variety of strategies have been widely employed for *Phragmites* management including summer or fall herbicide application, mowing, burning, and flooding (Marks et al. 1994, Hazelton et al. 2014). But, as is often the case with natural resource management, due to limited time and money, there has been little monitoring of success or any systematic evaluation of management strategies across the varied environmental conditions where *Phragmites* is found, particularly in Utah. Given the interest in effective management strategies for *Phragmites*, there is a need to evaluate and monitor the success of different techniques. Another complicating factor in effective *Phragmites* management is that, contrary to popular belief, *Phragmites* spreads largely by seeds rather than rhizomes (Kettenring and Mock 2012). While a fall herbicide spray is widely used to manage *Phragmites*, this occurs *after Phragmites* has produced its seeds. Managers need additional tools to prevent seed production in conjunction with managing existing stands (e.g., mowing in conjunction with herbicide or using herbicide application earlier in the year). Finally, while the herbicide glyphosate has been widely used to manage *Phragmites*, another herbicide, imazapyr, has recently been shown to be effective for managing *Phragmites* (Mozdzer et al. 2008, Hazelton et al. 2014). Further research is needed to compare the effectiveness of these herbicides, including the best time for application, for *Phragmites* management and native plant recovery. We have embarked on a five-year set of experiments where we are evaluating potential strategies for dealing with new infestations of *Phragmites* as well as large, dense monocultures of *Phragmites*. Here we report on the effectiveness on the first two years of management treatments (implemented in 2012 and 2013; **PART I**). The third year of management treatments will be applied in early July and early September 2014.

Given the extent of the *Phragmites* problem in Utah and elsewhere, managers need to understand what factors explain its current distribution and how to prioritize management efforts at the landscape scale. Continued advancements in remote sensing technologies now allow researchers and managers to look at widespread patterns of vegetation distribution. We have capitalized on these technologies to determine the current extent of *Phragmites* in GSL wetlands using remote sensing (http://maps.gis.usu.edu/gslw/index.html; Kettenring 2012). In turn, data collected with remote sensing have formed the basis of species distribution modeling whereby we are looking at relationships between the current distribution of *Phragmites* with factors that may explain its distribution. Factors such as elevation, proximity to water control structures (a proxy for disturbance), soil type, or surrounding land-use may help explain why it is found in some but not all locations along the GSL. Here we report on factors that best explain the current distribution of *Phragmites* in GSL wetlands (**PART II**).

Prioritizing sites for *Phragmites* management based on current distributions, model predictions about future spread, and other conservation priorities will be critical to successful management of this plant in the GSL watershed. Spatial prioritization is a useful tool for restoration planning and has been used in conservation planning, and wetland, stream, and riparian restoration (White and Fennessy 2005, Mollot and Bilby 2008). While it is becoming common to develop maps using species distribution modeling that predict potential areas of invasion by species, few studies have explicitly addressed what to do next with this information. There are often large areas that are predicted to be susceptible to invasion. Having a framework to decide how to prioritize sites for management (based on current and predicted, future distributions), and what areas will have the most impact if managed, will improve the overall effectiveness of a *Phragmites* management program. Here we report on the prioritization framework that we have developed for *Phragmites* in GSL wetlands (**PART II**).

PART I: *Phragmites* management studies (Chad Cranney's and Christine Rohal's M.S. thesis projects)

Objective: To evaluate potential management strategies in small patches and large stands of *Phragmites* for restoring wetlands in the GSL watershed.

Methods

The management studies are being conducted at two spatial scales – 0.25 acre treatment areas to evaluate strategies that may be effective for dealing with initial invasions of *Phragmites* and 3 acre treatment areas to evaluate strategies that may be more effective and logistically feasible for dealing with large, well-established stands of *Phragmites*.

Large stand study. We have four sites with extensive stands of *Phragmites* where we are conducting the management treatments: Ogden Bay Waterfowl Management Area (WMA), Farmington Bay WMA, sovereign lands west of Ogden Bay WMA, and sovereign lands northwest of Farmington Bay WMA. At each site, we are applying 5 treatments to each 3 acre *Phragmites* stand (15 acres total per site). The five treatments we are applying are: (1) summer glyphosate spray followed by winter mow, (2) summer imazapyr spray followed by winter mow, (3) fall glyphosate spray followed by winter mow, (4) fall imazapyr spray followed by winter mow, and (5) untreated area. Management techniques were applied in 2012 and 2013 and will be applied again in 2014.

Small patch study. We have six sites (Inland Sea Shorebird Reserve, Ogden Bay WMA, Farmington Bay WMA, Bear River Migratory Bird Refuge, and two areas at TNC Shorelands Preserve) where we are evaluating *Phragmites* management treatments that might be effective for small *Phragmites* invasions. At each site, we are applying one of six management treatments to a 0.25 acre *Phragmites* patch. The six treatments we are applying at each site are: (1) summer mow, then cover with heavy duty black plastic; (2) summer mow followed by fall glyphosate spray; (3) summer glyphosate spray followed by winter mow; (4) fall glyphosate spray followed by winter mow; (5) summer imazapyr spray followed by winter mow; and (6) untreated area. These treatments were applied in 2012 and 2013 and will be applied again in 2014.

The *Phragmites* treatments for both studies were chosen based on our initial survey of GSL wetland managers (Kettenring et al. 2012b); extensive conversations with Randy Berger and other state, federal, and private managers; and our reading of the *Phragmites* management literature. We chose treatments that were logistically feasible for managers to apply, and chose a balance of treatments that represented commonly applied strategies as well as less common ones that hold great promise for GSL wetlands.

For both studies, treatment effectiveness is being assessed by looking at *Phragmites* cover and stem density, as well as native plant cover. Vegetation is being monitored with on-the-ground surveys for both studies. In addition, we are collecting high resolution (5cm * 5cm) remotely sensed imagery for the large stand study before and after management once per year (2012-2014), to look at changes in *Phragmites* and native plant cover. In addition, we are characterizing sites with respect to nitrogen (ammonium, nitrate), phosphorous (phosphate), salinity (electrical conductivity), organic matter content, and soil moisture / flooding levels, all factors that could affect treatment success. Such data will be critical for making recommendations on which treatments to apply in which areas of the GSL.

Results

Large stand study. After one year of herbicide treatments, all plots had significantly reduced *Phragmites* cover compared with the untreated plots. Type of herbicide used and timing of application are not statistically different when compared to each other (**Figure 1**). Across all sites and all herbicide treatments, *Phragmites* cover was reduced by an average of 87%.

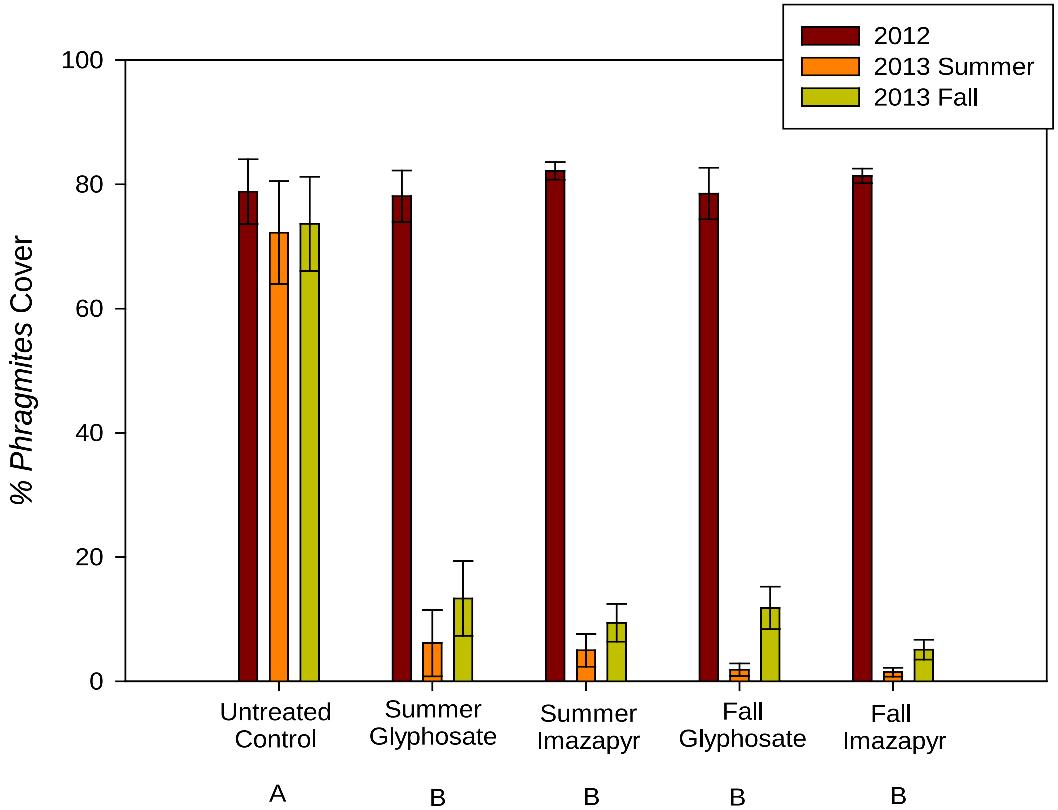


Figure 1: Effects of treatments on* Phragmites *percent cover pre-treatment (2012) and two sampling occasions one year post-treatment (2013). Letters below treatment type indicate a significant difference between herbicide treatment types ($p < 0.10$).

