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Wetland vegetation recovery and effectiveness of *Phragmites australis* herbicide treatment on the shores of Grand Traverse Bay, Michigan.

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ABSTRACT *Phragmites australis,* an invasive reed capable of forming monospecific stands and reducing biodiversity, has been treated with herbicides along Grand Traverse Bay, Michigan for three years, 2009-2011 (Chambers et al. 1999, The Watershed Center, Grand Traverse Bay 2011). To determine the effectiveness of herbicide treatment and the floristic value of recovering vegetation, herbicide treated sites were sampled and compared to control shoreline vegetation unaffected by *Phragmites* or herbicide. Herbicide effectiveness was determined by comparison of *Phragmites* stem counts between herbicide treated areas and nearby controls. Similarity between herbicide and control sites was determined using Sørenson's Similarity Index and the Floristic Quality Assessment was used to give a value to each species (Herman et al. 2001). Herbicide treated and control sites were determined to have similar species composition, but significant differences existed between the qualities determined by floristic values of herbicide and control sites.

KEY WORDS: Floristic Quality Assessment, herbicide, *Phragmites australis,* Sørenson's Similarity Index, vegetation recovery.

For several years the common reed, *Phragmites australis* (Cav.) Trin ex Steudel (hereafter *Phragmites*), has been invading shores of Grand Traverse Bay, Michigan (The Watershed Center, Grand Traverse Bay 2011). *Phragmites* is capable of vigorous vegetative reproduction and often forms dense, monospecific stands (Marks et al. 1994). This plant can expand rapidly because of its aggressive rhizomes. A rhizome is an underground stem that sends shoots upwards and roots downwards. One rhizome can grow as much as 3.5 meters in one growing season, and each shoot can grow upwards around 1.5-4.0 meters per season. If broken into pieces, one single piece of rhizome can grow into a whole stand of *Phragmites. Phragmites* is a clonal species, so each shoot in a stand is genetically identical because all shoots can grow off the same rhizome creating one large plant. *Phragmites* is believed to have first been established in the United States in the late 17th century or early 18th century. The rhizomes of this common reed are believed to have been brought from Eurasia in the ballast water of ships, and then established along the eastern coast of the United States. From the eastern coast, the plant spread to the states along the Gulf of Mexico and into the Great Lakes region.

These monospecific stands reduce biodiversity by crowding out native plant species. If a stand of *Phragmites* is prohibiting the sunlight from reaching other vegetation, no other plants will grow in the area. *Phragmites* also diminishes habitat, so a less diverse suite of wildlife and waterfowl will inhabit the wetlands (Chambers et al. 1999, Minchinton et al. 2006). *Phragmites* has a negative economic effect, as it can damage property values and increase fire potential. The common reed can diminish recreational activities and view sheds of the Great Lakes, leading to possible economic losses in tourism. In the Great Lakes region *Phragmites* easily expands when water levels drop and temperatures rise; this occurs because *Phragmites* easily colonizes bare soil left by receding water levels (Tulbure and Johnson 2010). Wetland areas disturbed by human activity can be susceptible to this expansion; often because bare soil is exposed by heavy machinery or human traffic (Ailstock et al. 2001).

A native haplotype, or subspecies, of *Phragmites* exists in the United States; but invasive, aggressive forms are likely non-native haplotypes (Chambers et al. 1999, Saltonstall 2003). A haplotype is a group of genes on the same chromosome that are inherited together. Although the invasive haplotype of *Phragmites* is the same species as the native form of *Phragmites*, the different genes present in the invasive form of *Phragmites* give the plant the ability to outcompete other vegetation. Haplotype M, a rapidly expanding invasive haplotype, was probably the species of *Phragmites* introduced to the Atlantic Coast of North America in the late 1700s or early 1800s (Saltonstall 2002). Today, *Phragmites* is found every state in the continental U.S. (Cheshier et al. 2012). *Phragmites* is considered invasive in several states including all states in the Great Lakes region. The native haplotype of *Phragmites* can often be found in the same areas as invasive haplotypes. Native *Phragmites* usually does not inhibit other vegetation, and is usually smaller in height.

