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

Management of *Phragmites* in the Great Salt Lake watershed

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Problem statement and report overview

Phragmites australis (common reed) is an invasive grass that has rapidly invaded wetlands across North America (Marks et al. *1994*) and is widespread and dominant in wetlands, ditches, and roadsides in northern Utah (Kulmatiski et al. *2010*, 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 Unfortunately, tens of thousands of acres of diverse native wetland vegetation have been replaced by invasive *Phragmites*, reducing the availability and quality of habitat.

Given the extent of the *Phragmites* problem in Utah and elsewhere, managers need tools to determine its current extent, to understand what factors drive its distribution, and to predict where it may spread in the future. Recent developments in remote sensing technologies now allow researchers to look at widespread patterns of vegetation distribution. In turn, data collected for remote sensing can form the basis of species distribution modeling whereby researchers can look at relationships between the current distribution of an invasive species with factors that may explain those distributions. Here we report on our efforts to determine the current extent of *Phragmites* in the eastern third of the Great Salt Lake using remote sensing. Future work will use this imagery for modeling efforts to look at factors related to its current distribution.

In addition to determining the current extent of *Phragmites*, there are numerous factors we can learn about its invasion and potentially important control techniques by "tapping into" local knowledge about this species. Here we report on the results of our survey of 42 wetland managers in the Great Salt Lake watershed. In our survey, we sought to determine the timing of initial *Phragmites* invasion in the Great Salt Lake watershed, factors potentially contributing to its invasion, and current *Phragmites* management practices including those that managers generally find to be most successful.

Taking these findings from the manager survey one step further, we think it is important to directly evaluate how best to control this plant. A variety of strategies have been widely employed including summer or fall herbicide application, mowing, burning, and flooding (Marks et al. *1994*). 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 control strategies across the varied environmental conditions where *Phragmites* is found, particularly in Utah. Given the interest in effective control strategies for *Phragmites* in Utah and across North America, there is a need to evaluate different potential techniques and then monitor the success of techniques. Another complicating factor in effective *Phragmites* control 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 control *Phragmites*, this occurs *after*

Phragmites has produced its seeds. Managers need additional tools to prevent seed production in conjunction with controlling existing stands (e.g., mowing in conjunction with herbicide or using herbicide application earlier in the year). In general, there is a critical need to provide guidance to managers to improve the efficacy of control efforts and to ensure that scarce resources are not wasted on unsuccessful techniques. Thus, 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 control treatments we are evaluating and the response variables we will monitor to determine control effectiveness in our on-going studies.

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Final report to UDNR FFSL, Part I

Determining the current extent of *Phragmites australis* in Great Salt Lake wetlands using multi-spectral remote sensing techniques

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Background

Currently, the full extent of the *Phragmites* infestation around the Great Salt Lake (GSL) is not known. There have been some previous mapping efforts of *Phragmites* around the GSL, but the scale of these studies was coarse, and the information is outdated, as *Phragmites* has likely expanded significantly since the last mapping efforts. To make accurate management decisions, current and detailed information about the extent of *Phragmites* in wetlands around the GSL is necessary. *Phragmites* dominated marshes are dense and difficult to walk through, making field surveys of *Phragmites* difficult and time consuming. Additionally, *Phragmites* marshes are often also difficult to access due to deep water, water control structures, land ownership issues, etc. For these reasons, using remote sensing to determine current extent of *Phragmites* around the lake is a good option. Remote sensing can produce large datasets of species distribution information that might be hard to come by using field techniques, and is often easily repeatable (Gilmore et al, 2008, Andrew and Ustin 2009). We chose to use multispectral remote sensing to map the current extent of *Phragmites* in GSL wetlands because such data have been shown to reliably be able to map vegetation to the species level, and perform just as well as field data (Ustin *et al.*, 2004, Davis et al., 2007). Our overall objective was to produce maps of emergent wetland vegetation for the eastern third of the GSL using remote sensing.

Methods

We acquired high resolution multi-spectral imagery in May and June, 2011 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. Images had a 60% overlap between the flightlines, and a 30% overlap between the images. The USU system consists of several digital cameras mounted on a Piper Seneca II aircraft that have interference bands to capture green, red blue and near infrared (NIR) wavelengths (Neale et al 2007). The area flown for data collection included all major wetland areas around the GSL (**Figures 1 and 2**). At the time of the flights in May and June 2011, some vegetation had "greened up", while other marsh vegetation had not, allowing for differentiation between different vegetation types. Growing vegetation reflects highly in the near infra red range (NIR), and absorbs in the red range. We chose to conduct our flights in late spring because previous studies have identified this time period as the ideal time to distinguish *Phragmites* using remote sensing (Maheu-Giroux and de Blois, 2005).

Following image acquisition, we orthorectified, mosaicked, and calibrated the aerial images using ERDAS Imagine software. We ground truthed the imagery following orthorectification to acquire sample points to use as training pixels for the vegetation classification. We visited major wetland units captured by the imagery in the fall of 2011, and again in the spring of 2012 where necessary, to acquire the sample points. We randomly collected GPS points for each major wetland vegetation type at eight different wetland complexes. We collected a minimum of 10 GPS points at each area for each vegetation type. We classified vegetation into nine groups of major vegetation to determine the distribution of wetland plant species of interest. These vegetation classes are: *Phragmites australis* (common reed), *Typha* spp. (cattails), *Distichlis spicata* (saltgrass), *Salicornia europeae var. rubra* (pickleweed), *Schoenoplectus acutus* (hardstem bulrush), playa wetlands, native emergent wetland, upland, and open water. The native emergent class consists of both wet meadows and emergent species such as *Schoenoplectus maritimus* (alkali bulrush) and *Schoenoplectus pungens* (three-square bulrush). In total we collected 450 ground-truthing GPS points. In addition, we made notes and hand drawn polygons on field maps, and digitized this information using ArcGIS 10. This resulted in approximately another 1000 digitized points in GIS.

Following ortho-rectification, mosaicking, and ground truthing, we used ERDAS Imagine 2010 software to perform supervised classification of the imagery. Supervised classification is performed by using training pixels for each vegetation class based on known data determined from ground truthing surveys. The computer then assigns the remaining pixels to the class that most closely matches the training pixels. We conducted the supervised classification as an iterative process. We used the signature extraction tool to specify training pixels. We then analyzed signatures for overlap using the Transformed Divergence method. If signatures were too similar to each other we kept only one of the two training pixels.

Following classification, we conducted an accuracy assessment of the classification to validate the imagery. For the imagery processed so far, we used 515 of the initial ground-truthed points as training pixels, and we used the other 750 for accuracy assessment. Currently seven of the 11 wetland complexes (**Figure 2**) have been classified. The remaining areas will be completed by the end of July 2012, and final numbers for both the accuracy assessment and area of each class will be reported on an interactive website.

Results and Discussion

Accuracy assessment

Our accuracy assessment showed that we had an overall accuracy rate of 72%. *Phragmites* had an accuracy rate of 79%. The most common classes to be confused with each other were open water and playa wetlands, as well as *Phragmites* and playa wetlands. Using additional ground truthing points and recoding some problem areas will increase the accuracy of the imagery. Confusion between *Phragmites* and cattail was not as large of an issue as expected. Out of the 750 verification points, there were only 11 instances of either cattail being identified as *Phragmites*, or *Phragmites* being identified as cattail.

Current extent

Our mapping effort represents the most comprehensive mapping effort of *Phragmites* around the GSL to date. Our classification shows that *Phragmites* is widely distributed in wetland areas around the GSL and has covers 22,375 acres in the seven mapped areas (**Table 1**). This number only represents the *Phragmites* cover in areas processed so far, and will change once additional areas are classified and ground truthing data is used to reclassify areas found to be inaccurate (areas still to be classified are: West-East Lake, Willard Bay East, Stansbury, and Timpie Springs; Figure 2). Because previous mapping efforts were at a much coarser resolutions, our 1-m resolution data allows a much more detailed look at *Phragmites* distribution around the GSL. Our findings highlight the large extent of the *Phragmites* invasion and the enormous challenge that managers currently face. However, an important and hopeful finding is that playa wetlands and native emergent wetlands covered substantially more acreage than *Phragmites*. These data suggest that there is significant habitat that should be protected from *Phragmites* invasion and that a lot of important habitat could be lost if future *Phragmites* invasion is not halted.

The extent of the *Phragmites* invasion is substantial in key federal, state, and private wetland areas. *Phragmites* is widely distributed in areas such as Farmington Bay WMA, Ogden

Bay WMA, and Bear River Migratory Bird Refuge (**Figures 3, 5, and 7**), moderately distributed at the Inland Sea Shorebird Reserve (**Figure 4**), and somewhat less prevalent at more upstream areas such as Salt Creek WMA (**Figure 6**). We will conduct a more detailed analysis of the current distribution and factors driving *Phragmites* presence following completion of image classification.

Future directions

These data lay the foundation for future work to determine correlations between environmental and anthropogenic variables and the presence of *Phragmites*, as well as between environmental variables and desirable native wetland vegetation. Determining what factors determine *Phragmites* presence will allow land managers to potentially manipulate factors to prevent *Phragmites* expansion. In addition, understanding which factors promote presence of beneficial native wetland vegetation will allow managers to facilitate these types of environmental conditions to achieve management goals. Also, an analysis of spatial patterns of *Phragmites* around the GSL, like average stand size, will provide additional information about the characteristics of *Phragmites* distribution.

Utility of follow up flights

Data from future flights could be used to answer a number of different questions. Data from future flights could be compared to the 2011 distribution data to evaluate *Phragmites* expansion over time. In addition, such information could be used to validate models created that predict areas of *Phragmites* expansion.

Dissemination of work

Progress of this project was presented to land managers at the Utah Weed Association meeting in winter 2012, and at the Friends of the Great Salt Lake Conference in spring 2012. Presenting progress and preliminary results of the project allowed us to gain land manager input on the project, and help refine our project objectives and methods to ensure the final product will provide results that are useful and relevant to land mangers.

The raster layer, as well as a classified shapefile will be made freely available online through the Kettenring lab website. Additionally, this layer will be displayed on a Google map-like interface on the same website. Website development is currently underway, and the finalized data will go up on the website later in summer 2012.

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Figures and Tables

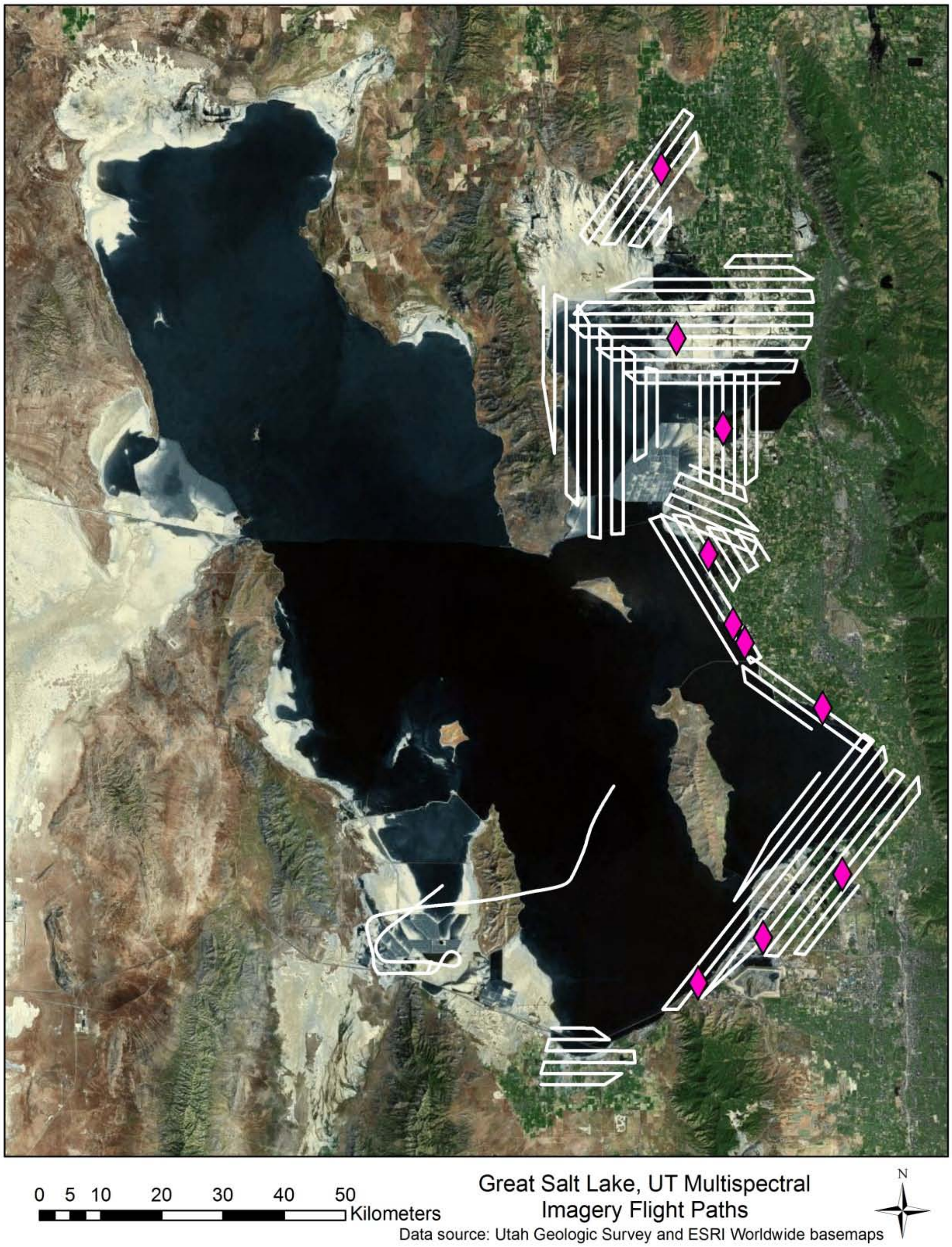


Figure 1. The multispectral imagery flight paths (white lines) and ground truthing sites (pink diamonds) in the Great Salt Lake.