Germination of native plant species was very minimal at all sites for all treatments, with only trace amounts of emergent species returning including; *Schoenoplectus maritimus* (alkali bulrush), *Schoenoplectus americanus* (three-square bulrush), and *Typha* spp. (cattails) (**Figure 2**). We believe one factor contributing to minimal native plant recovery was the large litter layer left after mowing. In some cases this litter layer is 25-35 cm deep (**Figure 3**). Sites with deeper (>12 cm) water appeared to decompose the litter faster, or move it around, leading to more open water habitats with large amounts of *Lemna* spp. (duckweed) (**Figures 4 and 5**). With minimal amounts of native vegetation coming back after two years of treatments, the effect of treatment type on native plant recovery is indistinguishable.

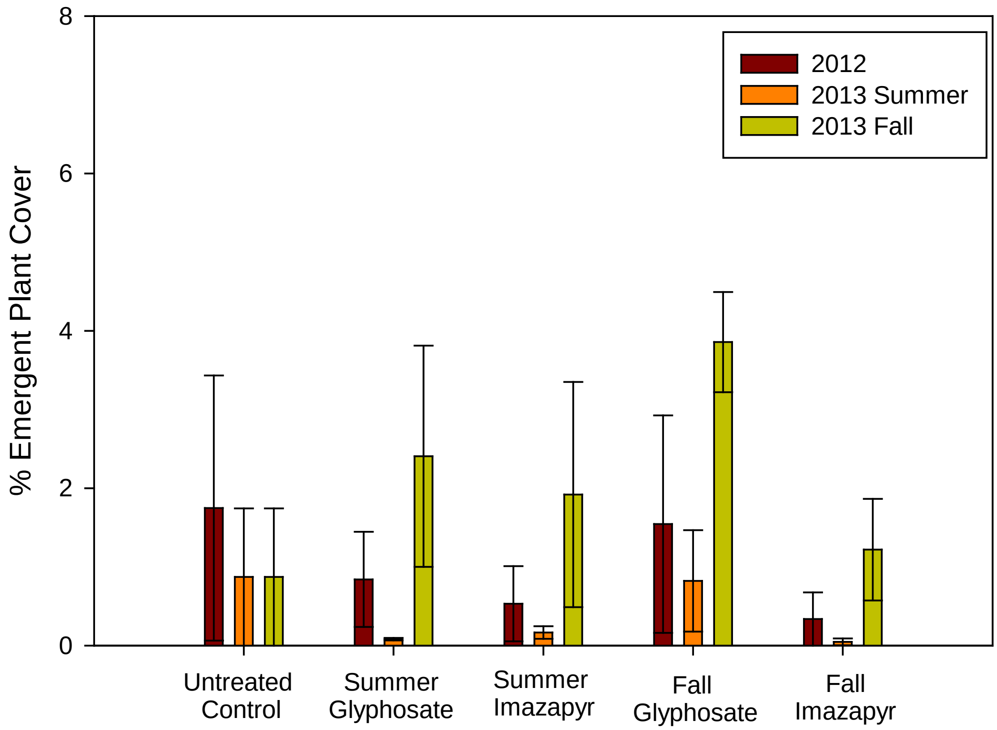


Figure 2: Effects of treatments on native emergent plant percent cover pre-treatment (2012) and two sampling occasions one year post-treatment (2013).

Figure 3: Howard Slough WMA summer glyphosate treatment plot showing large litter layer left behind by mowing.

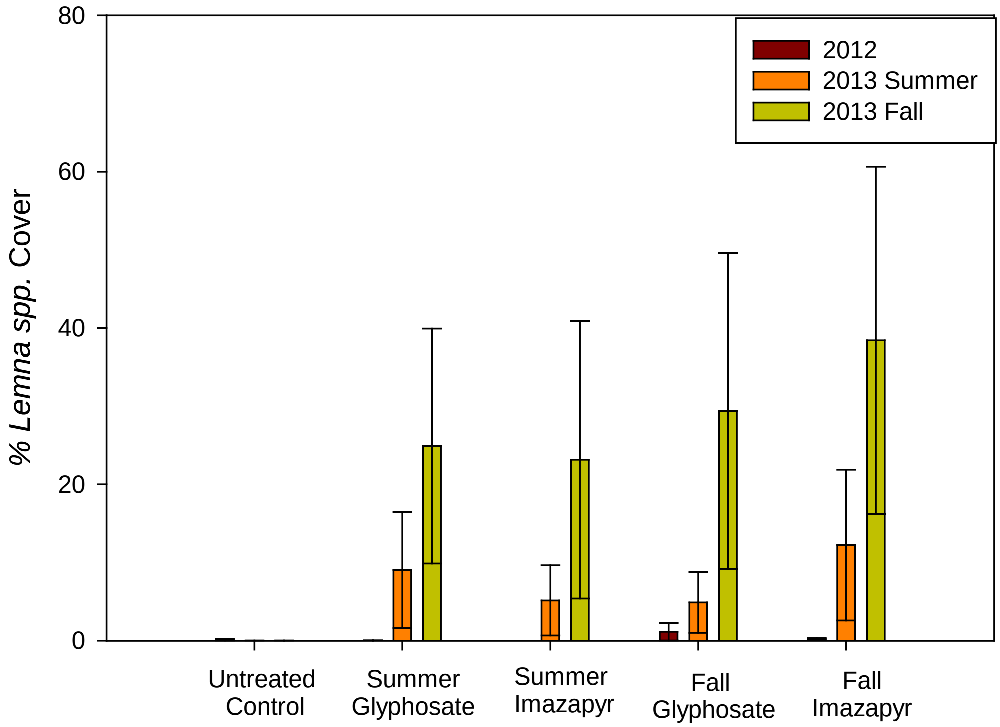
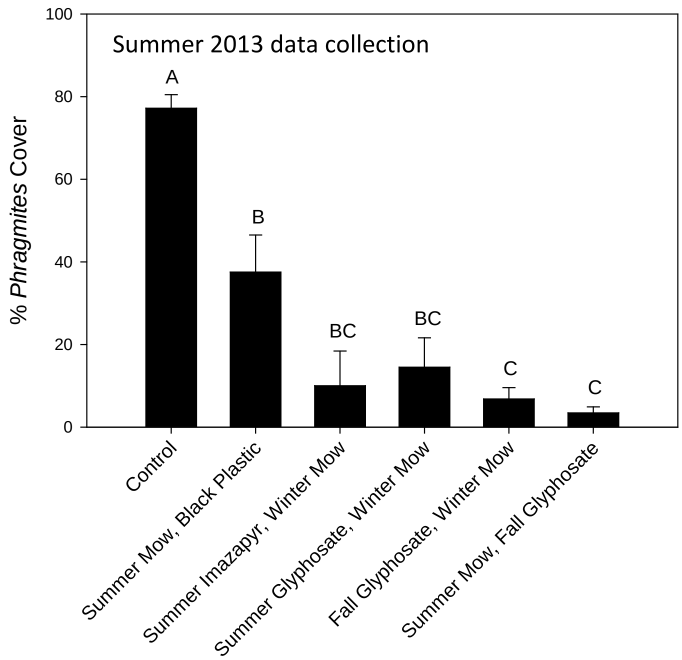


Figure 4: Effects of treatments on* Lemna *spp. percent cover pre-treatment (2012) and two sampling occasions one year post-treatment (2013).

Figure 5: Treatment plot at Farmington Bay WMA with > 12cm water. Lower portion of picture shows large amounts of* Lemna *spp. on the surface of the open water.

Small patch study. All treatments, except the mow + black plastic, were effective at significantly reducing the cover of *Phragmites* (**Figure 6**). The four herbicide and mowing treatment combinations were statistically indistinguishable from each other. In other words, they were equally effective at reducing *Phragmites* cover.



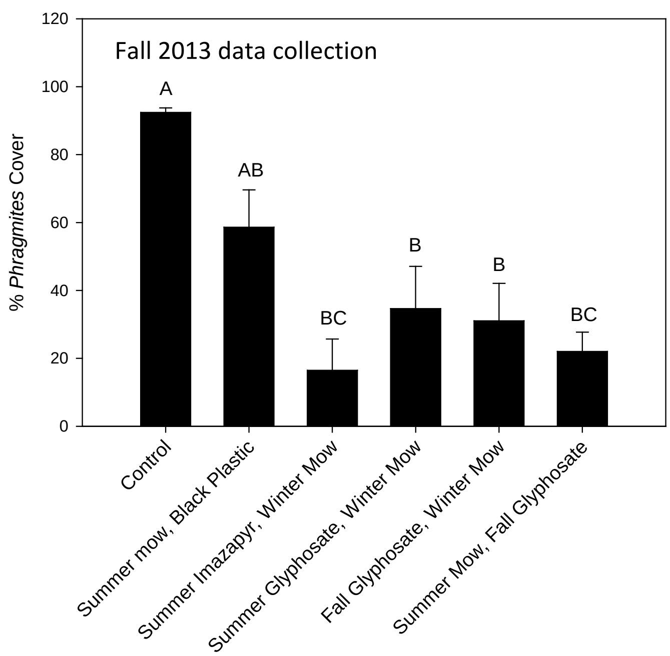


Figure 6. Effects of herbicide treatments on **Phragmites** ***cover in summer 2013 (top graph) and fall 2013 (bottom graph) in the small patch study. Herbicide was applied in summer and fall 2012 depending on the treatment. For plots assessed in fall 2013, herbicide had already been applied in the summer but not fall herbicide plots. Bars with different letters are significantly different from each other.***

The effects of the treatments on *Phragmites* stem density was less clear. Although the *Phragmites* treatments reduced average stem density in most cases compared to the untreated control, the differences were not statistically significant (**Figure 7**).