Grand Traverse Bay environmental managers have attempted to control *Phragmites* using herbicides. Herbicides effectively halt expansion of *Phragmites*, but the reed returns once treatment stops (Marks et al. 1994, Ailstock et al 2001, Back and Holomuzki 2008, Derr 2008). Using herbicides is not a selective process; native vegetation in the area will also be eliminated (Wilcox and Whillians 1999). Other methods of control have been evaluated; such as biological control and mowing, but neither has proved as effective. A previous study inventorying plant species found in Grand Traverse Bay wetlands led to a request by Grand Traverse Regional Land Conservancy, the Grand Traverse Conservation District and the Watershed Center to determine what vegetation is re-colonizing herbicide treated areas in these wetlands (de Sosa 2011). Our study areas have received three consecutive years (2009-2011) of the herbicide Rodeo™, which is an aquatic-sensitive formulation of glyphosate (The Watershed Center, Grand Traverse Bay 2011). The Watershed Center in Grand Traverse Bay, which sprayed the *Phragmites* in the Grand Traverse Bay area, considered the use of herbicides the lesser of two evils in this situation. Rodeo is non-toxic and biodegradable. In the Grand Traverse Bay area *Phragmites* stems were sprayed with a backpack sprayer, so all vegetation in the area would be affected by the herbicide.

Many studies have determined the effectiveness of treating *Phragmites* with herbicide, but a limited number of studies have considered the recovery of native vegetation post-*Phragmites* treatment (Ailstock et al. 2001, Carlson et al. 2009). Our research evaluated effectiveness of treatment by counting *Phragmites* stems in herbicide treated areas, determined floristic value of re-colonizing vegetation in herbicide sites, and determined similarity between *Phragmites* treatment sites and control *Phragmites*-free sites unaffected by herbicide treatment. The removal of *Phragmites* by herbicide should allow floristic values to increase to levels similar to areas unaffected by *Phragmites* herbicide treatment along Grand Traverse Bay, Michigan due to an increased availability of sunlight, nutrients, and unoccupied soil releasing the naturally occurring seed bank.

MATERIALS AND METHODS

Study Area

We selected six herbicide treated sites in coastal wetlands along Grand Traverse Bay, Michigan for this study. All locations were along the eastern shore of the East arm of Grand Traverse Bay in Acme Township and have been treated for *Phragmites* with herbicides for three consecutive years, 2009-2011 (Fig. 1). In relation to a shoreline dune ecosystem, these sites were in wetland zones between the beach and the foredune (Michigan DNR 2012). The average size of the herbicide treated areas was 7.7 m^2. Sites were located at Deepwater Point Nature Preserve, Acme Township Bayside Park and East Bay Roadside Park (Appendix A). Outside of preserved areas, many wetlands along Grand Traverse Bay are unprotected, highly developed, or located on private property.

Transect Procedure

We positioned line transects through each herbicide area for sampling of vegetation. The size of each transect was a representative portion of herbicide-infected area (Appendix A). We placed a stratified succession of 0.25-m^2 quadrats within each transect, and recorded all species found within each quadrat. For example, if a herbicide treated area was 1.5 meters wide and 6 meters long, a total of twelve stratified quadrats were recorded; two quadrats for each meter of length. Each herbicide treated area had a paired control section. For a species to be counted in a quadrat, its roots must be located inside the square. We sampled control sections in areas of shoreline within 10 m of the herbicide treated site. These controls had not received herbicide and contained no monoculture stands of *Phragmites*. Control transects were kept the same distance from the shoreline as herbicide-treated sites because of known correlation in species number and density in relation to distance from the water in dune shoreline ecosystems (Michigan DNR 2012). We used the same number of quadrats for herbicide and control sites and placed the same number of quadrats on both sides of the transect. If an obstacle, such as a stream, maintained beach, or walking path was close to herbicide treated area, all control quadrats were recorded to one side of the treated area. We took GPS readings for each site using a Garmin GPSmap76 and marked sites visibly with stakes to ensure the same transect position for both samples. We sampled each treated and control site twice between 27 June 2012 and 18 July 2012. Sampling twice throughout the summer flowering time period permitted easier identification and a more complete sampling.

Plant Identification

Plant identification took place on site using *Newcomb's Wildflower Guide* (1977), Chadde's *A Great Lakes Wetland Flora* (1998), and Crow and Hellquist's *Aquatic and Wetland Plants of Northeastern North America* (2000). We collected voucher specimens of unknown species which were later identified by comparison to specimens in the Au Sable Institute herbarium (Mancelona, Michigan) or Michigan Flora Online (Reznicek 2011).