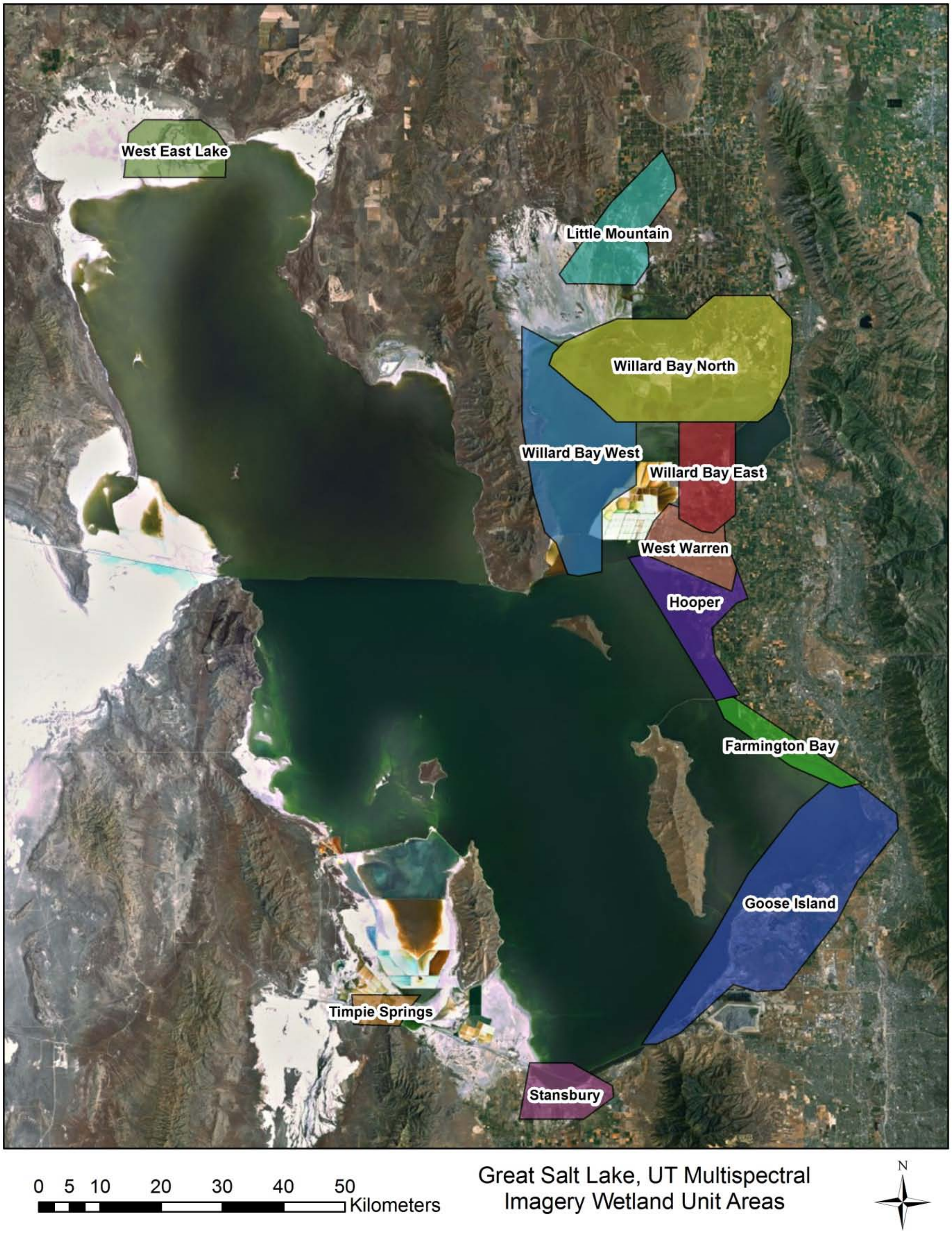


Figure 2. Wetland complexes around the Great Salt Lake where imagery was acquired.

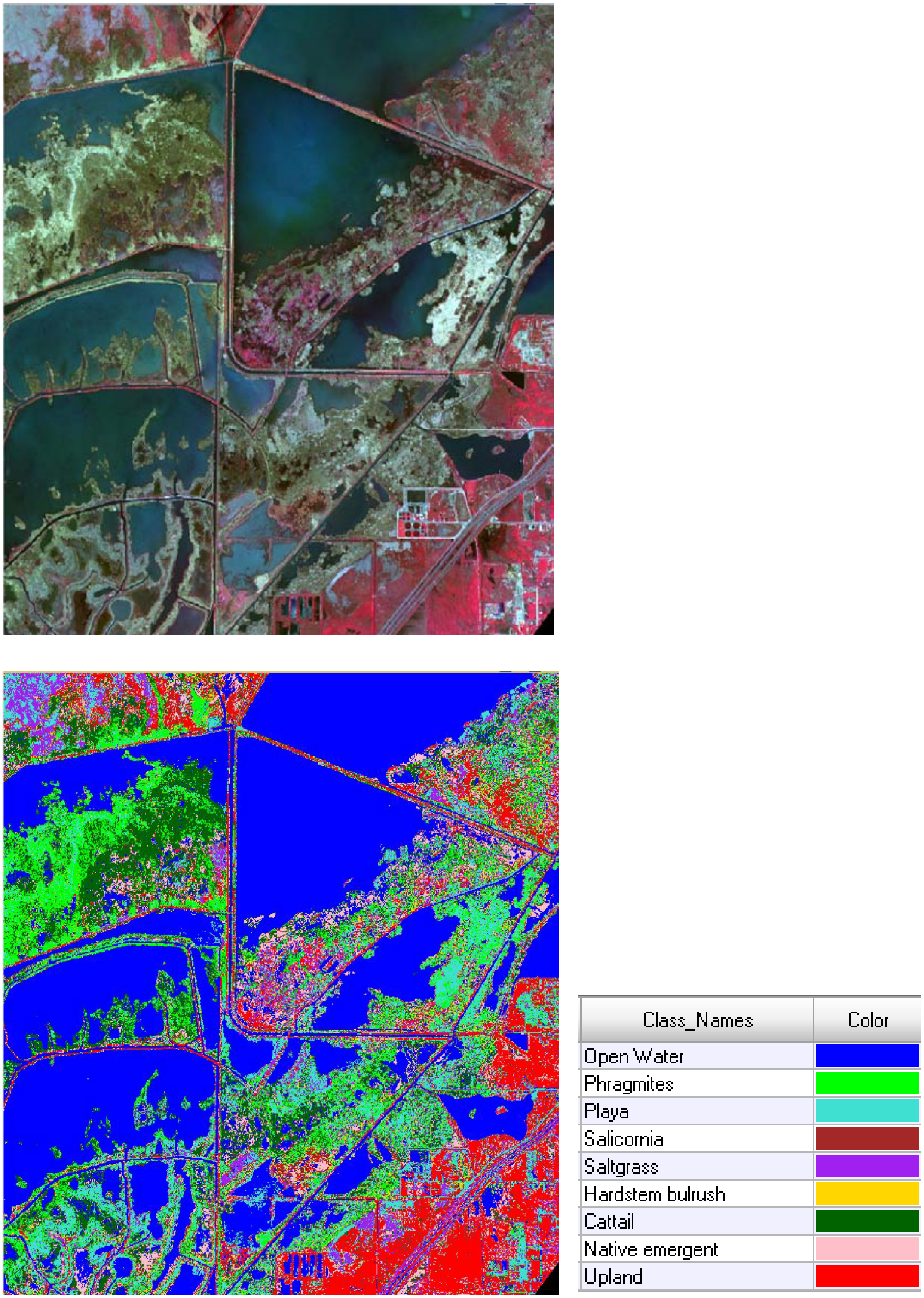


Figure 3. Multispectral image of Farmington Bay (top) and corresponding classified image (bottom).

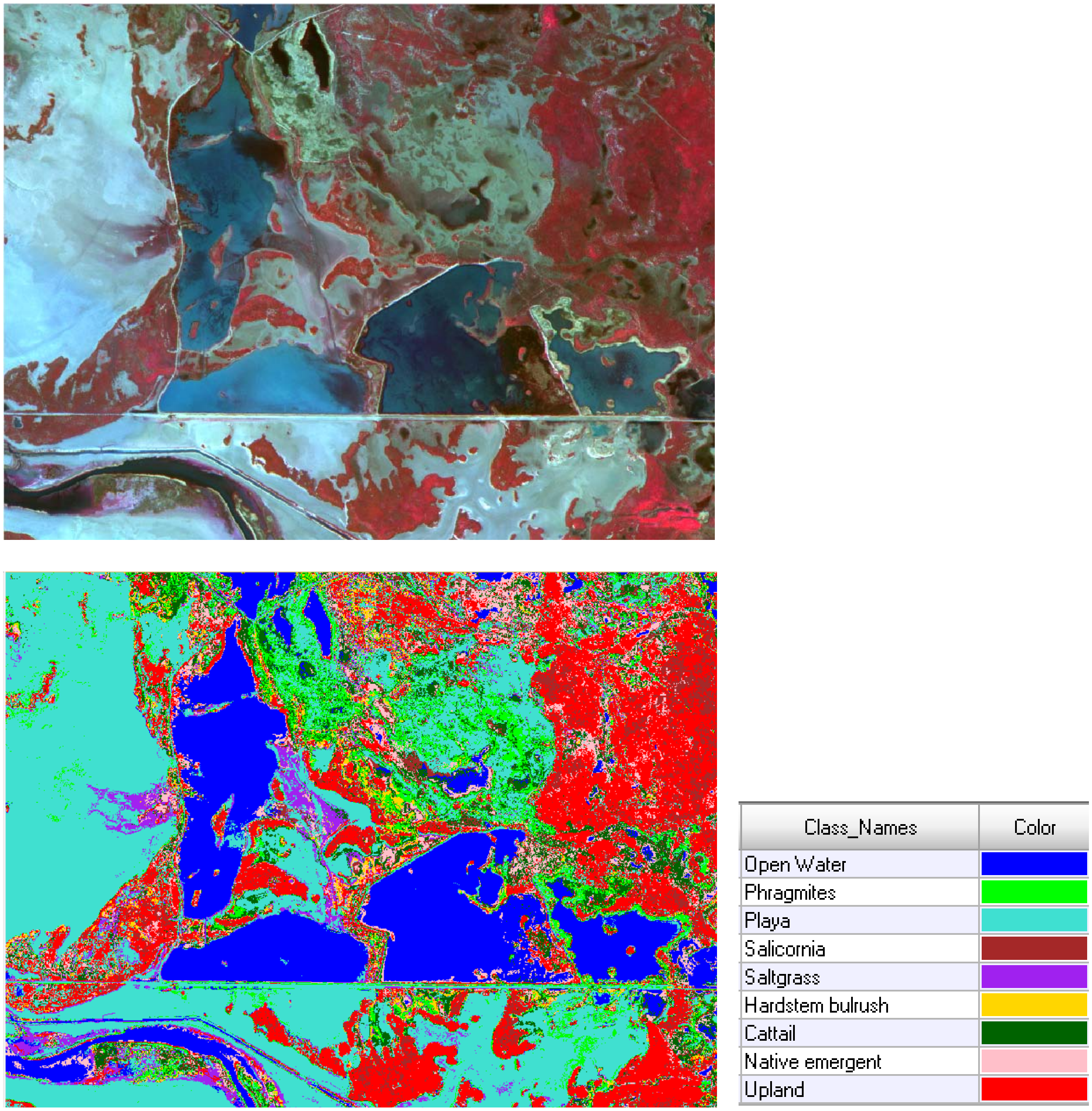


Figure 4. Multispectral image of Inland Sea Shorebird Reserve (top) and corresponding classified image (bottom).