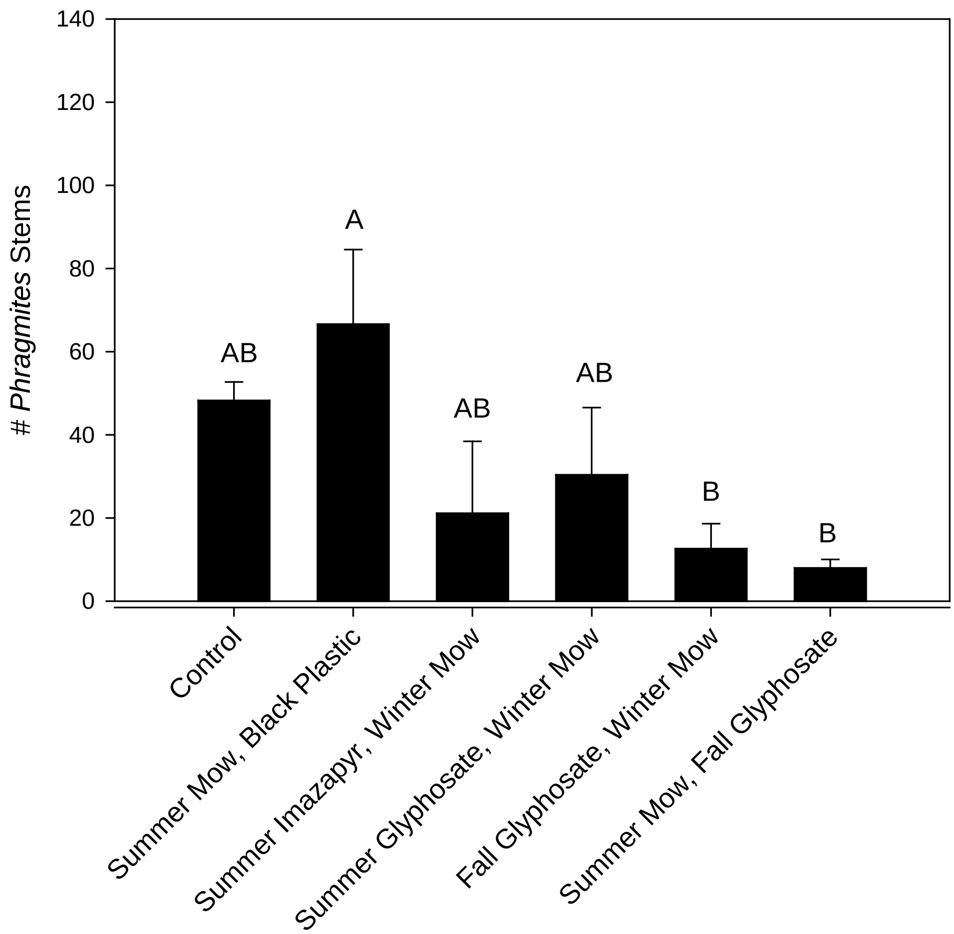


Figure 7. The effects of different treatments on* Phragmites *stem density.

The summer mow and spray treatments significantly reduced *Phragmites* inflorescence density (**Figure 8**). Given that *Phragmites* spreads predominantly by seeds, these findings indicate multiple treatments that can be used to reduce *Phragmites* invasion potential.

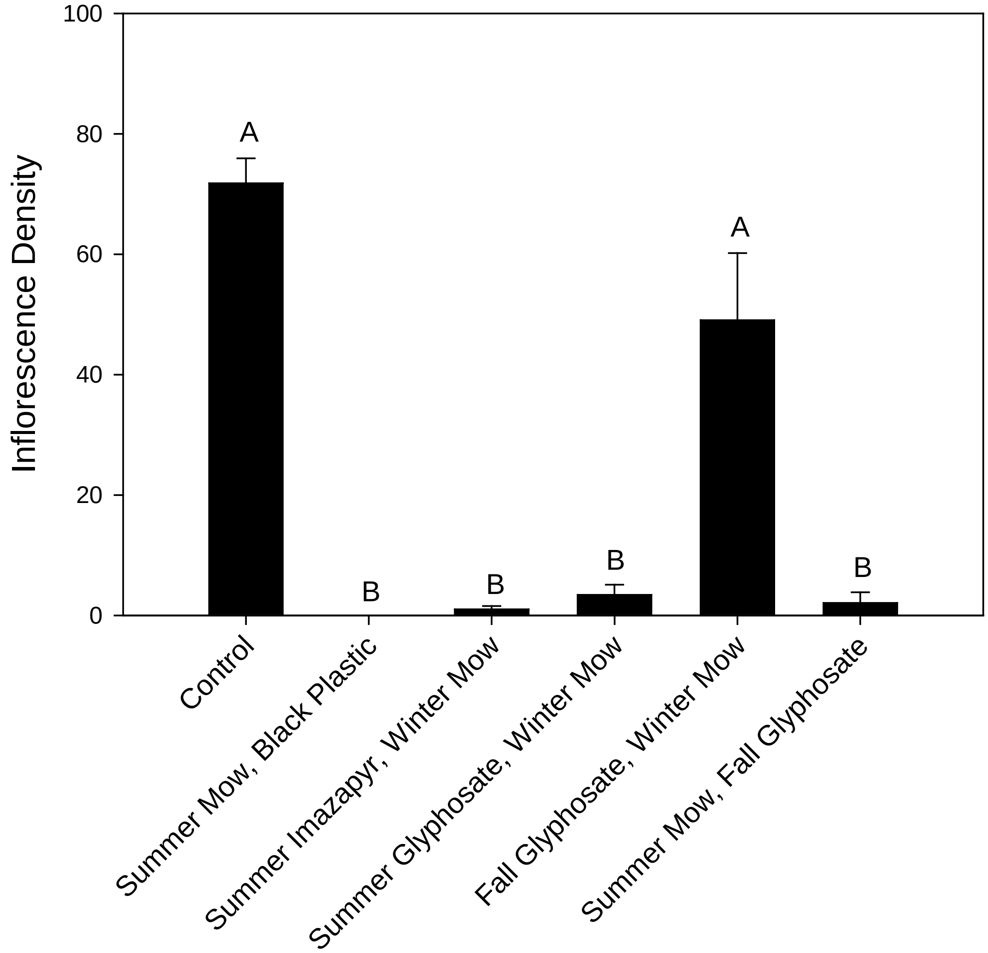


Figure 8. Effects of herbicide and mowing treatments on* Phragmites *inflorescence density, as measured in fall 2013.

There has been some recovery of native species in the various *Phragmites* treatment plots but at this stage, native plant cover is still quite low (**Figures 9-11)**.

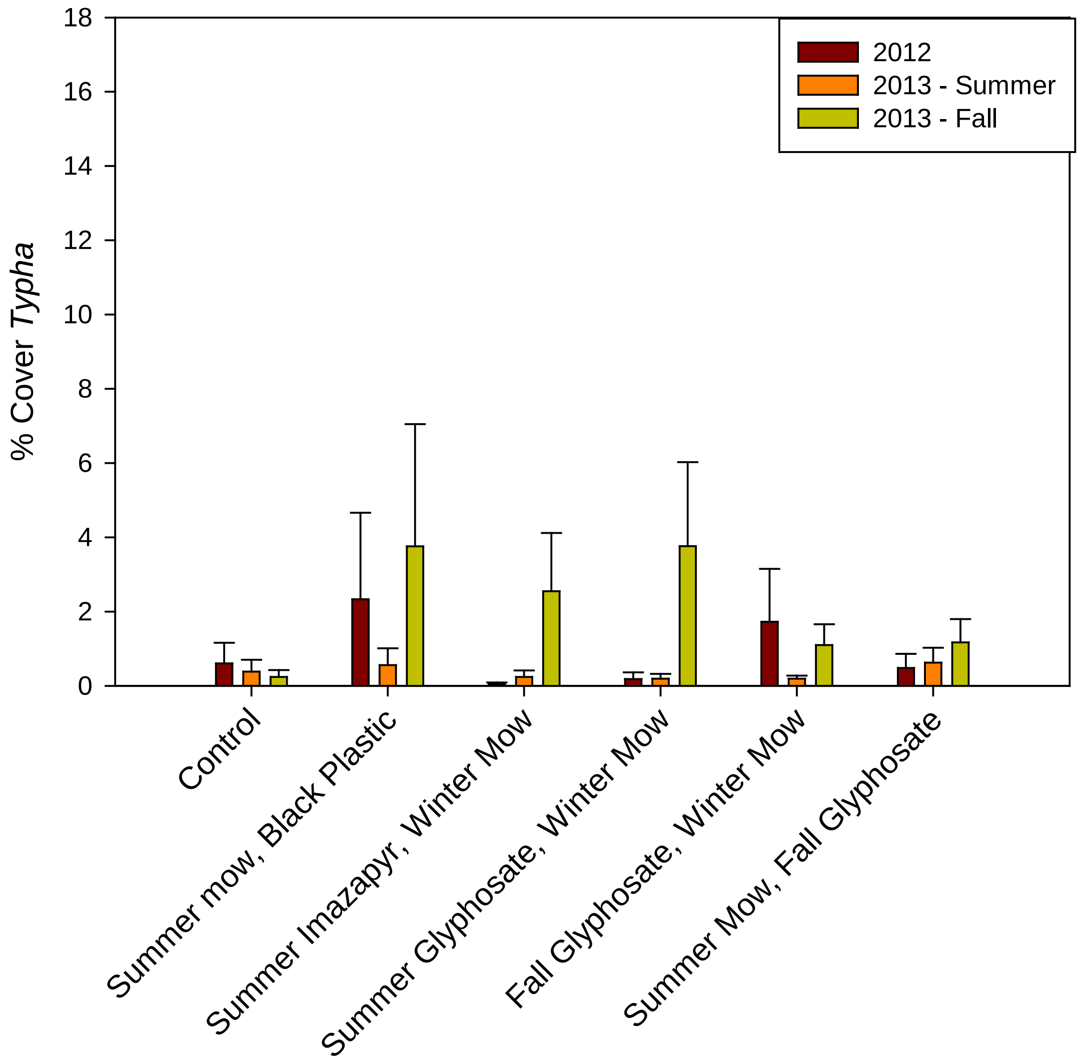


Figure 9. Cover of* Typha *spp. (cattails) in treated and untreated* Phragmites *plots.