Data Analysis

We evaluated effectiveness of herbicide treatment by counting *Phragmites* stems in every quadrat sampled. We assessed floristic value of each herbicide and control site by calculating mean coefficient of conservatism (*C*) values and floristic quality index (*FQI*) from pre-determined values by Herman et al. (2001) *Floristic Quality Assessment for Michigan*. Each plant species found in Michigan has a coefficient of conservatism; ranging between zero and ten. This number represents the likelihood of that particular species existing in an ecosystem unaltered from pre-European settlement (Herman et al. 2001). Species with a value of zero appear in a wide variety of plant communities; whereas, species with a value of ten are found only in specific natural habitats. An example of a species commonly found in Grand Traverse Bay wetland areas with a coefficient of conservatism of ten is the Kalm's lobelia. The *FQI* allows for a more in-depth comparison between two different sites by taking into account the size of the study site (Herman et al. 2001). Floristic Quality Assessment is a useful indicator of conditions in Great Lakes coastal wetlands and can successfully assess vegetation in an ecosystem (Bourdaughs et al. 2006). Mean *C* values for all quadrats sampled were compared using a two sample Mann-Whitney test. Statistical assumptions were met for comparing *FQI* values for all herbicide and control quadrats using a one-tailed, two sample t-test assuming equal variance. We calculated similarities between species present in herbicide treated and control sites using Sørenson's Similarity Index (Sørenson 1948). Sørenson's Index gives a percent similarity between two sites by indicating the presence or absence of species. A 50% similarity or higher between two sites is considered significantly similar.

RESULTS

The number of *Phragmites* stems counted in each herbicide treated area was between zero and 41 (Fig. 2). We counted no *Phragmites* stems in control sites.

The mean *C* values for herbicide treated and control quadrats were 3.0 and 3.5 respectively. The mean *FQI* values for all herbicide treated and control quadrats were 7.2 and 10.1 respectively. A Mann-Whitney Test comparing the mean *C* values indicated significant difference between herbicide treated and control ($d.f. = 138$, $P = < 0.01$). *FQI* values for all species found in each site were calculated between 12.0 and 22.0 (Fig. 4). Comparison of *FQI* values for each quadrat indicated significant difference between floristic quality of herbicide treated and control ($d.f. = 138$, $t = 1.66$, $P = < 0.01$). The Sorenson's Similarity Index showed all sites contained significantly similar species lists, except site one which had a similarity of 45.83% (Table 1). A total of 70 species were identified in this study. Fifty-five species were found in herbicide sites and 63 were found in control sites (Appendix B, Appendix C). One species belonging to the family Asteraceae was left as an unknown.

DISCUSSION

All sampled herbicide treated sites had an average *FQI* of less than 20 indicating the impact of *Phragmites* has reduced the floristic value. However, the herbicide treatment has allowed for higher *FQI* values compared to monoculture stands of *Phragmites.* This means the herbicide treated areas are improving from monoculture strands of *Phragmites*, but not yet at the value of an area unaffected by *Phragmites.* In Michigan, most habitats have an *FQI* of less than 20, signifying minimal similarities to the pre-settlement vegetation of Michigan (Herman et al. 2001). A site with an *FQI* of over 50 is rare and represents a piece of the natural landscape of Michigan (Herman et al. 2001). Herbicide treated sites do not have similar floristic values to control sites as shown by the significant differences between mean *C* and *FQI* values. The Sørenson's Similarity Index indicated species found in control sites were similar to species found in herbicide treated sites. However, because mean *C* and *FQI* values were significantly different, species found only in control sites had higher *C* values and were found in more quadrats resulting in higher *FQI* values for control sites. Sørenson's Similarity Index only compares the types of species found, not the amount of species found, so the Sørenson's Similarity Index value is less conclusive for this study than the *FQI* values. The six sites sampled represent a small portion of herbicide-treated areas along Grand Traverse Bay and some difference is expected among sampling sites. More information needs to be collected to determine why differences existed in site one.

The herbicide treatment did not completely eliminate *Phragmites* from all six treated areas. Often it takes as long as five to seven years before a herbicide treated site will show no signs of *Phragmites* (Back & Holomuzki 2008, Lombard et al. 2012). Even though *Phragmites* was not completely eliminated, the cost of treating *Phragmites* for a fourth year will decrease because only sparse stems would need to be coated with the herbicide (Carlson et al. 2009, Lombard et al. 2012). Realistically, goals of herbicide treatment are to reduce numbers of *Phragmites* instead of completely eliminating the species (Marks et al. 1994, Warren et al. 2001).