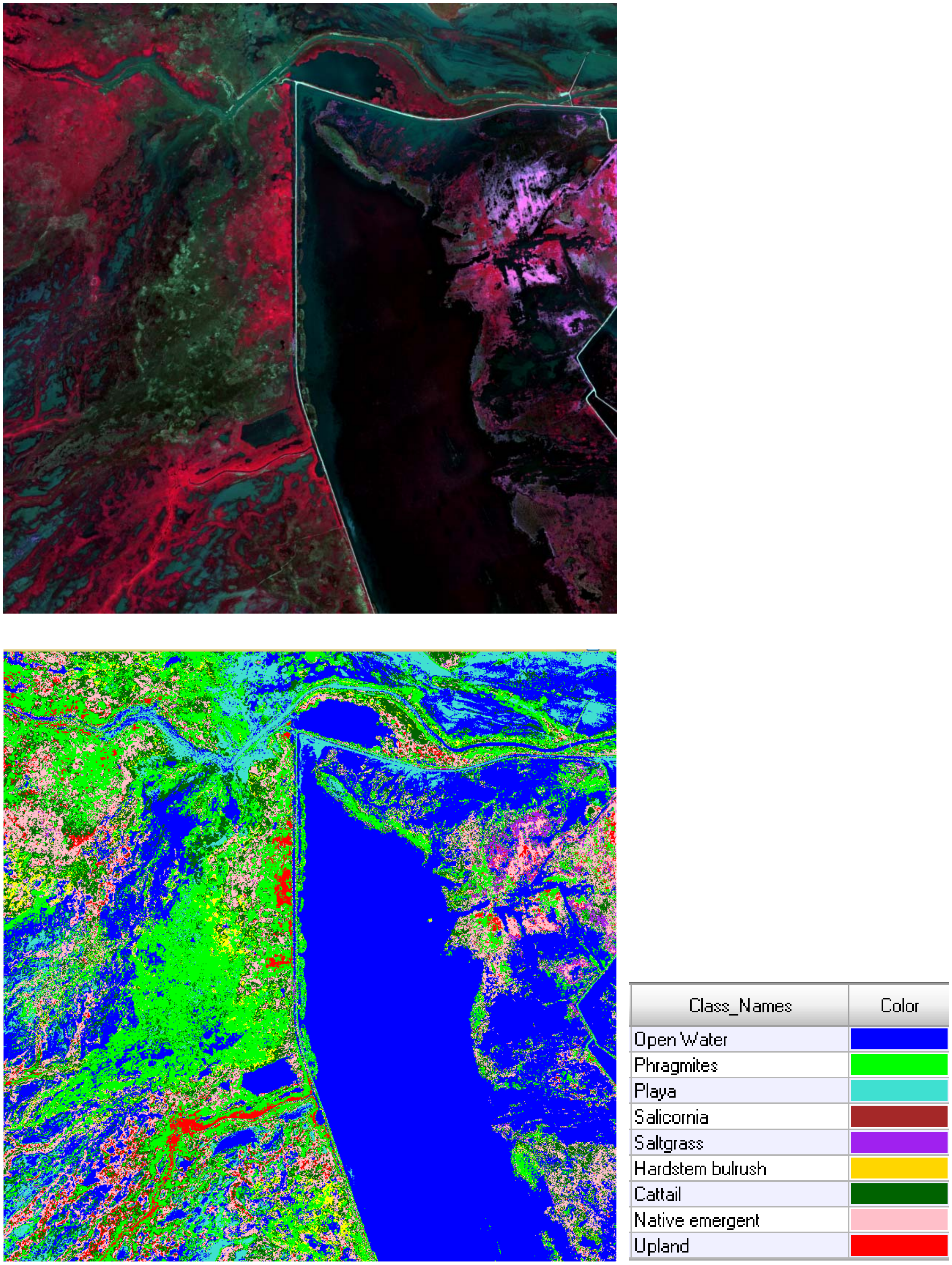
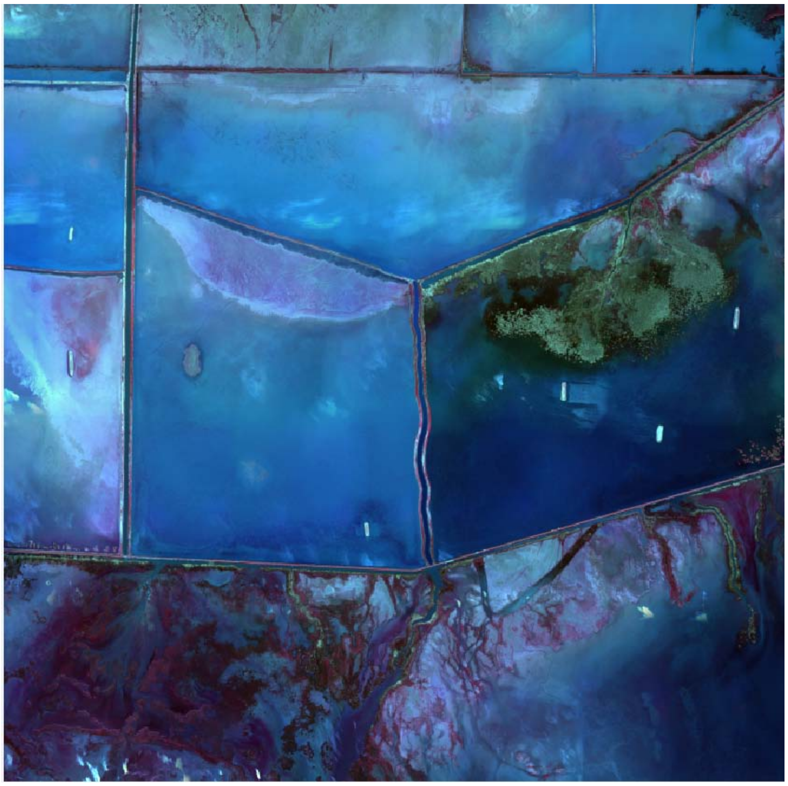


Figure 5. Multispectral image of Ogden Bay WMA (top) and corresponding classified image (bottom).



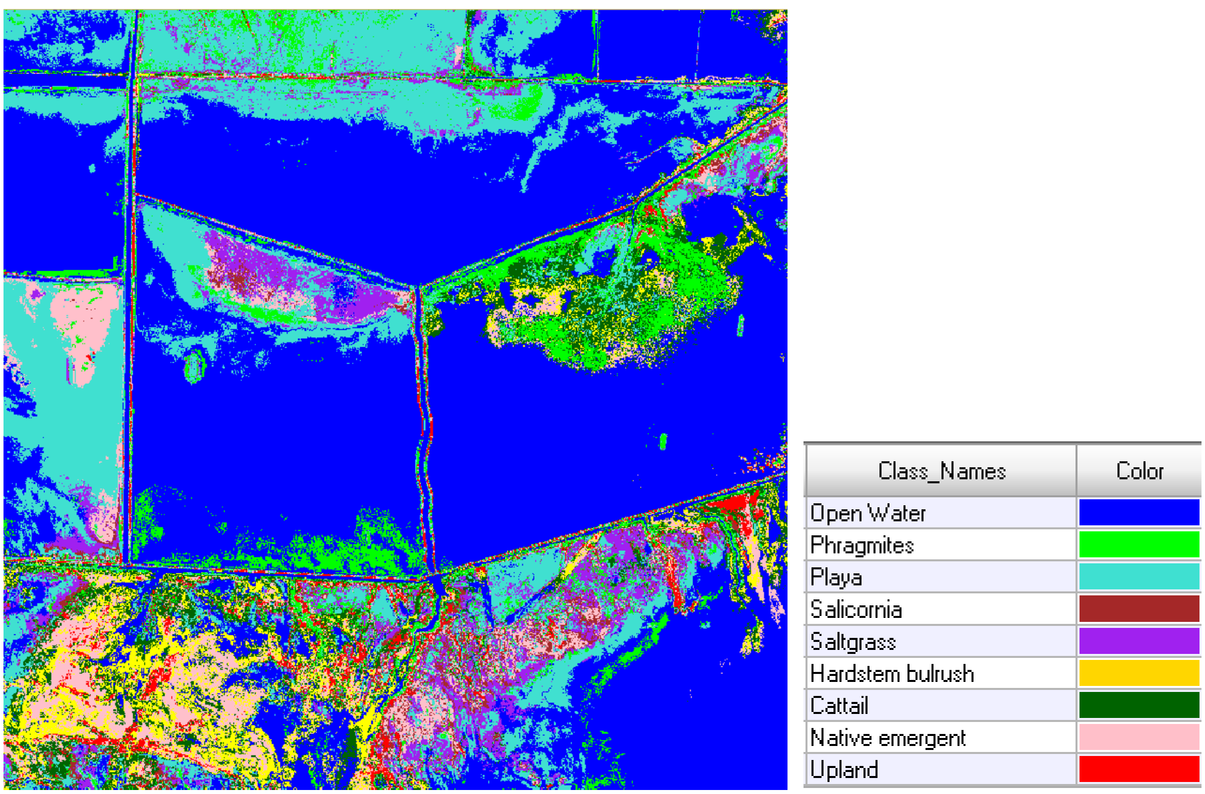


Figure 6. Multispectral image of Bear River Migratory Bird Refuge (top) and corresponding classified image (bottom).

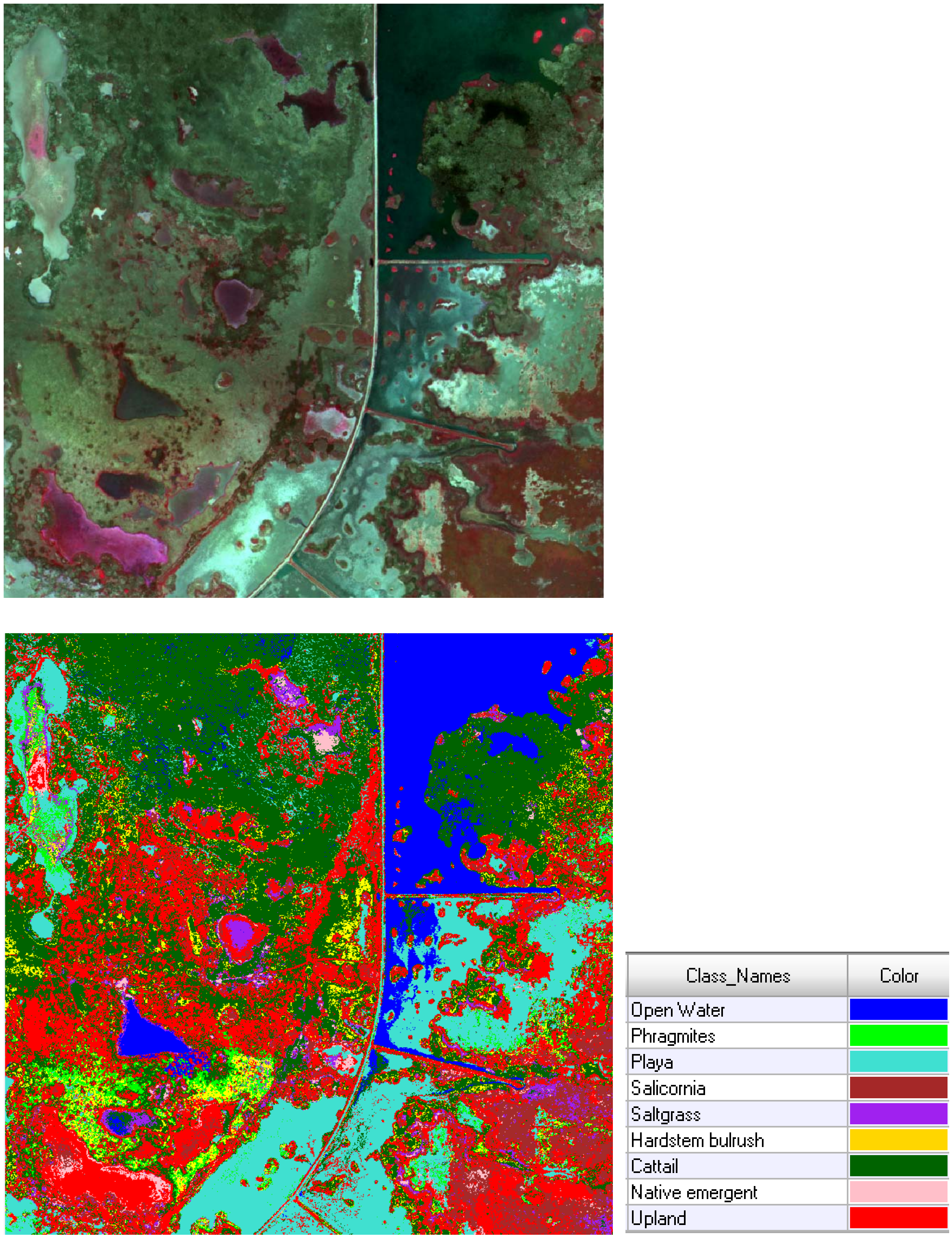


Figure 7. Multispectral image of Salt Creek WMA (top) and corresponding classified image (bottom).