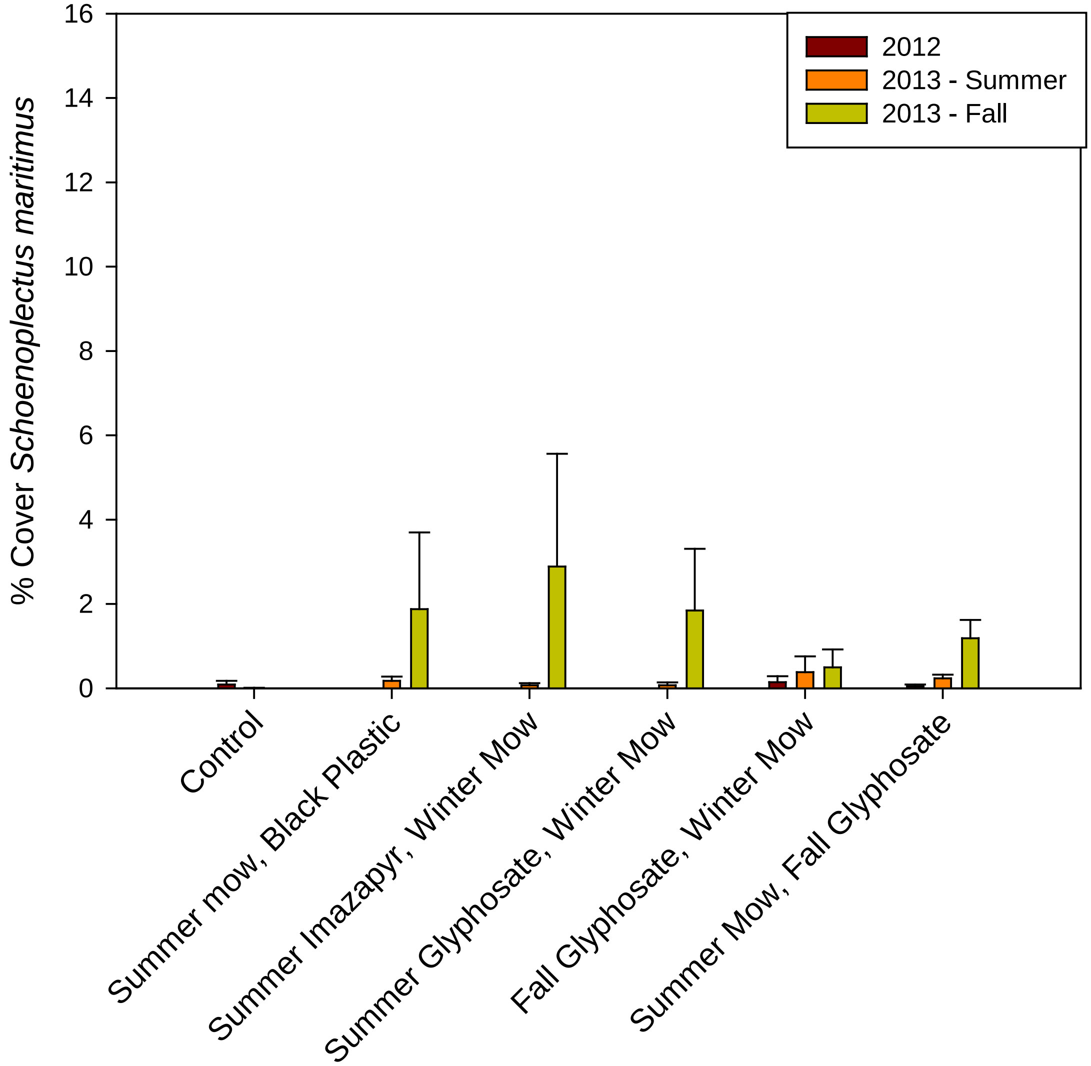


Figure 10. Cover of* Schoenoplectus maritimus *(alkali bulrush) in treated and untreated* Phragmites *plots.

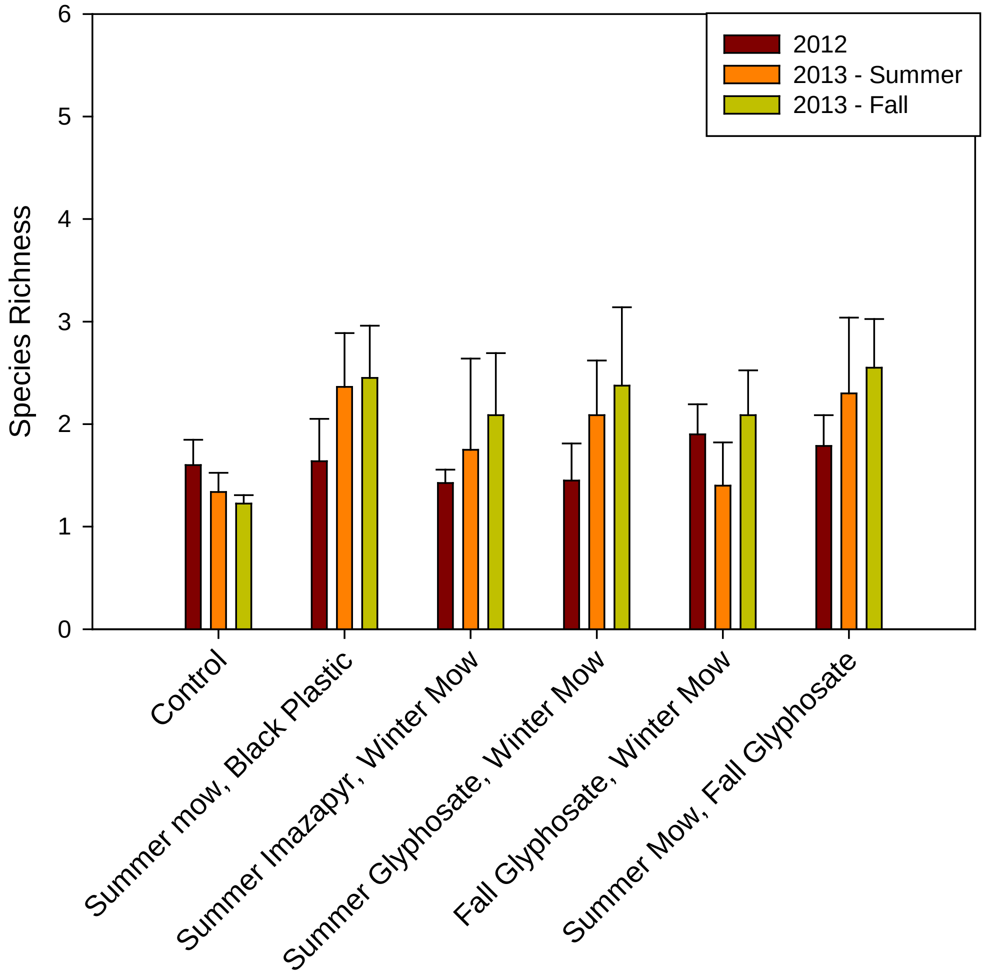


Figure 11. Species richness (number of species per m^2) in treated and untreated* Phragmites *plots.

The very large amounts of litter left behind from mowing seemed to be the most substantial impediment to the regrowth of native species in all plots, but more so in the plots that were mowed in the winter (although differences between treatments were not statistically significant; **Figure 12**). The fall glyphosate, winter mow treatment consistently had very high amounts of litter, greater than the summer spray treatments (perhaps because the *Phragmites* had more time to accumulate biomass). The summer mow followed by a fall glyphosate spray treatment resulted in substantially less litter, which was reflected in seemingly higher numbers of native species reemerging.