If treatments are continued only the few remaining stems of *Phragmites* would need to be coated with herbicide; leading to a smaller area affected by herbicide and better opportunity for recovery of native vegetation (Back & Holomuzki 2008). However, if herbicide treatment is not continued *Phragmites* is likely to return due to the large underground rhizomes of the plant that could still be active in the soil (Ailstock et al. 2001, Derr 2008, Cheshier et al. 2012, Lombard et al. 2012). More research on weighing the cost and effectiveness of the treatment needs to be completed to determine if spraying should be continued in the following years.

These results should be viewed with some caution as the limited time frame prevented completion of a more thorough sampling on selected study sites. Some of the wetland vegetation observed was not in flower or easily identifiable during this sampling period. Due to this limitation it is possible some species were misidentified. As the summer progressed more vegetation flowered in sampled sites. The addition of a third sampling would have ensured better accuracy and a greater number of species represented. However, the bias would have been in the richer control sites, and thus the significance differences seen between the treated and control sites are likely under-estimates.

Since herbicides are not selective and affect targeted *Phragmites*, as well as other vegetation, a full recovery was not expected in three years. Vegetation growing in herbicide treated areas is expected to have lower *C* values because impact of herbicide alters the natural landscape. Ailstock et al. (2001) discovered a slow recovery of vegetation in herbicide-treated areas the first year post-treatment, but species diversity increased over four years post treatment. Since the sampled herbicide sites were treated in 2011, a full site recovery is not expected for this year of study. The numbers of species found in herbicide-treated sites are a great improvement to a single species stand of *Phragmites.* To better determine if herbicide treated sites are recovering it is important to continue this study for at least another three years. Comparing these results to those found in future years will better determine if herbicide treated areas are increasing in species diversity and therefore recovering from *Phragmites* and herbicide treatment.

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APPENDIX A

Site number, size of sampled area (m^2), location, and GPS coordinates for all six sites studied along East Grand Traverse Bay, Michigan. Site locations abbreviated as followed: Deepwater Point Nature Preserve (DP), Acme Township Park (AT), and Acme Township Roadside Park (RP).

Site	**1**	**2**	**3**	**4**	**5**	**6**
Size m^2	6.0	16.8	3.5	7.8	7.0	5.0
Location	DP	DP	DP	AT	RP	RP
GPS	N 44˚46’38.3” W 085˚30’18.0”	N 44˚46’31.6” W 085˚30’22.4”	N 44˚46’30.5” W 085˚30’22.0”	N 44˚46’24.8” W 085˚30’15.1”	N 44˚45’50.1” W 085˚30’35.3”	N 44˚45’47.5” W 085˚30’39.6”

APPENDIX B

List of plants found at all herbicide sites along the East arm of Grand Traverse Bay, Michigan. Included is the species, common name, coefficient of conservatism (*C*) and at which site the species was observed.

Species	**Common Name**	***C***	**1**	**2**	**3**	**4**	**5**	**6**
Acer rubrum	Red maple	1						X
Asclepias incarnata	Swamp milkweed	6	X		X	X	X	X
Asclepias syriaca	Common milkweed	1					X	X
Aster puniceus	Swamp aster	5		X	X			X
Bidens frondosus	Common beggar-ticks	1					X	X
Carex bebbi	Bebb's sedge	4	X			X		
Carex flava	Sedge	4		X	X	X		
Carex hystericina	Sedge	2		X		X	X	
Carex leptalea	Sedge	5		X				
Centaurea maculosa	Spotted knapweed	*						X
Cirsium arvense	Canada thistle	*	X			X		X
Cirsium muticum	Swamp thistle	6	X			X	X	X
Cornus stolonifera	Red-osier dogwood	2				X		
Coronilla varia	Coronilla varia	*				X		
Elocharis obtusa	Spike-rush	3		X	X	X		
Epilobium hirsutum	Hairy willow herb	*	X			X		
Equisetum variegatum	Rush	8			X			
Eupatorium maculatum	Joe-pye weed	4		X	X	X		X
Eupatorium perfoliatum	Boneset	4			X	X		
Euthamia graminifolia	Grass-leaved goldenrod	3		X	X	X		X
Hypochaeris radicata	Cat's ear	*	X					
Impatiens capensis	Spotted touch-me-not	2	X				X	X
Juncus articulatus	Jointed rush	3		X				X
Juncus balticus	Baltic rush	4		X			X	
Lobelia kalmii	Kalm's lobelia	10			X			
Lycopus americanus	Horehound	2	X	X	X	X		X
Lycopus uniflorus	Northern bugle weed	2	X			X		X
Myosotis scorpioides	Forget-me-not	*	X				X	