Table 1. The areas in acres that each vegetation class was found to occupy in the classified imagery.

Class	Class name	Area (acres)
1	Open water	132,054.34
3	Playa wetland	71,638.48
9	Upland	48,309.56
8	Native emergent wetland	30,607.45
7	*Typha* spp. (cattails)	25,674.21
2	*Phragmites australis* (common reed)	22,375.88
5	*Distichlis spicata* (saltgrass)	13,574.79
4	*Salicornia europeae var. rubra* (pickleweed) wetlands	9,586.03
6	*Schoenoplectus acutus* (hardstem bulrush)	6,529.28

Photo by: K. Kettenring

Final report to UDNR FFSL, Part II

Phragmites invasion and control in the Great Salt Lake watershed: 2012 land manager survey

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Executive summary

We surveyed land managers in the Great Salt Lake (GSL) watershed to look at the timing of *Phragmites* invasion, factors potentially contributing to its invasion, current *Phragmites* management practices, and how *Phragmites* management may conflict with other land management activities. Key findings of our survey from 42 respondents are:

Timing, initial causes, and current extent of invasion

- Receding water lines within the GSL watershed was cited as the main event that allowed for the establishment of *Phragmites*. In addition, 88% of respondents felt that their management activities initially contributed to the spread of *Phragmites* on their property.
- GSL other managers (all managers except duck clubs) had the most total acres of *Phragmites* on their land (51,652 acres), followed by Utah Lake (15,130), GSL duck clubs (2,380), and Bear Lake (1,225) (**Figure 5**). The average percent of managed land (includes all uplands, wetlands, and open water) containing *Phragmites* was much lower for Bear Lake (1%) than the GSL (11%) or Utah Lake (5%).

Current Phragmites *management practices*

- A lower percentage of land managers surveyed currently manage *Phragmites* at Bear Lake than the other areas (67% vs. 92% for GSL duck clubs, 94% for the GSL other managers, and 86% for Utah Lake).
- GSL duck clubs were the first to control *Phragmites,* and on average began control efforts nearly 10 years before the rest of the land managers on the GSL.
- The top four treatments that managers use to control *Phragmites* are: herbicide (97% of respondents), burning (65%), livestock grazing (49%), and mowing (43%). All 24 respondents who burn also use herbicide. More land managers apply herbicide in the fall (28) than summer (20). The most common sequence of treatments is fall spray followed by a late winter/early spring burn (28% of respondents).
- Respondents stressed the importance of *Phragmites* biomass removal (either by burning, mowing, or grazing) to increase the effectiveness of herbicide.
- Numerous respondents suggested that grazing is a cost-effective method of *Phragmites* management in areas that can be dried out enough to allow for it.
- A total of 11 respondents seeded or planted target species after invasive *Phragmites* control. For land managers who do not seed, 86% "did not think it was necessary."

Challenges affecting current management practices

- *Phragmites* management often conflicts with other management objectives; in particular the personnel / time and costs associated with herbicide application were cited as the biggest challenges to balancing *Phragmites* control with other land management.

- Weather and air quality permitting were the greatest limitations to using burning for *Phragmites* control. Water levels and *Phragmites* density most often restricted grazing as a control method while water levels, weather, and personnel availability most often restricted mowing activities.

It is our hope that these research findings, along with our on-going *Phragmites* treatment experiments, will aid in the development of a comprehensive *Phragmites* management strategy for our region.

Background

This survey targeted wetland managers across public and private lands in the Great Salt Lake (GSL) watershed who have invasive *Phragmites* on their land, and are either currently working to control *Phragmites* as a part of their management strategy, or plan to do so in the future. The objectives of our survey were to:

1. Gain insight into the potential causes and timing of initial *Phragmites* invasion in the GSL watershed.
2. Assess how land managers have dealt with *Phragmites*, what their broad goals and specific objectives are for *Phragmites* control, and outline their most successful methods of control.
3. Determine the trade-offs between different *Phragmites* control treatments and what factors may limit control success.
4. Determine what potential conflicts might occur between *Phragmites* control efforts and other management objectives / activities.
5. Aid in the development of a comprehensive *Phragmites* management strategy for our region, including decision-making frameworks and monitoring protocols for land managers.

Survey methodology

Considering the goals of the survey, we tried to obtain responses from as many land managers as possible who had invasive *Phragmites* on their land. We targeted government, private duck club, and private non-profit land managers, and excluded private homeowners from our survey. All land managers for whom we were able to obtain contact information were contacted via phone, email, or both over a four month period (February - May 2012). In accordance with standard survey protocol, respondents were contacted more than once if necessary to increase response rate (Dillman *2000*). The overall survey response rate was 78% (42 out of 54 land managers contacted).

Throughout the summary, questions answered by all respondents have a sample size of N=42. For conditional questions, we denote how the sample size was adjusted based on how many respondents answered the question.

Results

Overview of management areas and presence of Phragmites

The majority of respondents manage land on the shoreline of the three major bodies of water within the GSL watershed – the GSL (29 respondents, one includes the Jordan River, which flows from Utah Lake into the GSL), Utah Lake (7), and Bear Lake (6), for a total of 42 surveys (**Figure 1**). Approximately 1/3 of surveys were from private duck clubs on the GSL representing a total of 18 individual duck clubs as some managers oversee more than one duck club. There are no duck clubs on Bear Lake or Utah Lake. Overall, more than half of all respondents (22) were from either state or federal agencies (**Figure 2**). Three respondents chose two or three organization types, the rest chose a single organization type.

The survey provided general information about the size and habitat type of managed areas. Most respondents characterized their wetlands as a mix of open water, emergent wetland, riparian area, seasonally flooded flat/playa, moist soil management area, and grassland / shrubland. Sixty percent of respondents (25) attempt to increase cover or density of particular plant species to manage for certain habitats and/or land uses (N=42). Across all major wetland habitat types, the species most widely managed for are: sago pondweed (*Stuckenia* pectinata; 68%), alkali bulrush (*Schoenoplectus/Scirpus maritimus*; 68%), saltgrass (*Distichlis spicata*; 60%), pickleweed (*Salicornia* spp.), native grasses (56%), and willows (*Salix* spp.; 56%) (N=25).

Acres of land under management jurisdiction ranged from 21 acres to ~1.4 million acres, with a median area of ~3,095 acres (N=40; **Figure 3**). Eighteen respondents (45%) had 2,500 acres or less and six respondents (15%) had 500 acres or less (**Figure 4**). Three respondents had acreage well over 100,000 acres – one at 250,000, and two at over a million (1.2 and 1.4 million acres). Twenty one respondents (54%) actively managed 100% of their acreage, with respondents managing a mean of 74% of their land (N=39).

The top current objectives for land managers are waterfowl habitat or production (81%), non-waterfowl *wetland* habitat (62%), non-waterfowl *upland* habitat (60%), livestock grazing (55%) and public wildlife viewing/education (43%) (N=42) (**Table 1**). Eleven respondents also specifically mentioned recreation and/or hunting in the “other” category. The relative ranking of historic objectives was similar to current although the overall percentages for current objectives were higher (more respondents filled out a current objective) (**Table 1**). Not surprisingly, there was a difference between historic and current objectives for nine respondents (21%). The shift involved livestock grazing for five out of those nine. Three respondents (33.3%, N=9) who *did not* historically manage for livestock grazing currently do. Two respondents (22.2%) who *did* historically manage for livestock grazing currently do not. The remaining respondents (3) historically managed for livestock grazing and one or two other objectives and currently expanded their objectives to include two to four additional objectives. Interestingly, three respondents also began managing for public wildlife viewing/education in the last 5 years.

In terms of total acres, GSL other managers had the most total acres of *Phragmites* (51,652 acres), followed by Utah Lake (15,130), GSL duck clubs (2,380), and Bear Lake (1,225) (**Figure 5**). Overall, the mean area of invasive *Phragmites* per land manager was 1,759 acres (median 125 acres). The largest area of *Phragmites* for a single respondent was 30,800 acres (out of 1,374,467). To put the total acres of *Phragmites* into perspective, at ~4,400 km^2 the GSL is more than 10 times the size of Bear Lake or Utah Lake, which explains why the majority of acres of *Phragmites* were reported for this area (even after accounting for the greater number of

GSL respondents). It is interesting to note that while Bear Lake is approximately ¾ the size of Utah Lake (~280 km^2 versus ~380 km^2), Bear Lake managers reported less than $1/10^{th}$ the amount of *Phragmites* of Utah Lake managers. The amount of *Phragmites* in Utah Lake is roughly proportional to its size relative to the GSL.

For the majority of respondents (76%, N=38), *Phragmites* comprised between 1 and 10% of total land area on their property (**Figure 6**). The highest percentage of *Phragmites* was 46% (150 out of 325 acres) and the minimum percentage was 0.03% *Phragmites* (1 out of 3000 acres), for a mean of 8% (median 4%) of total acres (**Figure 5**). Duck clubs reported almost twice as much *Phragmites* (14% of land managed) as the rest of the GSL managers on a percentage basis (8%) (**Figure 7**). This finding might be attributed to the fact that duck club managers can give more accurate estimates on their smaller parcels of land rather than necessarily having a higher percentage of *Phragmites*. At the other extreme, the percent of managed land (uplands, wetlands, and open water) containing *Phragmites* was about 1% for Bear Lake land managers.

It is important to note that not all *Phragmites* is invasive – native *Phragmites* is also present in the GSL watershed (Kulmatiski et al. *2011*, Kettenring and Mock *2012*). Forty-four percent of respondents (17) stated that they personally knew how to differentiate native vs. invasive (non-native) *Phragmites* (N=39). Sixteen respondents (41%) claim to have native *Phragmites* on their property, nine (23%) do not, and fourteen (36%) are not sure (N=39). Of those with native *Phragmites*, five manage to *decrease* its cover or density while the rest *do not* attempt to change its cover or density (and no one manages specifically to *increase* native *Phragmites*). More than half of respondents (51%) consider native *Phragmites* beneficial habitat for wildlife (N=37). Interestingly, two respondents manage to decrease native *Phragmites* even though they consider it beneficial habitat.

Timing and cause of invasion

For Bear Lake, the timing of *Phragmites* first detection ranged from 1996-2012. For Utah Lake, one respondent said 1980s, another said 1998. For the GSL, more than half of the respondents (16 out of 29) specifically cited the GSL flood of the mid-1980s/early 1990s and four more wrote a date corresponding to the flood (whether they mentioned it directly or not). Similarly, 23 out of 33 respondents said that the arrival of *Phragmites* on their property appeared to coincide with abnormal weather or events. Seven respondents (22%) had aerial imagery or other documentation showing when *Phragmites* was first detected on their property (N=34).

Even though flooding or drought seemed to be a contributing factor in allowing invasive *Phragmites* to establish, 88% of respondents also thought that their management activities (water management, vegetation management, or both) contributed to the introduction or spread of invasive *Phragmites* on their property (N=32) (Figure 8). At the time of detection, most respondents were managing their land for both waterfowl habitat or production (82%) and non-waterfowl wetland/upland habitat (50%) (choices were not mutually exclusive, N=28).