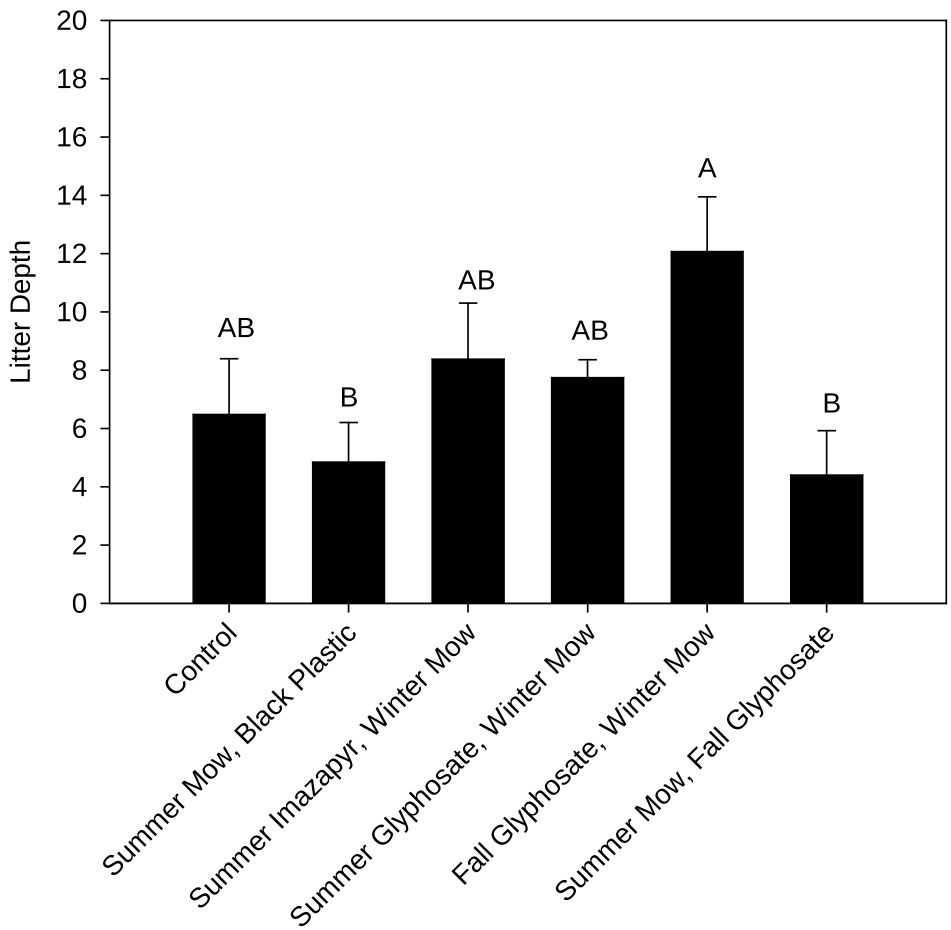


Figure 12. Effects of herbicide and mowing treatments on litter depth, as measured in summer 2013.

PART II: *Phragmites* distribution modeling and prioritization framework (Lexine Long's M.S. project)

Objective: Determine what factors best explain the current distribution of *Phragmites* in GSL wetlands and develop a watershed-wide *Phragmites* prioritization scheme

Methods and Results

Multi spectral imagery data collection. In May and June 2011, we acquired high-resolution of the eastern third of the GSL using USU's airborne multispectral digital imagery system. Images were acquired at 1-m resolution, with imagery in 4 bands: red, green, blue, and near-infra red. We used ERDAS Imagine 2010 software to perform supervised classification of the imagery (i.e., to delineate the vegetation shown in the imagery into vegetation types listed in **Table 1)**. Supervised classification is performed by using training pixels for each vegetation class based on known field locations determined from ground truthing surveys. The computer then assigns the remaining pixels to the class that most closely matches the training pixels according to the multispectral signature. The final product of this imagery classification process was a raster dataset consisting of the nine different vegetation classes (**Table 1**) for all wetland areas on the eastern third of the GSL (**Figure 13**). We calculated total acres around the GSL for each vegetation class, as well as acres of *Phragmites* in major managed wetland areas around the GSL (**Table 2**).

Table 1. Wetland vegetation classes and area

Class Name	Area (acres)
Open water	156,966
Phragmites australis (common reed)	23,126
Playa wetlands	94,449
Salicornia spp. (pickleweed)	12,532
Distichlis spicata (saltgrass)	19,054
Typha spp. (cattail species)	28,348
Schoenoplectus acutus (hardstem bulrush)	7,570
Other emergent wetland vegetation	31,209
Upland	89,923

Table 2. Acres of *Phragmites* in major GSL managed wetland areas, and percent of land occupied by *Phragmites* for each managed land area.

Wetland Area	*Phragmites* area (acres)	Percent of land occupied by *Phragmites*
Great Salt Lake Shorelands Preserve	664.0	14.9%
Inland Sea Shorebird Reserve	179.6	4.5%
Harold Crane Wildlife Management Area	961.4	9.3%
Farmington Bay Wildlife Management Area	1602.8	7.3%
Howard Slough Wildlife Management Area	351.4	14.8%
Ogden Bay Wildlife Management Area	2405.5	14.5%
Bear River Migratory Bird Refuge	4506.1	4.4%

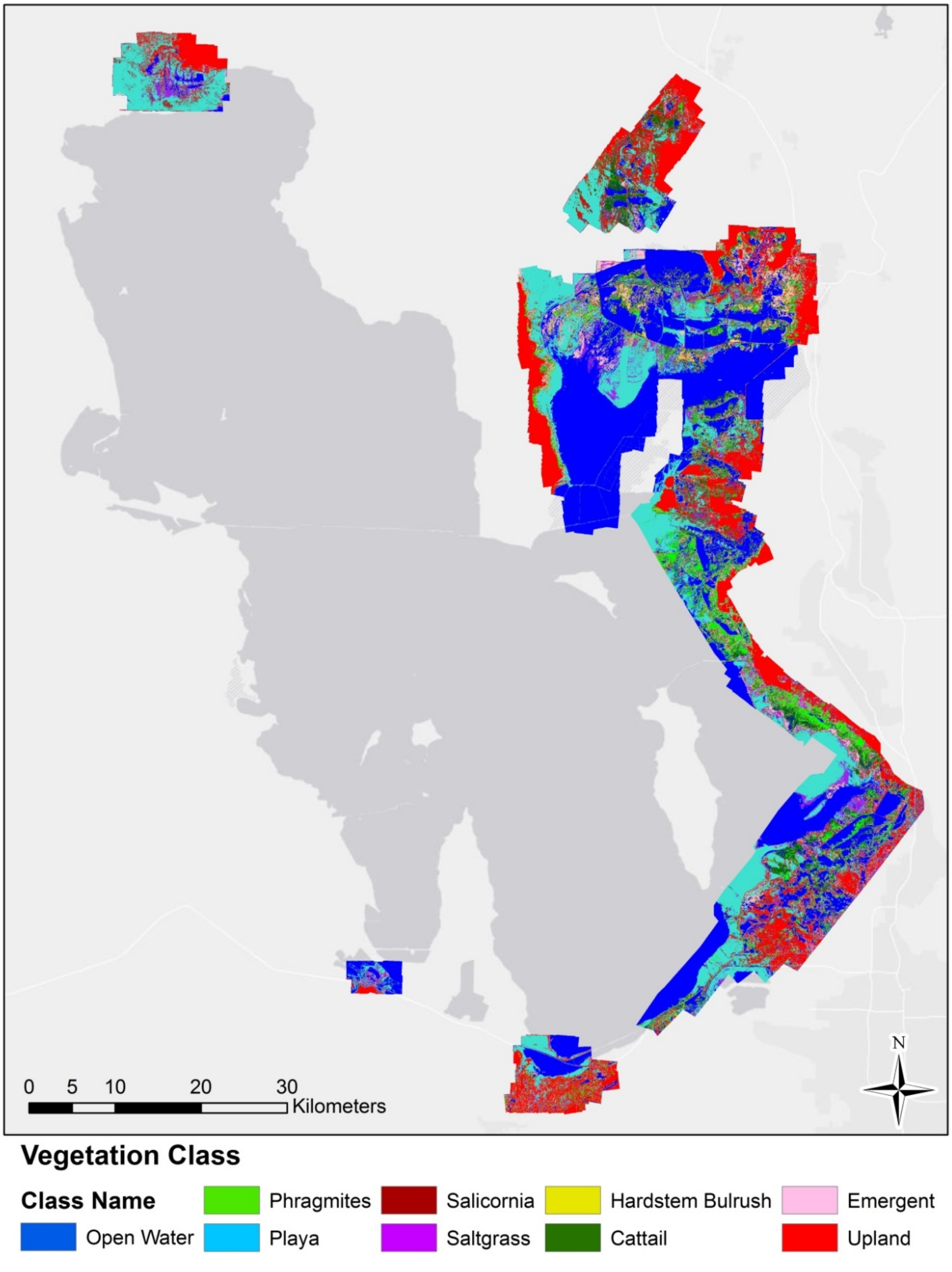


Figure 13. Wetland vegetation distribution around GSL wetlands based on classified 1-m multispectral imagery.

Phragmites *species distribution modeling*. To better understand what determines *Phragmites* presence and help predict its future expansion in the GSL region, we used species distribution models to examine relationships between the current distribution of *Phragmites* and a suite of different environmental variables. Species distribution models are useful tools that can relate the presence and distribution of a certain species with environmental, geographic, or management predictors (Elith et al. 2006). We selected predictor variables that would describe environmental characteristics that may be important at a site (such as nutrient levels, hydrology, etc), as well as variables to measure disturbance (such as land use or road density) that may also drive *Phragmites* distribution.

Species distribution models are created by using presence and absence data points for a species and relating those data to environmental and/or management predictor variables. We used the final classified imagery to generate presence and absence points for *Phragmites* species distribution modeling. To create our initial models, we generated 1000 random *Phragmites* presence points, as well as 1000 random absence points (i.e., areas where *Phragmites* does not exist), which were stratified between the remaining non-*Phragmites* vegetation classes.

We obtained data for the predictor variables from available datasets around the GSL. Most of these datasets were publically available from the State of Utah Automated Geographic Reference Center (http://gis.utah.gov/). Other data sets were obtained from Environmental Protection Agency (EPA) data, National Resource Conservation Service (NRCS) data, and management records from wetland managers around the GSL.

To determine the optimal set of predictor variables, we followed guidelines from Genuer et al. 2010 and Hill et al. 2013, and removed variables with small importance, and then used a stepwise variable selection procedure. We developed the final model by iteratively adding in predictor variables until the addition of predictors no longer improved model performance. Once we had selected the optimal set of predictor variables, we ran the model for all raster cells across the entire study area. Our final model included 10 of the original 15 candidate predictor variables (**Table 3**). We also used the final model to predict the probability (0 to 1) that each raster cell was suitable habitat for *Phagmites*.

Table 3. *Phragmites* presence predictor variables used in the species distribution modeling.