Oenotera biennis	Common evening primrose	2	X		X	X		
Panicum capillare	Witch grass	1	X	X	X	X	X	X
Panicum lindheimeri	Lindheimerigrass	8			X		X	
Parthenocissus quinquefolia	Virginia creeper	5						X
Phalaris arundinacea	Reed canary	0	X		X	X	X	X
Phragmites australis	Common reed	0	X	X		X		X
Plantago lanceolata	English plantain	*	X					
Plantago major	Common plantain	*	X					
Plantago rugelli	Rugel's plaintain	0				X		
Poa palutris	Fowl meadow grass	3	X	X	X		X	
Potentilla anserina	Silverweed	5	X	X	X	X		
Prunella vulgaris	Heal-all	0		X				
Puccinellia distans	Alkali grass	*	X	X	X			X
Salix myricoides	Blue-leaved willow	9						X
Schoenoplectus pungens	Three-square	5		X	X	X	X	X
Solidago canadensis	Canada goldenrod	1	X	X	X	X	X	X
Solidago juncea	Early goldenrod	3						X
Solidago rugosa	Rough goldenrod	3		X		X		
Sonchus asper	Prickly sow thistle	*	X			X		
Taraxacum officinale	Dandelion	*	X			X		
Teucrium canadense	Germander	4	X			X		
Thuja occidentalis	White cedar, Arbor vitae	4		X				
Typha angustifolia	Narrow-leaved cattail	*					X	
Veronica anagallis-aquatica	Water speedwell	4	X					
Veronica serpyllifolia	Thyme-leaved speedwell	0					X	
Vitis riparia	Riverbank grape	3						X

APPENDIX C

List of plants found at all control sites along the East arm of Grand Traverse Bay, Michigan. Included is the species, common name, coefficient of conservatism (*C*) and at which site the species was observed.

Species	Common Name	*C*	1	2	3	4	5	6
Acer rubrum	Red maple	1					X	
Asclepias incarnata	Swamp milkweed	6			X	X	X	X
Aster puniceus	Swamp aster	5	X	X	X			
Betula papyrifera	Paper birch	2			X			
Bidens frondosus	Common beggar-ticks	1					X	
Carex bebbi	Bebb's sedge	4	X					X
Carex flava	Sedge	4	X	X	X			X
Carex garberi	Sedge	8		X	X			
Carex granularis	Sedge	2					X	
Carex hystericina	Sedge	2	X			X	X	X
Carex leptalea	Sedge	5		X	X			
Carex stricta	Hummock sedge	4	X	X		X		
Cirsium arvense	Canada thistle	*				X		X
Cirsium muticum	Swamp thistle	6				X	X	X
Cirsium vulgare	Bull-thistle	*				X		X
Cornus stolonifera	Red-osier dogwood	2	X	X	X	X		
Coronilla varia	Coronilla varia	*				X		
Elocharis obtusa	Spike-rush	3		X	X	X		X
Epilobium hirsutum	Hairy willow herb	*				X	X	
Equisetum variegatum	Rush	8			X			
Eupatorium maculatum	Joe-pye weed	4		X	X	X		X
Eupatorium perfoliatum	Boneset	4			X			X
Euthamia graminifolia	Grass-leaved goldenrod	3	X	X	X	X		X
Fragaria virginiana	Wild strawberry	2		X				
Galium palustre	Marsh bedstraw	3	X				X	
Impatiens capensis	Spotted touch-me-not	2	X				X	X
Juncus articulatus	Jointed rush	3		X	X			X
Juncus balticus	Baltic rush	4	X	X	X	X	X	X