Historic and current control of Phragmites

GSL duck clubs were the first land manager group to control *Phragmites*, and on average began control efforts nearly 10 years before the rest of the land managers on the GSL (**Figure 9**). The more recent invasion of *Phragmites* at Bear Lake could explain why a smaller percentage of land managers are controlling invasive *Phragmites* at Bear Lake. Alternatively, there may be less control occurring because there is less *Phragmites* or because there was a bias in our survey respondents since we did not target private land owners, who may own significant amounts of land with *Phragmites.*

Eighty-eight percent of respondents (37) currently control *Phragmites*. Of those, the top four treatments are: herbicide (97%), burning (65%), livestock grazing (49%) and mowing (43%) (**Figure 10**). Overall, current methods of *Phragmites* control have remained relatively proportional to historic, the exception being a drop in the use of discing from 6 to 2 respondents (**Figure 10**). Of the 36 who currently use herbicides, 30 provided additional information about type of herbicide and application rates. Twenty-nine of them use glyphosate, seven use imazaypyr, one used Quest (an ammonium fertilizer), and 18 also use surfactant. Six of the seven people using imazapyr also used glyphosate.

The most common times for land managers to apply herbicide are fall (28) or summer (20), while burning tends to be done in the spring (20) or fall (9) (**Figure 11**). Mowing appears to largely occur in the summer and fall. Some control methods such as grazing and flooding are largely carried out year round. The spikes in herbicide application and burning in **Figure 11** coincide with the burn and spray (or spray and burn) sequence of treatments used by a large number of land managers.

A majority of respondents (66%) referred to a specific sequence of treatments to control *Phragmites* within the last 5 years (N=38). The most common sequence of treatments is fall spray followed by a late winter / early spring burn (28%). Three respondents (8%) reported using a spring burn followed with a summer spray. Eight respondents (21%) cited spraying in the summer, followed by burn in fall or trample winter (3), a burn in spring (2), flood winter/spring (1), or summer mow (1). Overall, some combination of burning and spraying was mentioned by 20 respondents (53%). All GSL duck clubs use herbicide except for one, which has yet to begin any *Phragmites* treatment.

There is also a direct correlation between the number of control methods used and the amount of *Phragmites* by management area. Bear Lake managers, dealing with ~1% *Phragmites*, use an average of 1.4 control methods. GSL duck club managers, with the largest percentage of *Phragmites* (14%), average 4.4 control methods. This does not mean that managers are using four treatments across all acres (different areas are better suited to certain treatments) but it does show that GSL duck clubs have the most diverse and/or intense management schedules. Six of the seven respondents using only one control method used herbicide (other was mowing). All 24 respondents who used burning also used herbicide (i.e. burning was never used alone). One manager reported the use of seven current control methods and three use six methods (combinations unknown). The average across all managers was 3.3 control methods.

Respondents stressed the importance of burning dead *Phragmites* to remove the previous year's biomass to increase the effectiveness of subsequent herbicide treatments. Grazing and mowing also reduce biomass to allow for more effective spraying. In addition to being the most cost effective, respondents noted that grazing has the advantage of removing seeds before pollination, reducing spread through rhizomes, speeding decomposition, and allowing other species to come in. Mowing and flooding can also stunt growth to prevent seed development.

In terms of broad goals for *Phragmites* control in the last 5 years, 61% of respondents (23) would like to stop the expansion of *Phragmites*, 45% (17) would like to eradicate it, and 37% (14) would like to reduce it to a certain size or percentage. For specific objectives, 58% have a goal in terms of acres or percentage of *Phragmites*/land. Eight respondents would like to treat 100% of their *Phragmites*, and four of these respondents are from duck clubs. Those treating 100% of their *Phragmites* have between 1 and 700 acres of *Phragmites* (mean=149 acres). On average, respondents would like to treat about 78% of their existing *Phragmites* on a yearly basis.

Twenty-one respondents provided estimates for herbicide costs and there was no obvious relationship between acres of *Phragmites* and costs. Estimates for materials ranged from $2 per acre to $855 per acre. Labor estimates were similarly wide ranging – from $12 per acre to $2,000 per acre. Estimates for duck clubs and state/federal agencies are relatively comparable ($7 to $75 per acre for materials and $12-$75 per acre for labor).

Management conflicts

The survey addressed two types of conflicts – when efforts to control invasive *Phragmites* conflicted with other management objectives (**Figure 12**) and the various factors that can affect four major *Phragmites* control methods (mowing, livestock grazing, burning, and flooding) (**Table 2**). For *Phragmites* control conflicting with other management objectives, respondents cited budget conflict for herbicide more than any other control method (12 respondents versus 4 for grazing and mowing), reflecting the budget strain of expensive aerial application or necessary personnel time required for ground application. Grazing on the other hand either has little to no cost or generates income (according to 10 respondents) so does not negatively influence budget (**Figure 12**). Equipment and personnel/time are the factors that affect grazing most frequently.

Phragmites manager survey

For factors affecting individual *Phragmites* control methods, weather and air quality/permitting were cited as major factors affecting burning for 20 respondents (**Table 2**). Although GSL duck clubs have a greater ability to acquire a burn permit than federal or state agencies (personal communication), there was no difference in survey results concerning permits between these two groups. One respondent said bird nesting affected their ability to burn. Burning can also negatively affect hunting as one respondent pointed out: the sharp burnt stems that remain damage the paws of hunting dogs. The main factors limiting livestock grazing were water levels (8) and density of *Phragmites* (7). Water levels also affected mowing (10) as well as weather (10) and personnel availability (9). This supports our personal communications with land managers over concern about having the right type of mower for deep water conditions and the time it takes to mow *Phragmites* (it can take an entire day just to clear 2 acres). Timing of water rights (5) and the ability to flood (4) most negatively affect the use of flooding to control *Phragmites* (**Table 2**).

Restoration efforts

Eleven respondents (30%) have seeded or planted after *Phragmites* control (N=37). Among these respondents, six harvested on site, six purchased from a nursery, and one obtained seeds from the Utah Division of Wildlife Resources (choices were not mutually exclusive). The different types of managers that seeded were GSL duck clubs (33% of respondents), 5 GSL other managers, and 2 Utah Lake managers. No one reseeded at Bear Lake. The top reason for not reseeding across the watershed was because the respondent "did not think it was necessary" (86% of respondents, N=22), followed by too costly to pay personnel (27%), and too costly to acquire seeds/plants (32%). Another 32% of respondents chose "other" and cited more specific reasons, such as "fluctuating lake level", "money and time", "wanted unvegetated mudflats", "seed source available on site already", or "proved ineffective with huge native dormant seed bank available".

Following *Phragmites* control, 100% (N=39) of managers prefer either a particular native species or *any* native species to take its place and aim to avoid the establishment of non-native plants and any other invasive plant. Greater than 50% of respondents selected alkali bulrush, hardstem bulrush, common threesquare, and/or salt grass as their preferred species to replace *Phragmites* (**Table 3**). The most common plants that managers aim to avoid coming back after *Phragmites* control are non-native thistles, poison hemlock, any invasive or non-native plant, non-native cattail, and hybrid cattail (**Figure 13**).

Acknowledgements

We are grateful to the many land managers who graciously donated their time to fill out our lengthy survey.

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Kettenring KM, Mock KE (2012) Genetic diversity, reproductive mode, and dispersal differ between the cryptic invader, *Phragmites australis*, and its native conspecific. Biological Invasions:*In press*

Kulmatiski A, Beard KH, Meyerson LA, Gibson JR, Mock KE (2011) Nonnative *Phragmites australis* invasion into Utah wetlands. Western North American Naturalist 70:541-552

Figures and Tables.

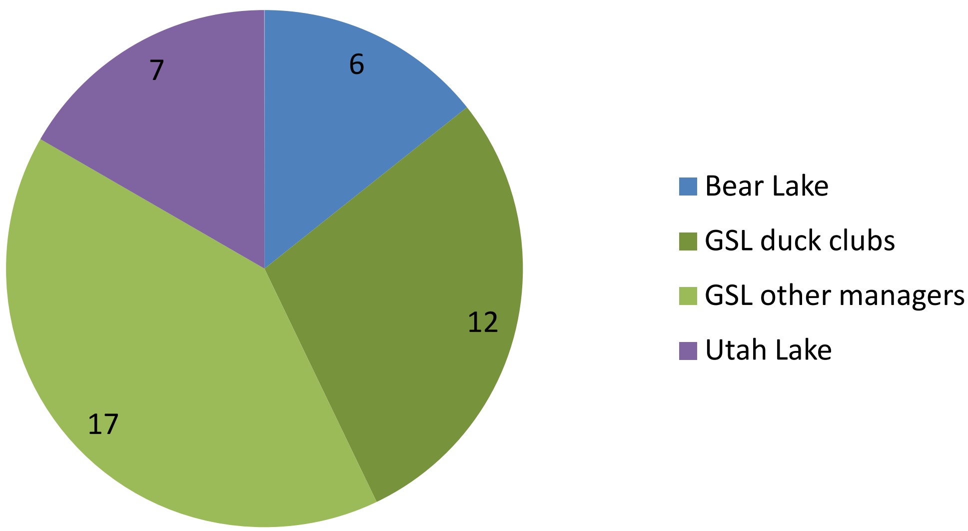

Figure 1. Survey respondents categorized by management area, N=42.

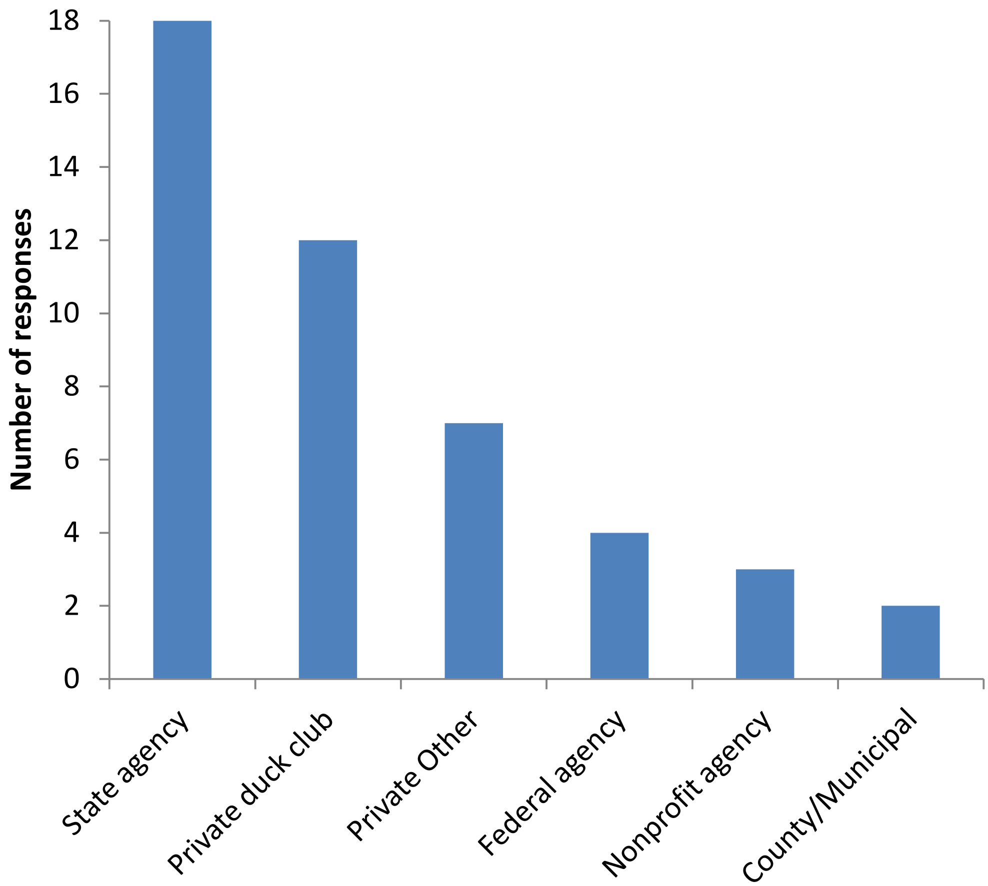

Figure 2. Type of organization that respondents belong to (choices not mutually exclusive, N=42).