Abbreviation
Elevation (m)
Distance from point sources of pollution (m)
Distance from freshwater inflow (m)
Distance from nearest road (m)
Distance from water control structure (m)
Aspect
Dominant Land Cover Type within buffer
Level 8 watershed
Slope
Distance from open water (m)

We used random forest models, which are a type of classification procedure that aggregates different classification tree models, for our analysis. Benefits of random forest models include having a higher accuracy than just single classification tree models, flexibility to perform different types of data analysis, and the ability to model complex interactions between variables (Cutler et al. 2007). Additionally, random forest models are fully non-parametric and do not make any assumptions about the distribution of data (such as normality). We used R statistical software for all modeling analysis. To test the accuracy of our model we used both 10-fold cross validation (which repeatedly tests the model fit on a subset of the data) and used the data points that were set aside as an independent data set. We used the Area Under the Curve (AUC) as an accuracy assessment. AUC is a measure of a model's ability to correctly discriminate between presences and absences. AUC ranges from 0 to 1, where 1 is a perfect discrimination between presence and absences and 0.5 is no better than by chance. Instead of using statistical significance to select variables to be included in models, random forests ranks variables by importance based on an algorithm (Cutler et al. 2007). This approach allows you to determine the most important variables in predicting *Phragmites* distribution.

The top predictor variables for our model included distance to open water, elevation, distance to point source pollution outflow, distance to freshwater inflow, and distance from shoreline (**Figure 14**). Many these top predictor variables are consistent with prior research with *Phragmites* in other regions, so we do not expect the top variables to change much with the addition of new variables. Distance to open water was a very important predictor for *Phragmites* presence, which is expected since it is a wetland plant. Elevation is often a proxy for the hydrology of an area. We found *Phragmites* was more likely to be found in lower elevations. Lower elevation wetland areas hold water for longer, and therefore are more hospitable for *Phragmites*. Distance to point source of pollution was an important predictor, and other studies have found that higher nutrient levels often correspond with *Phragmites* presence (King et al. 2007, Chambers et al. 2008). Hoffman et al. (2008) found that elevation and distance from river were the most important predictor variables for *Phragmites* along the North Platte River in Nebraska. A similar project that involved *Phragmites* mapping around the Great Lakes found that topography, land use, and road density were important predictors of *Phragmites* habitat suitability (Huberty et al. 2012).

The final results of our *Phragmites* species distribution modeling provides information on what variables are the most important in predicting *Phragmites* presence, and also identifies areas that are suitable habitat for *Phragmites* (**Figure 15**). Areas that are suitable habitat for *Phragmites* but not currently occupied should be considered more vulnerable to *Phragmites* invasion. For instance, there are substantial areas (shown in red in **Figure 15**) with suitable habitat for *Phragmites* on the north side of Farmington Bay as well as in Harold Crane WMA where *Phragmites* is not currently located.

These areas identified as vulnerable to *Phragmites* invasion will be added as a layer in our online interactive Great Salt Lake Vegetation Map (http://maps.gis.usu.edu/gslw/index.html). This vulnerability map can be an important resource for wetland managers, and can help with early detection of new *Phragmites* stands, as well as help with prioritizing areas for management. We used the results of the vulnerability map in our *Phragmites* management and restoration prioritization framework.

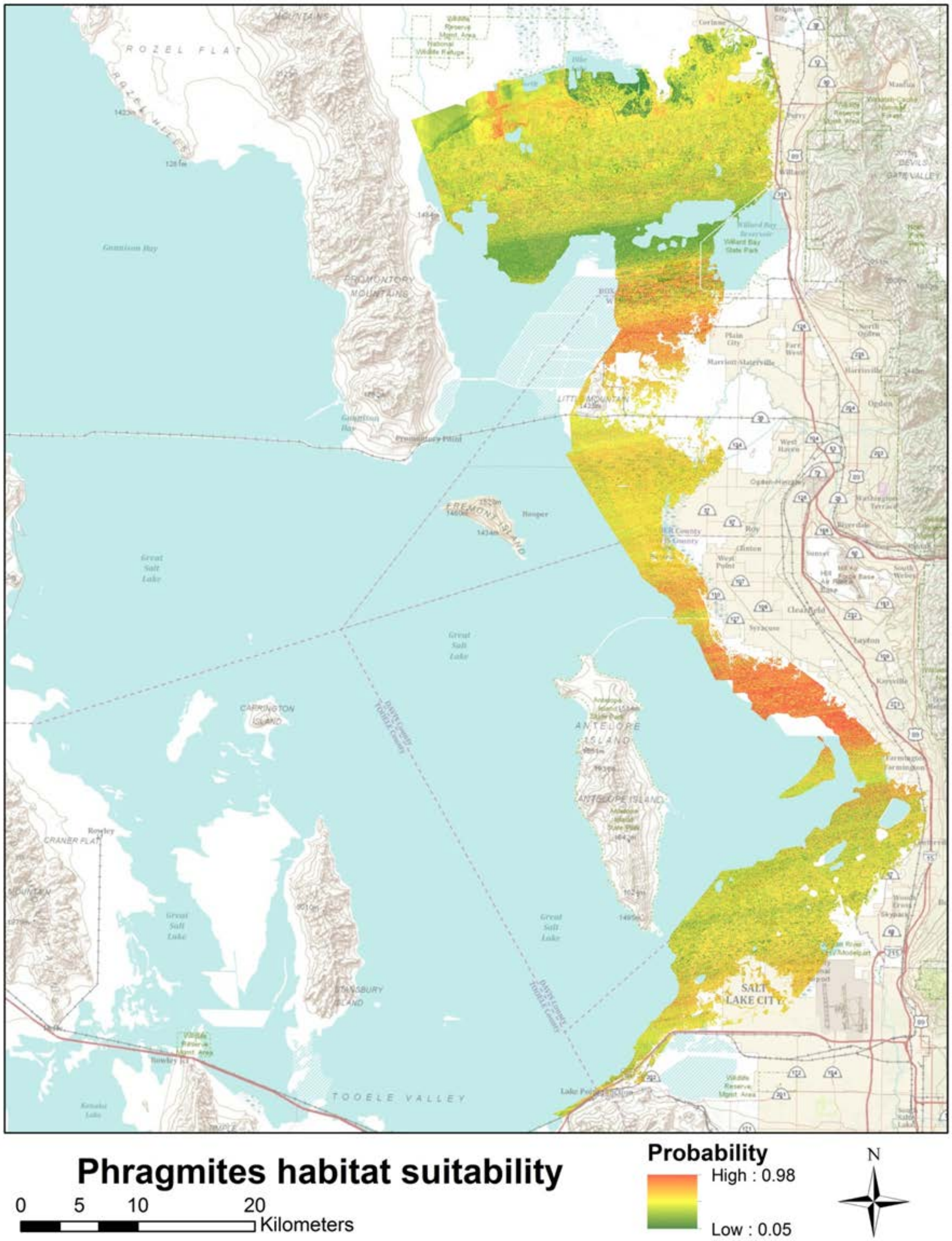


Figure 15. Predicted* Phragmites *habitat suitability. Areas shaded in reddish orange (probability of presence closer to 1) indicate more suitable habitat for* Phragmites*; areas shaded with greener colors (probability or presence closer to 0) are less suitable habitat for* Phragmites*.

Prioritizing sites for *Phragmites* management

To determine sites that should be targeted for *Phragmites* management and wetland restoration around the GSL, we developed a multi-criteria GIS prioritization model, and a corresponding spatially explicit map that ranks *Phragmites* patches by priority for management. GIS-based multi-criteria analysis has been used in other conservation and restoration applications as a way of prioritizing conservation or management actions (Orsi and Geneletti 2010). We used information about areas we identified as having a high suitability for *Phragmites* invasion in the species distribution model, as well as other environmental and land management variables. We selected variables for the prioritization model based on their known importance to *Phragmites* distribution and wetland ecological condition, and selected management variables based on their importance to *Phragmites* management as determined by wetland manager expert knowledge (such as ease of site access and ability to manipulate water levels). We conducted the prioritization analysis at the patch scale because setting priorities based on the patch scale will be more useful from both an ecological and management standpoint than doing the analysis on the pixel scale. We aggregated raster cells into patches based on pixels that are contiguous and are the same vegetation type.

Our prioritization model is based on a two part analysis – an assessment of the need for restoration of a patch, and an assessment of the likelihood that restoration will succeed in that patch. The ***restoration need*** score attempts to capture areas that have patches of *Phragmites* that would have a major benefit to the overall landscape if managed (**Table 4**) including areas that would be good wetland habitat if restored, such as areas with lots of desirable emergent vegetation in the vicinity. The ***restoration feasibility*** score is a measure of how likely restoration success is for that patch (**Table 5**). The feasibility score largely includes management or landscape disturbance factors that influence how feasible a site will be to restore. Each patch received both a restoration need score and a restoration feasibility score.

Table 4. Variables that were used to calculate the restoration need score.

Variable	Explanation / justification for use of variable
Proximity to areas vulnerable to future invasion	Whether or not a patch is close to areas that were identified as vulnerable to future invasion based on the results of the *Phragmites* species distribution modeling. Patches nearby to vulnerable areas will therefore have a higher need score.
Patch size	Larger *Phragmites* patches (if successfully restored) will potentially contribute more to overall wildlife value of a wetland complex, therefore warranting a higher restoration need score, although these will also be more logistically challenging to restore (see restoration feasibility score below).
Percent native wetland vegetation within buffer zone	The majority vegetation class within a 100m buffer. This metric is useful to determine if there is desirable wetland vegetation nearby that is already providing important wildlife habitat. Areas with majority of beneficial wetland vegetation classes (hardstem bulrush and native emergent) will receive a higher score.
Patch edge to core ratio	Geometric configuration of *Phragmites* patches can potentially affect how fast they expand. Linear, as opposed to circular, patches of *Phragmites* often expand rapidly due to their high edge to core ratio.