Juncus canadensis	Canadian rush	6						X
Liparis loeselii	Leosel's twayblade	5		X				
Lobelia kalmii	Kalm's lobelia	10		X	X			
Lycopus americanus	Horehound	2	X	X	X	X	X	X
Lycopus uniflorus	Northern bugle weed	2	X	X		X	X	X
Myosotis scorpioides	Forget-me-not	*					X	X
Oenotera biennis	Common evening primrose	2	X			X	X	X
Panicum capillare	Witch grass	1						X
Panicum lindheimeri	Lindheimerigrass	8		X	X			
Phalaris arundinacea	Reed canary	0	X	X	X	X	X	X
Plantago lanceolata	English plantain	*	X					
Plantago major	Common plantain	*		X				
Poa palutris	Fowl meadow grass	3		X	X	X		
Potentilla anserina	Silverweed	5	X	X	X		X	X
Potentilla recta	Rough-fruited cinquefoil	*	X					
Prunella vulgaris	Heal-all	0		X				
Puccinellia distans	Alkali grass	*		X				
Ranunculus sceleratus	Cursed crowfoot	1			X			
Salix myricoides	Blue-leaved willow	9			X			X
Salix petiolaris	Meadow willow	1	X		X			
Schoenoplectus acutus	Hardstem bulrush	5					X	X
Schoenoplectus pungens	Three-square	5	X	X	X	X	X	X
Solidago canadensis	Canada goldenrod	1	X	X	X	X	X	X
Solidago juncea	Early goldenrod	3						X
Solidago rugosa	Rough goldenrod	3				X		
Sonchus asper	Prickly sow thistle	*	X				X	
Sonchus oleraceus	Common sow thistle	*				X	X	X
Taraxacum officinale	Dandelion	*		X	X			
Teucrium canadense	Germander	4	X			X		
Thuja occidentalis	White cedar, Arbor vitae	4		X	X			
Typha angustifolia	Narrow-leaved cattail	*	X			X		
Verbena hastata	Blue vervain	4				X	X	X
Veronica serpyllifolia	Thyme-leaved speedwell	0				X		

Vitis riparia	Riverbank grape	3	X			X	X	X

Table 1. Sorenson's Similarity Quotient (QS) comparing herbicide-treated and control vegetation for all six sites along Grand Traverse Bay, Michigan.

Site	**1**	**2**	**3**	**4**	**5**	**6**
QS	45.83%	69.39%	65.22%	73.68%	50.00%	59.65%