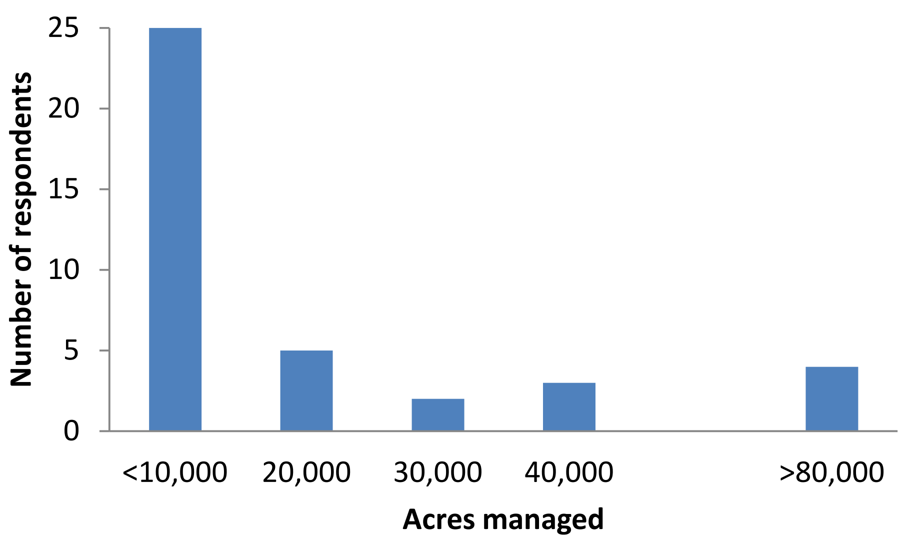

Figure 3. Frequency distribution of all respondents for acres managed in increments of 10,000 acres (N=40).

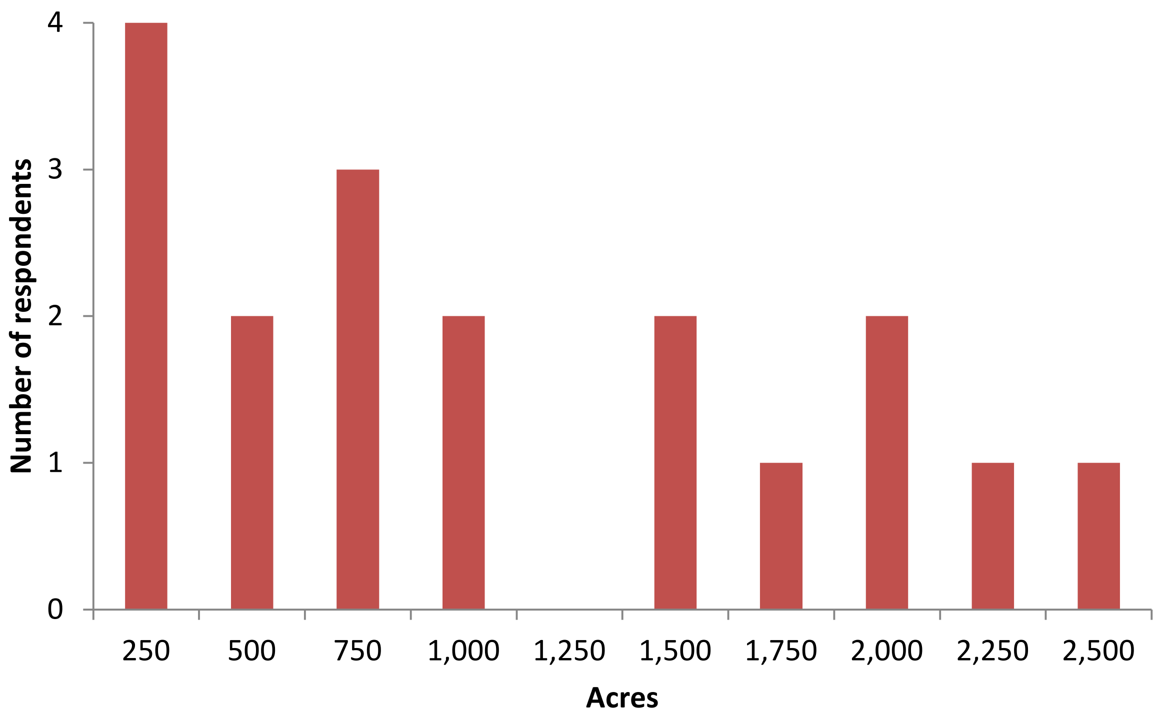

Figure 4. Frequency distribution for respondents with 2,500 acres or less (N=18).

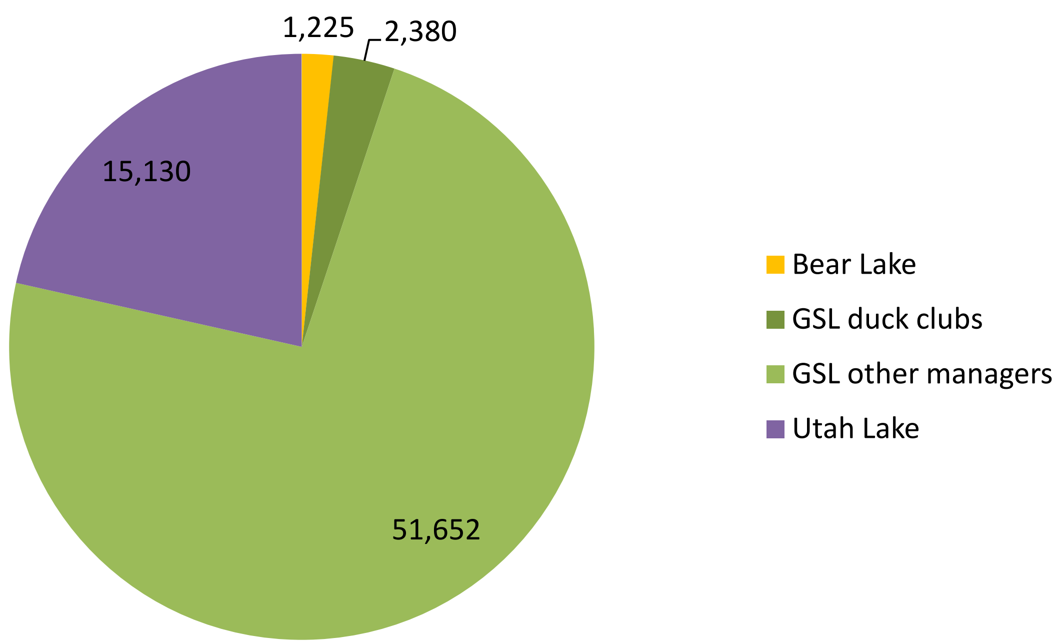

Figure 5. Total acres of *Phragmites* reported by respondents (N=40); we only surveyed managers who have *Phragmites* on their property. Total for all managers = 70,387 acres.

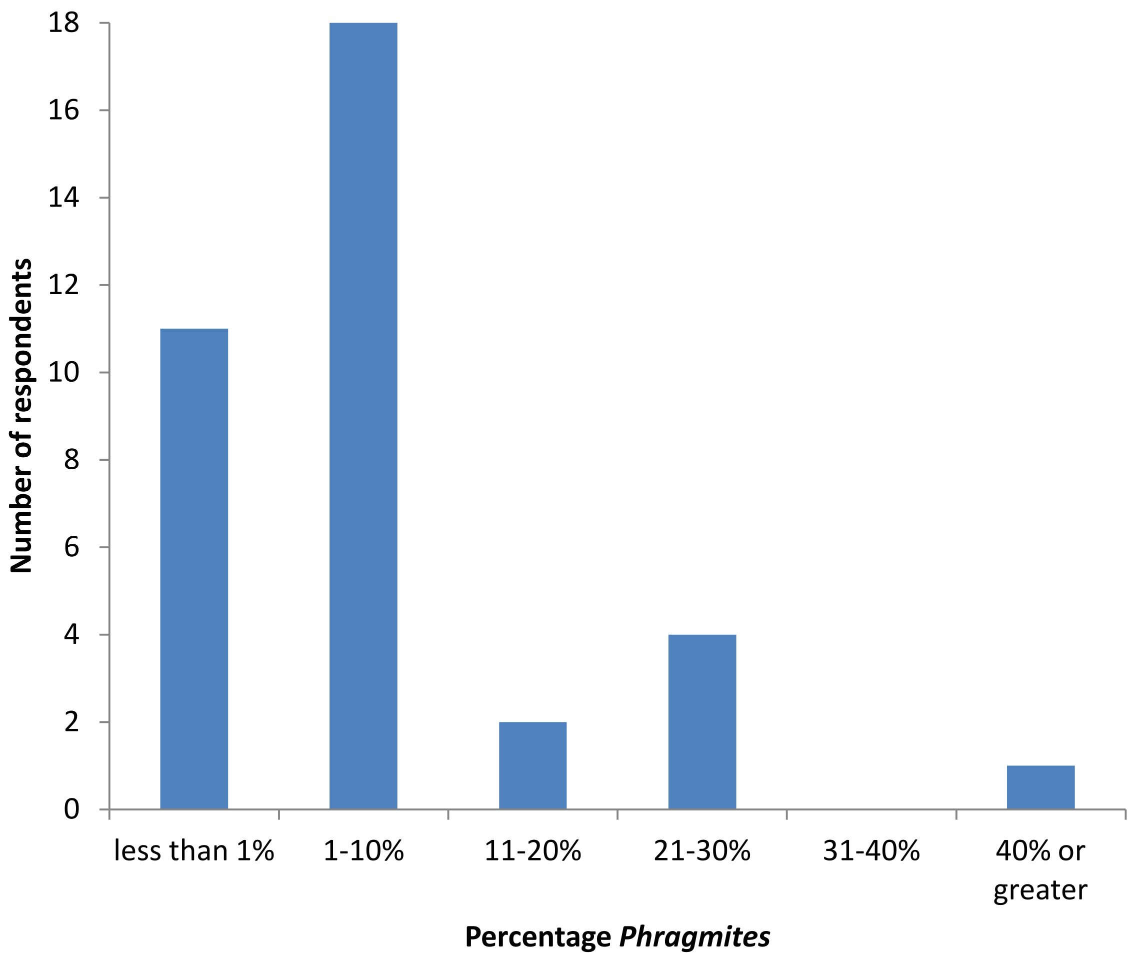

Figure 6. Average percentage of managed land containing invasive *Phragmites* per land manager (out of total acres managed, which includes upland and open water areas). (N=38)

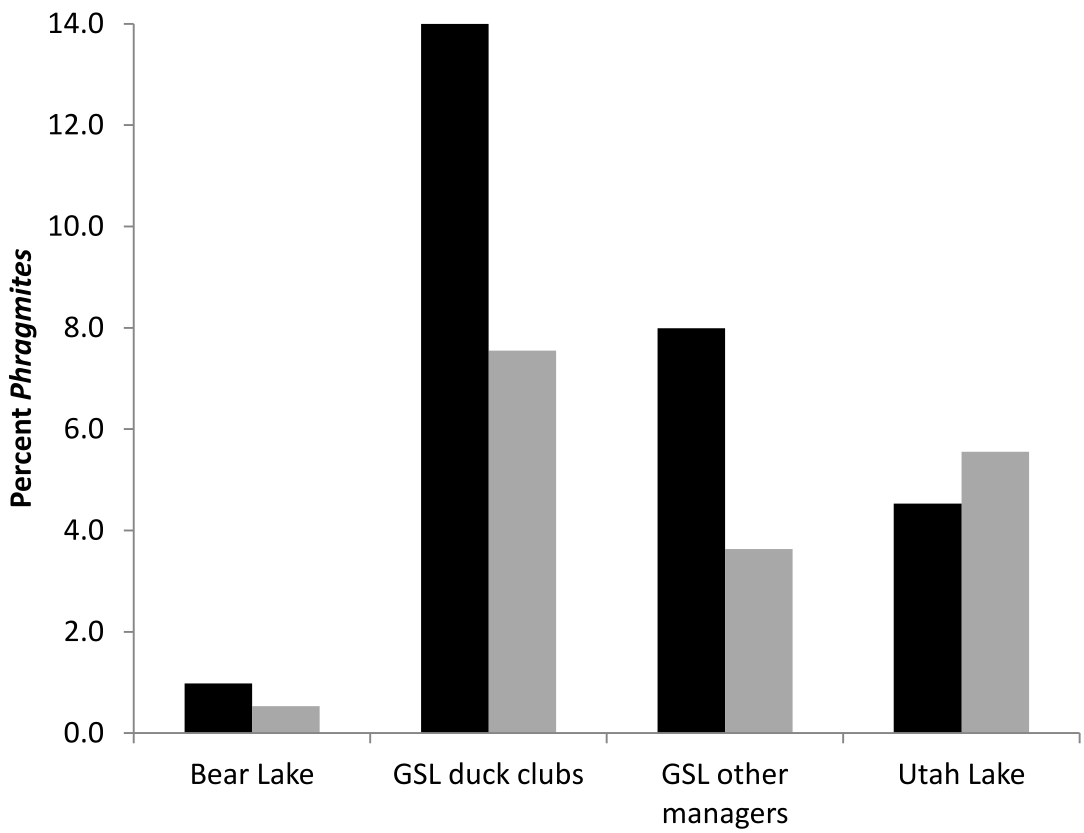

Figure 7. Reported percent *Phragmites* by management area. Black bars represent mean, gray bars represent median percent *Phragmites*. Bear Lake N=6, GSL duck clubs N=12, GSL other managers N=17, and Utah Lake N=7.