	Patches that may expand faster will have a higher priority for control.
Wetland type	Based on the National Wetland Inventory classification. Some wetlands may be more beneficial for waterfowl and shorebird habitat, and would receive a higher score.
Proximity to recreation	GSL wetlands are used heavily for recreation for birding, boating, and hunting. We used proximity to boat launches and Wildlife Management Areas to measure if patches were in a high value recreation area.

Table 5. Variables that were used to calculate the restoration feasibility score.

Variable	**Explanation / justification for use of variable**
Active management	Whether or not a patch is in an area that is currently actively managed, including management of *Phragmites.* We assumed actively managed areas are more feasible for future restoration compared with unmanaged areas.
Water level manipulation	Whether or not a patch is in an area where the water level is actively manipulated, as the ability to manage water levels can increase the feasibility of *Phragmites* management.
Cost of management	A relative estimate of cost (high, medium or low) of management based on patch size, access, etc.
Site access	How easy a site is to access by managers based on the presence of dikes, roads, boat ramps, etc. Easier site access will result in a higher feasibility score.
Vegetation class diversity within 150m buffer	Areas with high diversity of non-*Phragmites* vegetation within the vicinity of the *Phragmites* patch will have a higher likelihood of native plants recolonizing sites naturally, which will increase the feasibility of restoring native plant-dominated wetlands.
Patch size	Smaller patches will be easier to manage and more successful, therefore earning a higher feasibility score.
Distance to nearest *Phragmites* patch	Distance to nearest *Phragmites* patch is a measure of likelihood that an area will be reinfested from nearby patches of *Phragmites*. Higher feasibility scores will be given to *Phragmites* patches that are far from other *Phragmites* patches.
Land ownership	State, federal, private, or non-profit. Different management agencies have varying goals and resources for *Phragmites* management and wetland restoration, which can influence restoration success.

<u>Scenario Development</u>

We developed four alternative restoration scenarios based on the restoration need and feasibility maps (**Figure 16**). Each patch received a restoration need (either low or high) score, and a restoration feasibility score (either low or high). The combination of these scores determined which scenario each patch falls into. We also provide maps of two state Waterfowl Management Areas to provide examples of this prioritization scoring at a finer scale (**Figures 17 and 18**).

Scenario 1 (Low need / Low feasibility) – These patches are areas that have a low need for restoration (such as patches that are not close to suitable *Phragmites* habitat and not as likely to expand), but also low feasibility (difficult to access, for example). These areas could be put lowest on the priority list when dealing with limited resources.

***Scenario 2 (High need / Low feasibility)* –** These patches have a high restoration need (such as large areas of *Phragmites),* but low feasibility. They may require significant effort to manage, are difficult to access, or have other management factors that contribute to a low possibility of success. These may be areas that managers would want to put lower down on the priority list for management when dealing with limited resources, and first focus on the high need areas that also have a higher feasibility.

***Scenario 3 (Low need / High feasibility)* –** These patches would be good areas to target for management and restoration because they may be easy targets with high potential for success. For example, these might be areas that are small isolated patches of *Phragmites* that are easy to access, and surrounded by a lot of emergent wetland vegetation. These would be areas that are "low hanging fruit" to manage and restore, but could have a benefit in reducing the expansion of *Phragmites* around the lake.

***Scenario 4 (High need / High feasibility)* –** These patches were often large core *Phragmites* areas surrounded by lots of healthy wetland habitat that could have a big impact on the overall wetland condition if managed. Since these areas are high need, they may be bigger projects, but would still be worth the effort as they could eliminate large sources of *Phragmites* expansion.