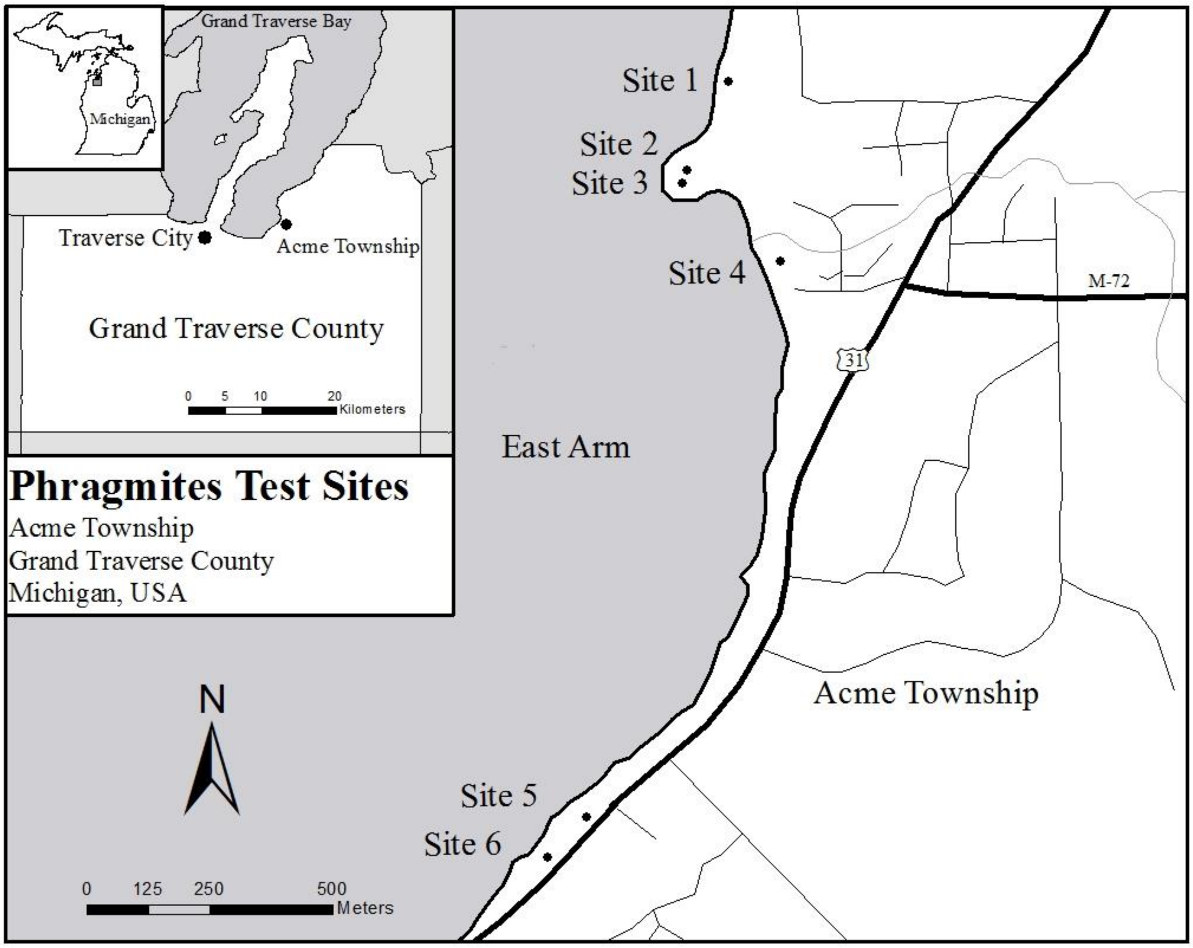
FIGURE LEGEND

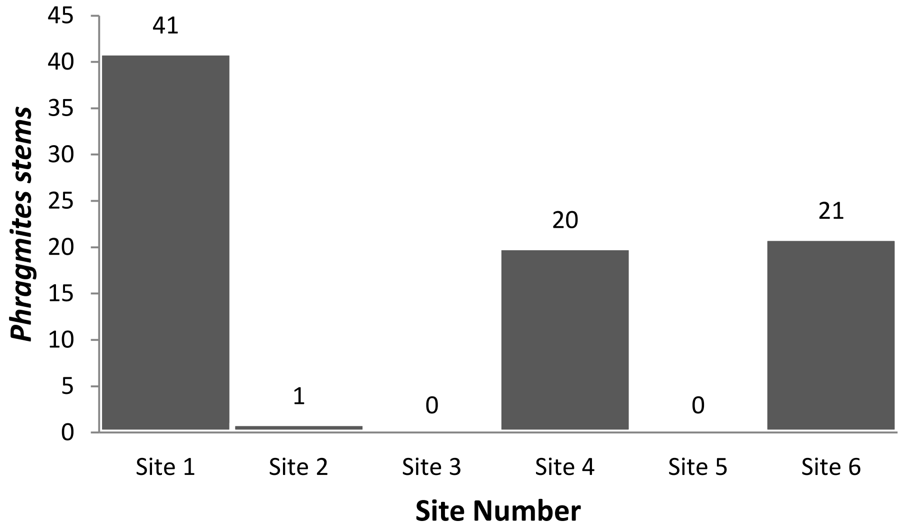
Figure 1. Map of six sampled sites along Grand Traverse Bay, Michigan.

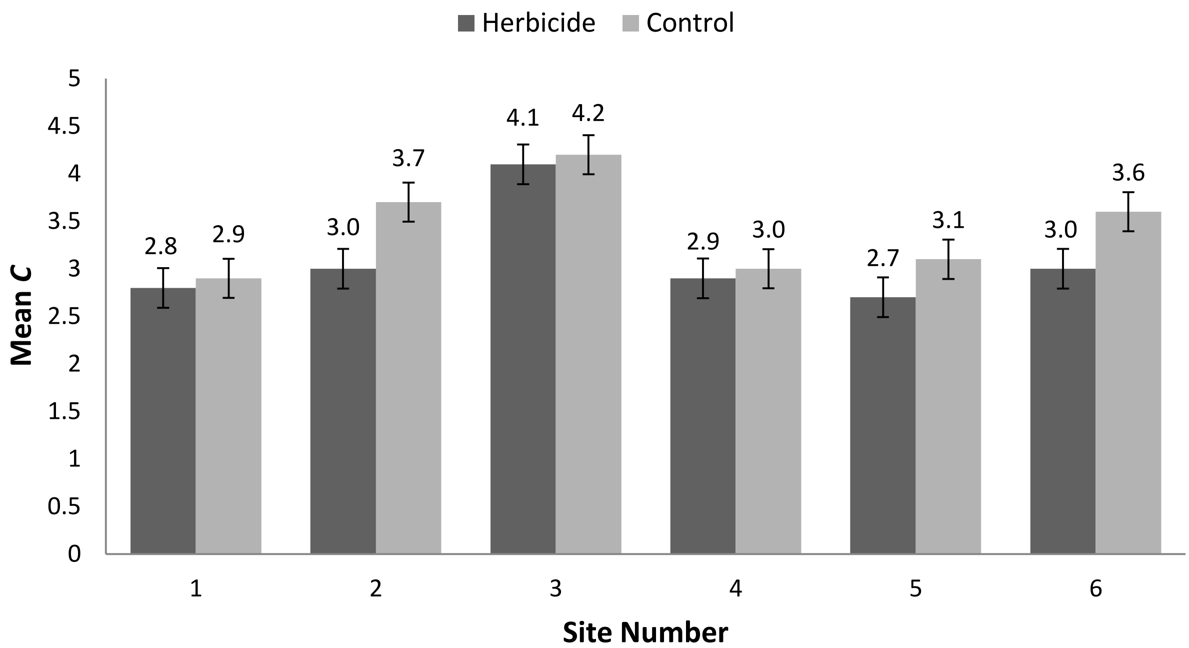
Figure 2. Number of *Phragmites australis* stems found at all herbicide treated study sites along Grand Traverse Bay, Michigan.