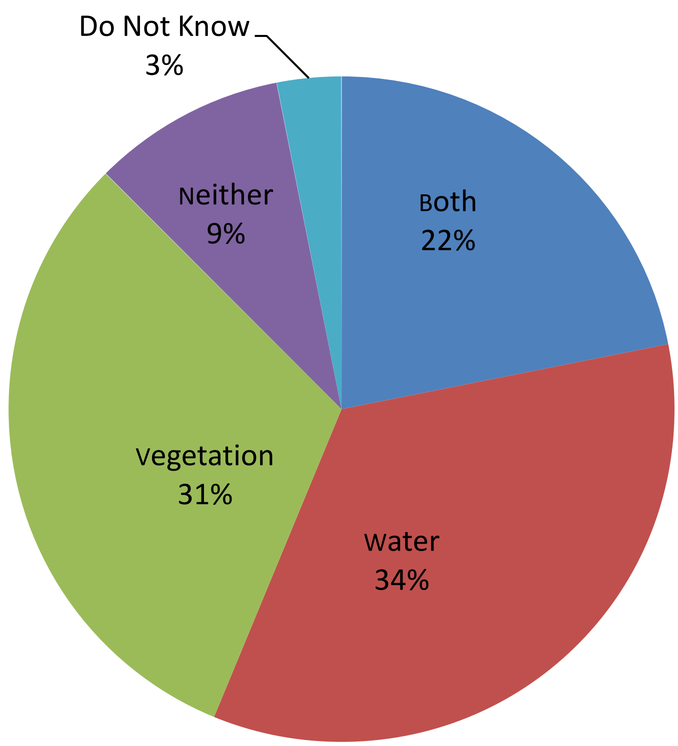

Figure 8. Percentage of respondents reporting that vegetation or water management activities may have contributed to the introduction or spread of invasive *Phragmites* on their property. (N=32)

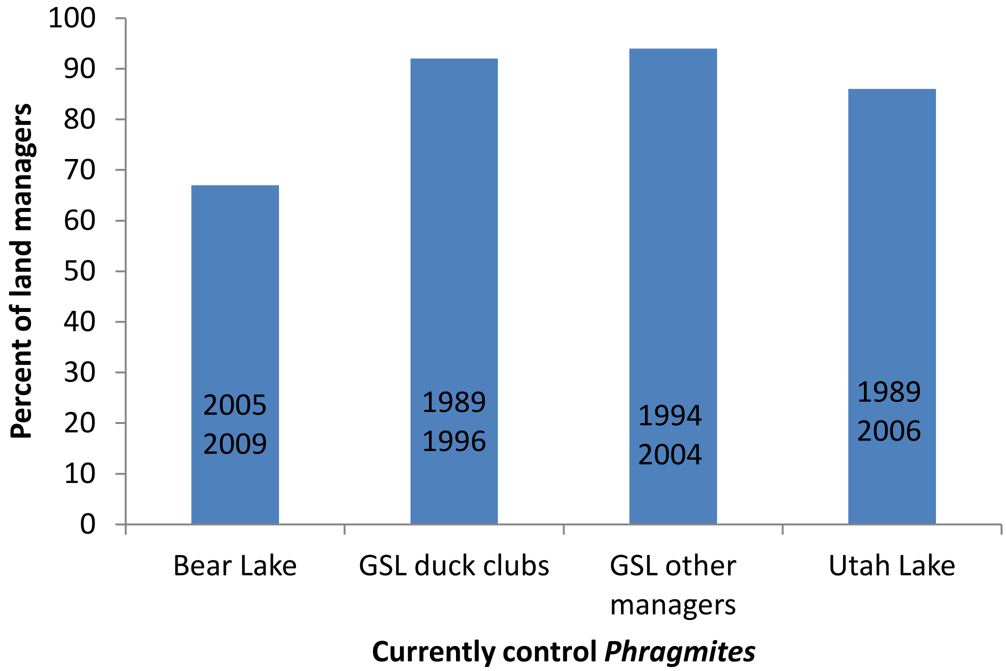

Figure 9. Percentage of land managers by area type that currently control *Phragmites*. Numbers at the base of bars represent the average year that managers detected *Phragmites* (top) and began *Phragmites* control (bottom). Bear Lake N=6, GSL duck clubs N=12, GSL other managers N=17, Utah Lake N=7.

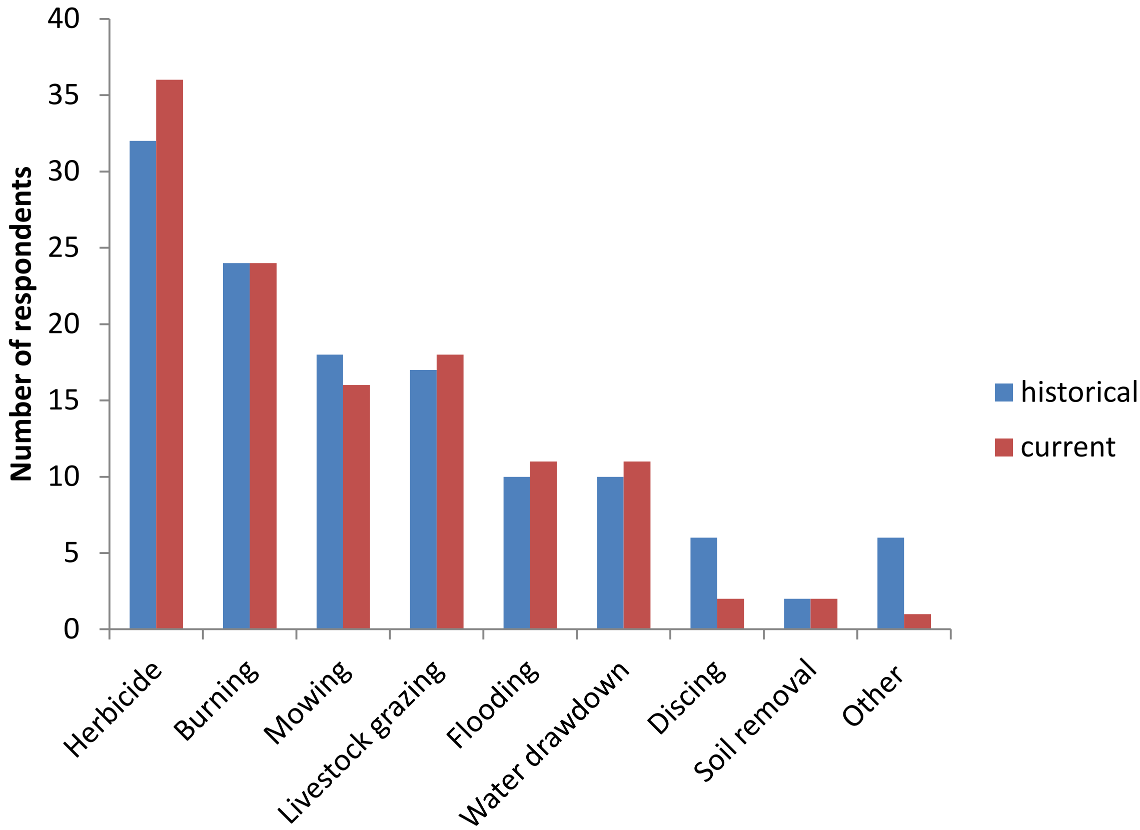

Figure 10. Historical versus current control methods. Other includes “increasing salts in some areas” and ”maintaining high water levels during growing season” (one respondent each; remaining did not specify).

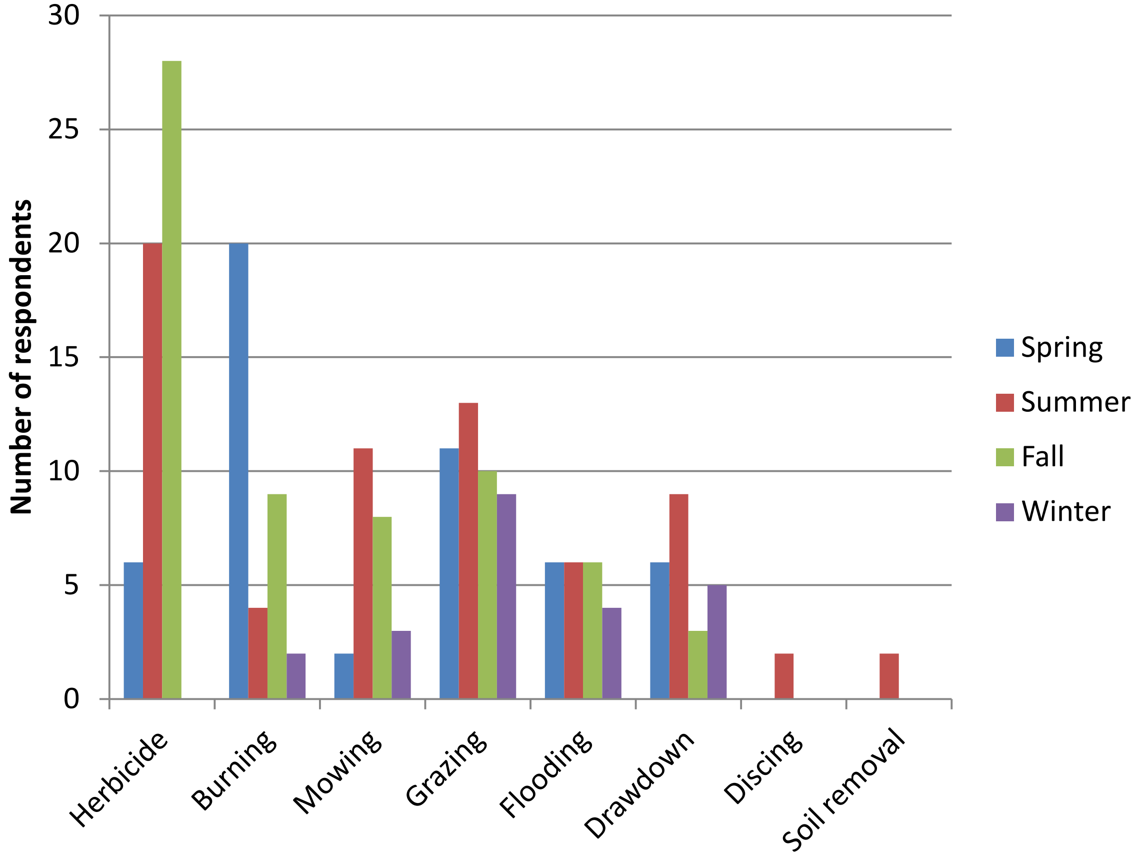

Figure 11. Seasonal timing of control methods. No managers reported livestock grazing at Bear Lake or flooding at Utah Lake.