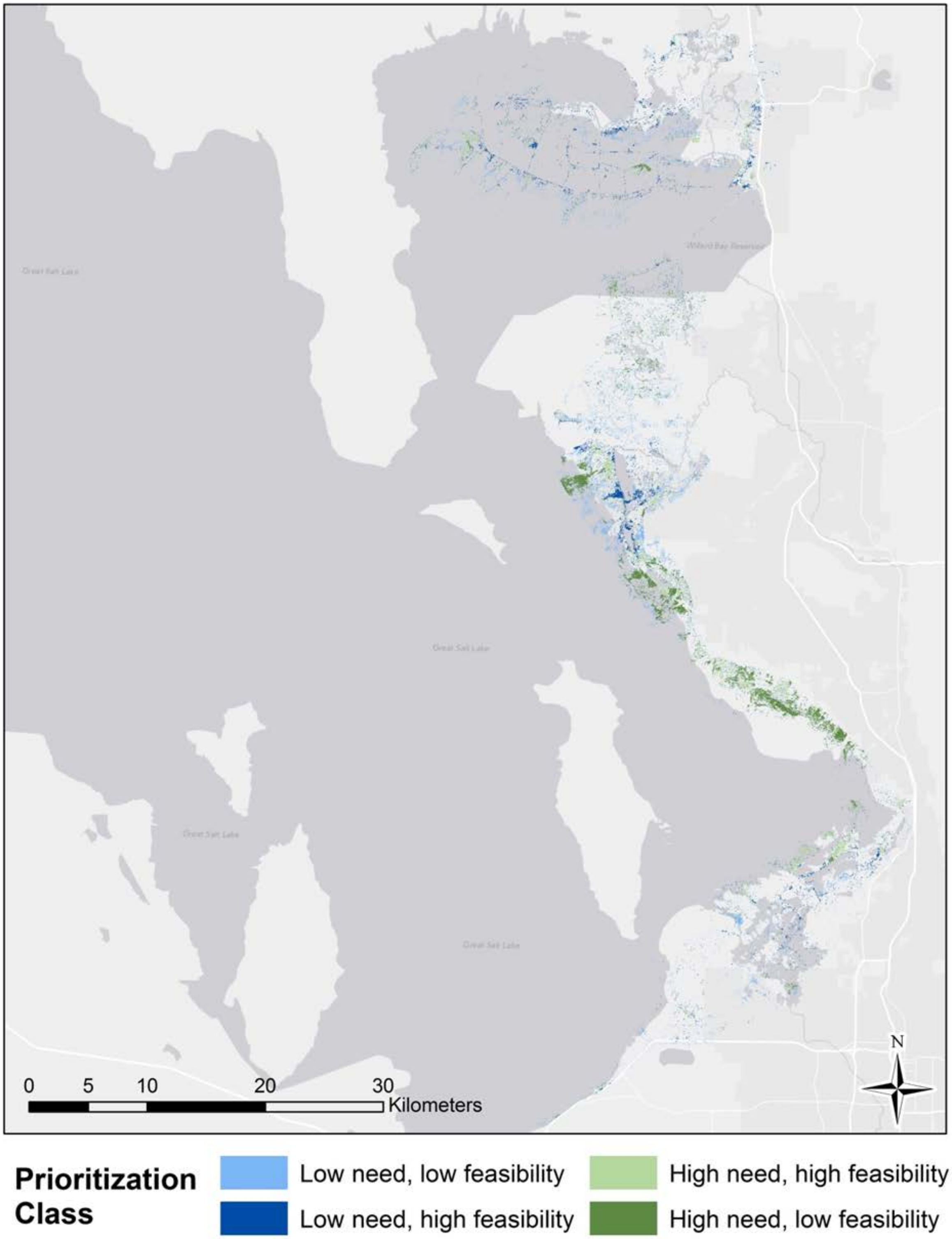


Figure 16. GSL **Phragmites** *prioritization model*

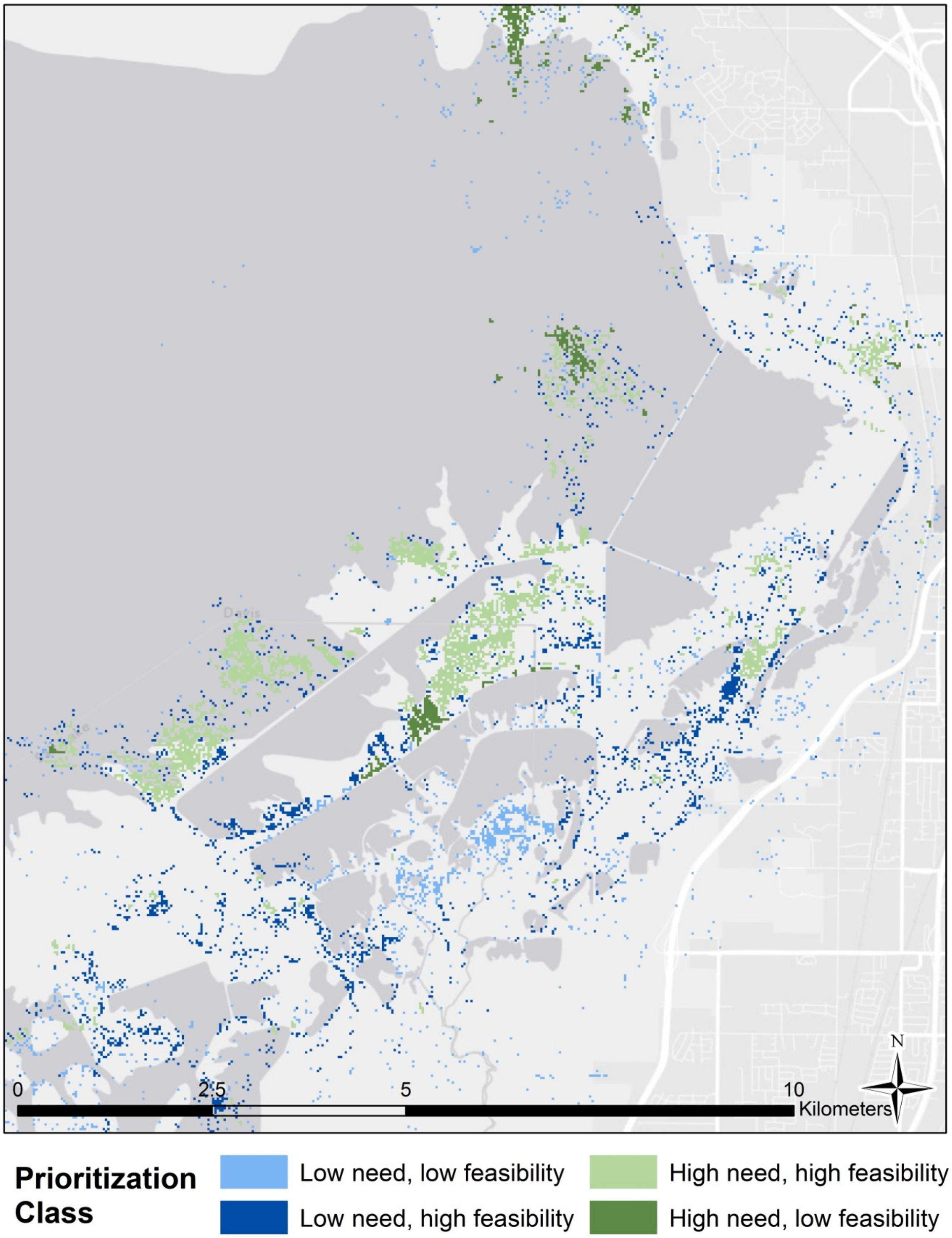


Figure 17. Farmington Bay WMA prioritization results.

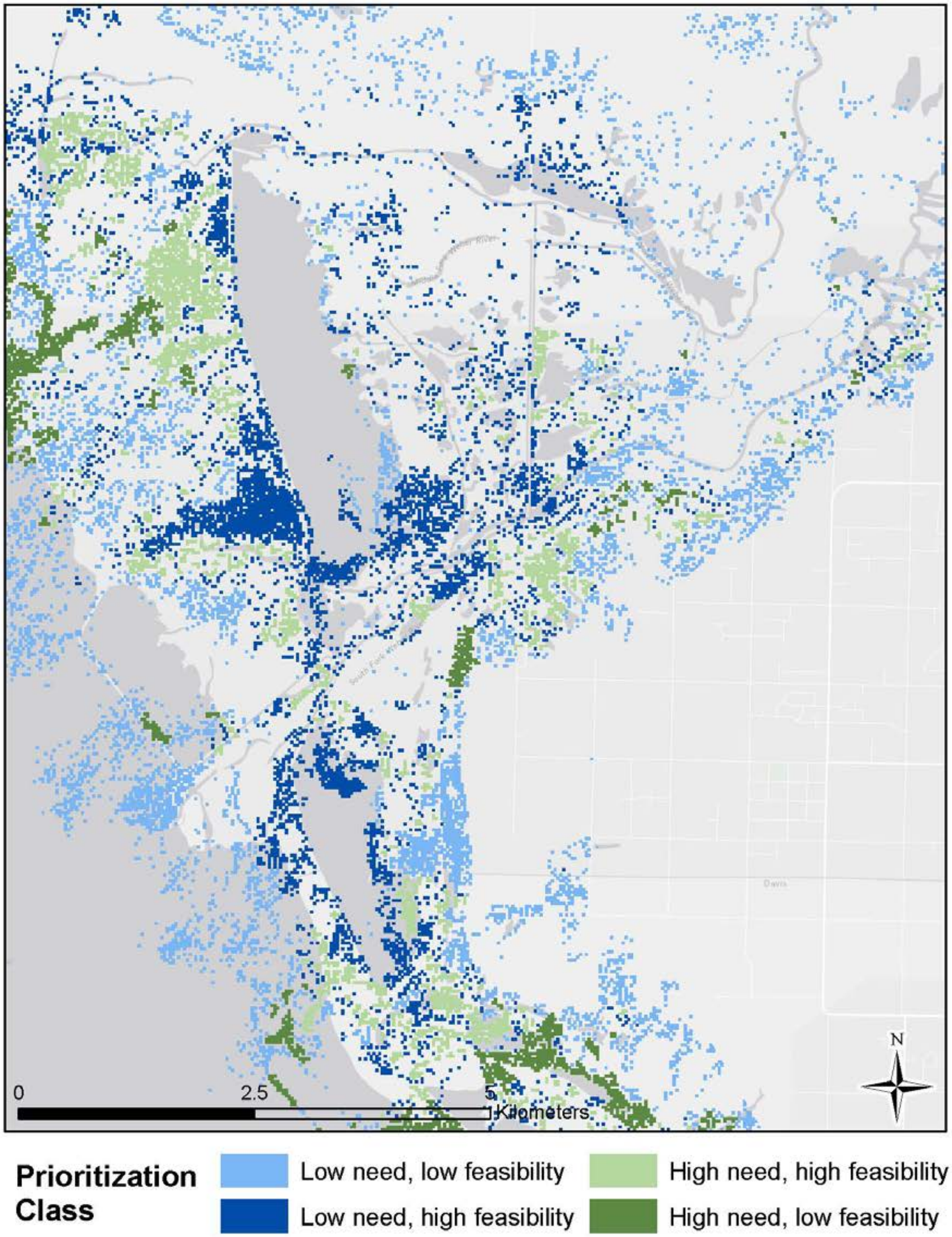


Figure 18. Ogden Bay WMA prioritization results.

Area of each scenario

We calculated the acres of *Phragmites* that fell under each restoration scenario (**Figure 19**). The high need, high feasibility areas, which should be the primary focus of managers initially, comprise about 3500 acres.

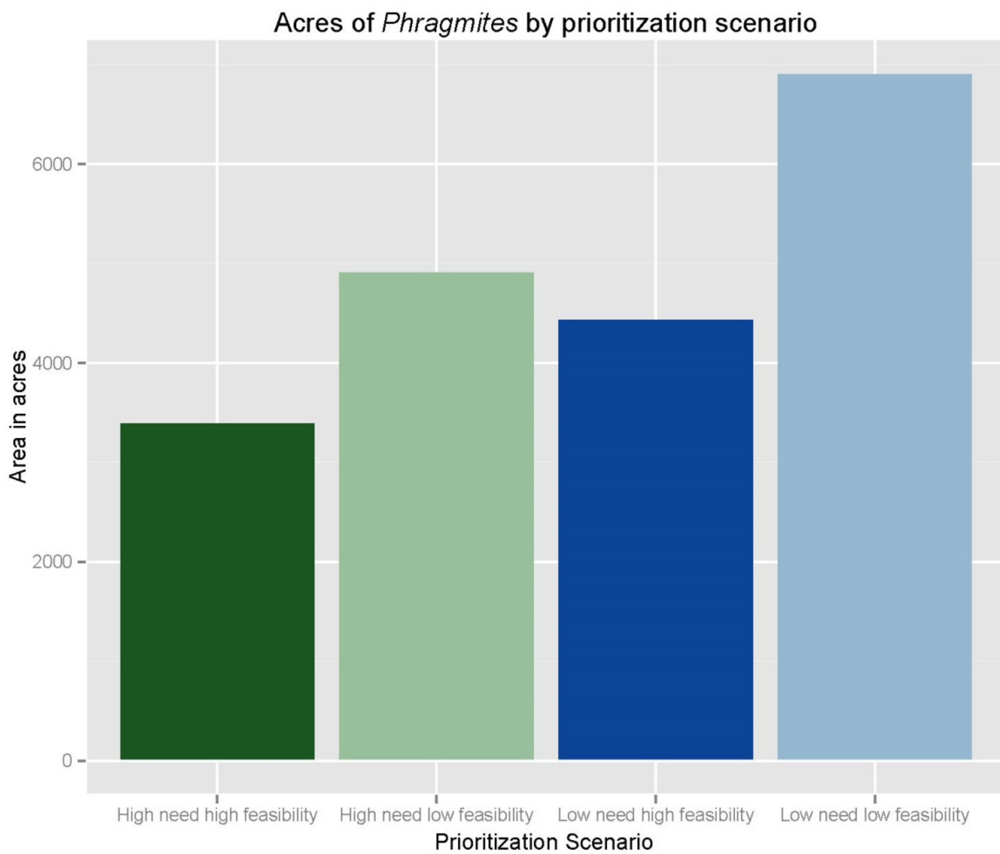


Figure 19. Acres of* Phragmites *by prioritization scenario.

While there is extensive research on impacts of invasive species, and factors leading to invasion, often this information is not directly translated into invasive species management action (Papeş et al. 2011; Levin-Nielsen 2012). There is a need to take outputs from ecological research and models on invasive species, and provide more specific management recommendations, and to put these recommendations in the context of related social or economic issues. Frequently with invasive species management the infestation is much larger than the time or resources available to most land managers (Skurka Darin et al. 2011). Studies on how to prioritize control efforts and specific recommendations for how to use results of invasive species research and models can help guide invasive species management. Here we provide different restoration priority scenarios to allow GSL wetland managers to determine what types of patches they want to focus their efforts on. There is great flexibility with this prioritization scheme because managers could choose to focus management efforts on patches from just one scenario, or a combination of scenarios based on their resources and goals. Our *Phragmites* restoration prioritization analysis could aid coordinated *Phragmites* management efforts and allow for more efficient and effective use of resources when managing *Phragmites* around the GSL.

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