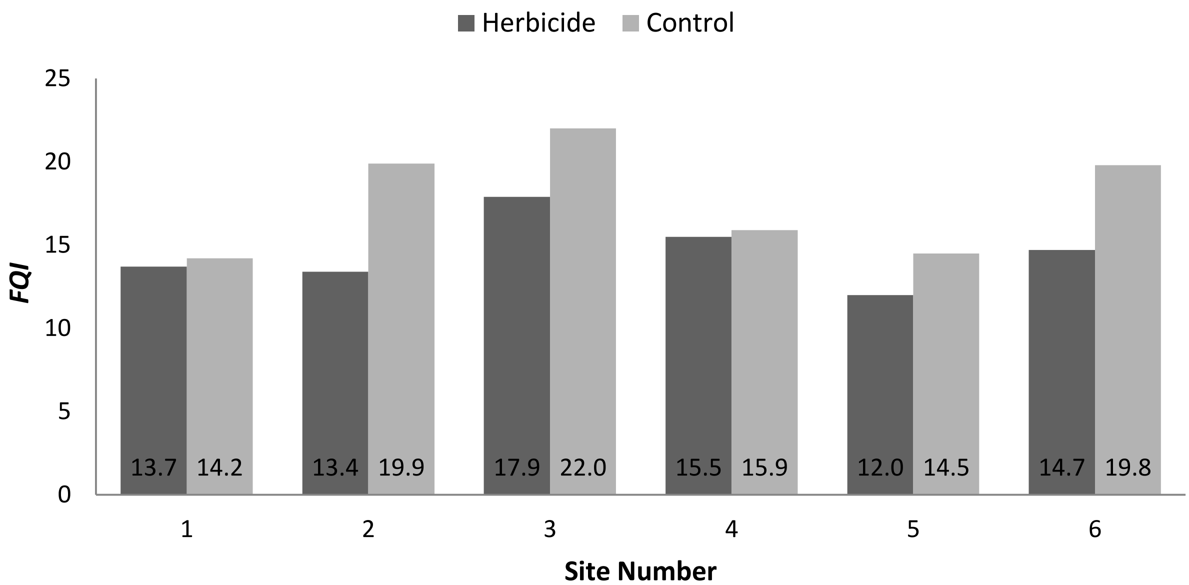
Figure 3. Mean coefficient of conservatism (*C*) values for species found in herbicide and control sites along Grand Traverse Bay, Michigan.

Figure 4. Floristic quality index (*FQI*) values for all species found in herbicide and control sites along Grand Traverse Bay, Michigan.


Grand Traverse Bay
Michigan
Traverse City
Acme Township
Grand Traverse County
0 5 10 20 Kilometers
Phragmites Test Sites
Acme Township
Grand Traverse County
Michigan, USA
Site 1
Site 2
Site 3
Site 4
M-72
31
East Arm
Acme Township
N
Site 5
Site 6
0 125 250 500 Meters


45
40
35
30
25
20
15
10
5
0
Phragmites stems
41
1
0
20
0
21
Site 1
Site 2
Site 3
Site 4
Site 5
Site 6
Site Number


Herbicide
Control
Mean C
Site Number
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
1
2
3
4
5
6
2.8
2.9
3.0
3.7
4.1
4.2
2.9
3.0
2.7
3.1
3.0
3.6


Herbicide
Control
25
20
15
10
5
0
FQI
13.7
14.2
13.4
19.9
17.9
22.0
15.5
15.9
12.0
14.5
14.7
19.8
1
2
3
4
5
6
Site Number