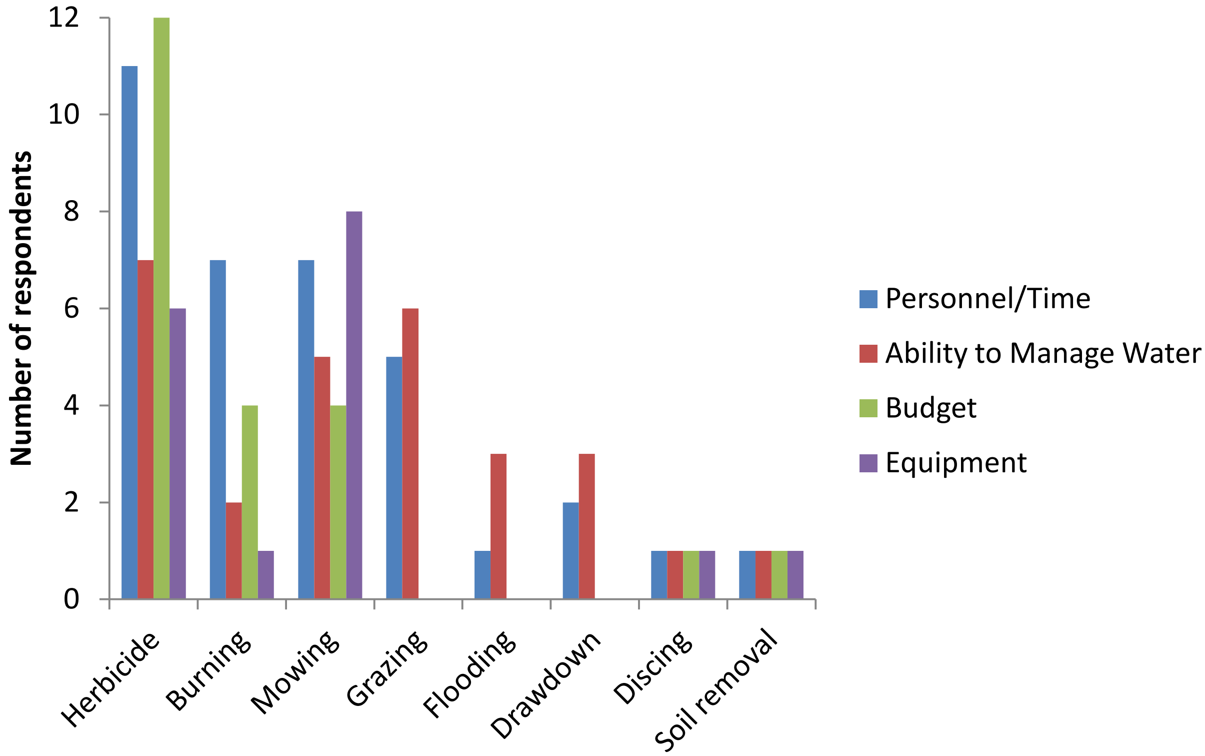

Figure 12. Conflicts of different potential *Phragmites* control methods with other management objectives.

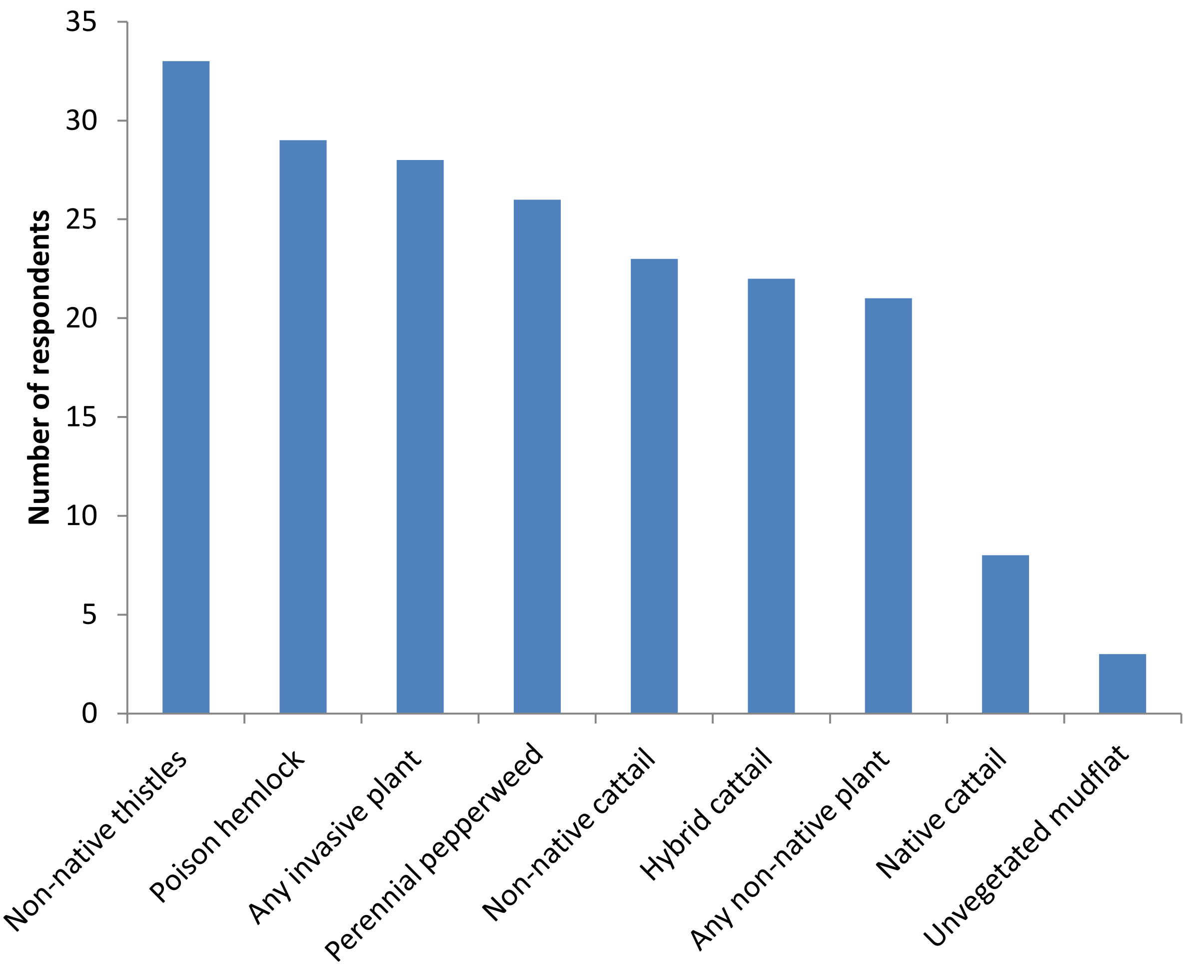

Figure 13. Species, vegetation type, and habitat type land managers aim to *avoid* coming back after invasive *Phragmites* control.

Tables

Table 1. Historic and current management objectives and ranking. Numbers represent percentage of respondents (N=18).

Management objective	A. Historical (>5 years ago)	B. Current (within last 5 years including 2012)	Individually rate your current objectives selected in column B (1=lowest priority, 5=highest priority)				
			1	2	3	4	5
Waterfowl habitat or production	59.5	81.0	9.5	2.4	9.5	4.8	52.4
Non-waterfowl **wetland** habitat	47.6	59.5	2.4	4.8	14.3	19.0	21.4
Non-waterfowl **upland** habitat	45.2	61.9	0.0	9.5	28.6	21.4	14.3
Row crops	16.7	28.6	21.4	7.1	4.8	2.4	2.4
Food plots for wildlife	23.8	35.7	11.9	11.9	9.5	9.5	2.4
Livestock grazing	45.2	54.8	19.0	9.5	7.1	9.5	9.5
Fish production	11.9	21.4	11.9	4.8	4.8	4.8	4.8
Public wildlife viewing / education	23.8	42.9	2.4	9.5	19.0	9.5	11.9
Other, please specify:	28.6	35.7	4.8	2.4	2.4	7.1	19.0

Table 2. Factors affecting top four control methods (other than herbicide). (N=31)

Method	Factors affecting control method	Respondents
Burning	Weather	20
	Air quality permitting	20
	Personnel availability	12
	Ability to manage water	7
	Other: bird nesting (1), size and location of patches (1), hurts dogs paws (1), only use burning following chemical treatment (1)	4
	Other permitting: local fire jurisdiction approval (1), Forestry Fire and State Lands availability (1), did not specify (1)	3
	Budgets	2
Livestock grazing	When water levels were low	8
	The density of the *Phragmites* patch	7
	Weather	6
	The size of the *Phragmites* patch	5
	Other: containing cattle (2), bird nesting (1), livestock availability (1), high water (1)	5
	When we lacked funding for other control methods	4
	Early in the invasion process right after detection	4
	When *Phragmites* invaded historic grazing parcels	4
	Personnel availability	3
	Budgets	0
	In dry years when grazing land was not available elsewhere	0
Mowing	Weather	10
	When water levels were low	10
	Personnel availability	9
	The size of the *Phragmites* patch	7
	The density of the *Phragmites* patch	6
	Budgets	5
	When we lacked funding for other control methods	3
	Other: bird nesting (2), equipment large enough to cut *Phragmite*s (1)	3
	Early in the invasion process right after detection	2
Flooding	Timing of water right	5
	Other: ability to flood deep enough (2), pond configuration cannot flood (1)	4
	Weather	3
	When we had extra water	3
	Personnel availability	1
	When water was being used for other activities	1
	Budgets	0

Table 3. Species, vegetation type, and habitat type land managers would like to see *replace* invasive *Phragmites*.

	Frequency	Percentage
Alkali bulrush *(Schoenoplectus/Scirpus maritimus)*	28	**71.8**
Hardstem bulrush *(Schoenoplectus/Scirpus acutus)*	25	**64.1**
Common threesquare *(Schoenoplectus/Scirpus pungens, americanus, or olneyi)*	22	**56.4**
Native broadleaf cattail *(Typha latifolia)*	15	38.5
Non-native narrowleaf cattail *(Typha angustifolia)*	1	2.6
Hybrid cattail *(Typha x glauca)*	2	5.1
Rushes *(Juncus spp.)*	19	48.7
Spikerushes *(Eleocharis spp.)*	13	33.3
Sedges *(Carex spp.)*	15	38.5
Saltgrass *(Distichlis spicata)*	20	**51.3**
Pickleweed *(Salicornia spp.)*	17	43.6
Iodinebush *(Allenrolfea occidentalis)*	4	10.3
Beggarticks *(Bidens spp.)*	2	5.1
Millet *(Echinochloa spp.)*	8	20.5
Smartweeds *(Polygonum spp.)*	8	20.5
Dock *(Rumex spp.)*	7	17.9
Foxtail barley *(Hordeum jubatum)*	3	7.7
Houndstongue *(Hieracium cynoglossoides)*	1	2.6
Goosefoot *(Chenopodium spp.)*	4	10.3
Willows *(Salix spp.)*	16	41.0
Cottonwoods *(Populus spp.)*	13	33.3
Annual grasses	12	30.8
Any native plant	19	48.7
Any plant – native or nonnative - except *Phragmites*	2	5.1
No vegetation, just open water	12	30.8
No vegetation, just unvegetated mudflat	11	28.2
Other	6	15.4

Photo by: K. Kettenring

Final report to UDNR FFSL Part III

Control of *Phragmites australis* in Great Salt Lake wetlands

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Background

We began two *Phragmites* control experiments on the Great Salt Lake (GSL) this summer, in accordance with our 2011 proposal to UDNR FFSL. Our overall objective for these studies is to evaluate potential *Phragmites* control strategies in small patches and large stands for restoring wetlands in the GSL watershed.

The control studies are being conducted at two spatial scales – 0.25 acre treatment areas to evaluate techniques that may be effective for dealing with initial invasions of *Phragmites* and 3 acre treatment areas to evaluate techniques that may be more effective and logistically feasible for dealing with large, well-established stands of *Phragmites*. We describe the details of the studies in more detail below.

Methods

Small patch study (Masters student: Christine Rohal).

We have six sites where we are evaluating *Phragmites* control treatments that might be effective for initial *Phragmites* invasions (Inland Sea Shorebird Reserve, Ogden Bay WMA, Farmington Bay WMA, Bear River Migratory Bird Refuge, and TNC Shorelands Preserve – two areas)

At each site, we are applying the control treatments to each 0.25 acre *Phragmites* patch (1.25 acres total per site). The six treatments we are applying are:

(1) summer mow, then cover with heavy-duty black plastic;

(2) summer mulching 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 followed by winter mow; and

(6) untreated control.

Control techniques will be carried out for three years and we will monitor treatment effectiveness for at least 2 years following the cessation of control, if possible. This year, the summer treatments were carried out June 25-July 6. Pre-treatment data on cover of all live plants, litter, and open water; stem density of all plants; and light levels at three points in the plant canopy were collected June 18-29, 2012. Soil samples were collected at all sites in March 2012 and will be grown in the greenhouse this summer to look at what species are present in the seed bank. Additional soil samples were collected during the June vegetation data collection to determine nitrogen, phosphorous, moisture, and salinity levels in the soil, all factors that could affect treatment success.

Large stand study (Masters student: Chad Cranney).

We are using four sites that have extensive stands of *Phragmites* for conducting the control treatments: Ogden Bay 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 this year 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 control.

Control techniques will be carried out for three years and we will monitor treatment effectiveness for at least 2 years following the cessation of control, if possible. The first round of control treatments were conducted July 2-6, 2012. Pre-treatment data were collected June 25-29, 2012, on cover of all live plants, open water, and litter; and water levels. Soil samples were also collected for later soil analyses as described in the previous study methods. In addition, we employed UAVs (unmanned aerial vehicles) to take high resolution (5-cm) imagery of the stands before control (and will do so again in each year of the study) to look at changes in *Phragmites* and native plant cover.