Research Reports

Enhancing native plant habitat in a restored salt marsh on Cape Cod, Massachusetts

By Jesse S. Wheeler, Rachel K. Thiet, and Stephen M. Smith

Abstract

The tidal restoration of Hatches Harbor, a 100-acre (41 ha) salt marsh in Cape Cod National Seashore, Massachusetts, has resulted in substantial native halophyte (salt-tolerant taxa) reestablishment in portions of the marsh. However, extensive stands of the invasive *Phragmites australis* still occupy a large area of the marsh. These stands present a physical barrier to the dispersal and establishment of seeds from the adjacent, recovering salt marsh. The goal of this study was to evaluate the establishment success of native halophytes in response to manual cutting of *Phragmites* growth in *Phragmites*-dominated areas of Hatches Harbor where halophyte reestablishment has been poor. We measured species composition, abundance, and diversity in one hundred 10.76 ft^2 (1.00 m^2) plots at Hatches Harbor over two growing seasons in 2008 and 2009. Very few halophytes naturally grew within dense stands of untreated *Phragmites*, whereas halophyte abundance and diversity were significantly greater in plots where *Phragmites* was mechanically removed. Thus, mechanical removal of *Phragmites* improves conditions for halophyte establishment, presumably by reducing barriers to seed dispersal and through increased light exposure.

Key words

Cape Cod National Seashore, halophyte, *Phragmites*, salt-marsh restoration, *Spartina*

MANY ATLANTIC SALT MARSHES HAVE BEEN SEVERELY degraded by structures such as roads and dikes that restrict tidal flow. Tidal restriction causes a reduction in salinity and a shift in salt marsh to brackish, freshwater, and even upland plant species (Amsberry et al. 2000; Smith 2007; Smith et al. 2009). Many of these tidally restricted salt marshes are being restored by increasing tidal exchange (Roman and Burdick 2012). However, the restoration of native salt-marsh plant communities can still be limited by the presence of the invasive common reed (*Phragmites australis*). Persistent stands of this salt-tolerant species, which tends to proliferate in tidally restricted systems, exclude native halophytes by impeding seed dispersal and shading the seed bank (Rand 2000; Minchinton et al. 2006).

The recovery of salt-marsh plant communities is partly dependent upon seed germination, which is influenced primarily by salinity and light availability (Rand 2000; Carter and Ungar 2004; Smith and Warren 2012). Halophyte seeds are dispersed by tides. They may be free-floating or, more commonly, mixed in with dead plant biomass (wrack) that forms large mats. These wrack mats are prevented from dispersing across marsh floodplains when they become trapped by physical barriers, such as *Phragmites* stands (Smith 2007). Smith (2007) showed that pathways cut into *Phragmites* zones allowed wrack to advance with the incoming tide, dispersing viable seeds and increasing halophyte establishment in more interior areas.

Cape Cod National Seashore manages several tidal restoration projects on Cape Cod, Massachusetts, USA. One salt marsh undergoing restoration is Hatches Harbor, which was diked for 70 years for mosquito control (Portnoy et al. 2003). The ensuing degradation of this system led to efforts in 1999 to reestablish seawater exchange by installing culverts in the dike (fig. 1). This has resulted in significant expansion of salt-marsh vegetation within the formerly restricted floodplain (table 1). However, 10 years after tidal restoration at Hatches Harbor, *Phragmites* stands continue to flourish where salinities are still between 10 and 25 parts per trillion (ppt) (Sun et al. 2007; Smith et al. 2009).

The goal of our study was to evaluate whether the establishment of halophytes could be enhanced by manual cutting of *Phragmites* and to assess relationships among salinity, elevation, and vegetation. Specifically, we evaluated the composition, abundance, and diversity of extant halophyte vegetation and the seed bank within halophyte-dominated areas, Phragmites-dominated areas, and areas where *Phragmites* was mechanically removed.

Methods

We established one hundred 10.76 ft^2 (1.00 m^2) plots in three sections of the tide-restricted area of Hatches Harbor. These sections were characterized as (1) undisturbed halophyte-dominated areas between the tidal creek and wrack line (n = 31), (2) undisturbed dense *Phragmites* stands (n = 33) (fig. 2, page 44), and (3) areas where we mechanically removed *Phragmites* stems from *Phragmites*-dominated areas between the wrack line and the upland habitat (n = 36) (fig. 3, page 44). In each plot we measured halophyte composition, abundance (density of mature and emerging stems), and diversity. The undisturbed Phragmites-dominated plots acted as control for the neighboring Phragmites removal plots. Halophyte species diversity was quantified using

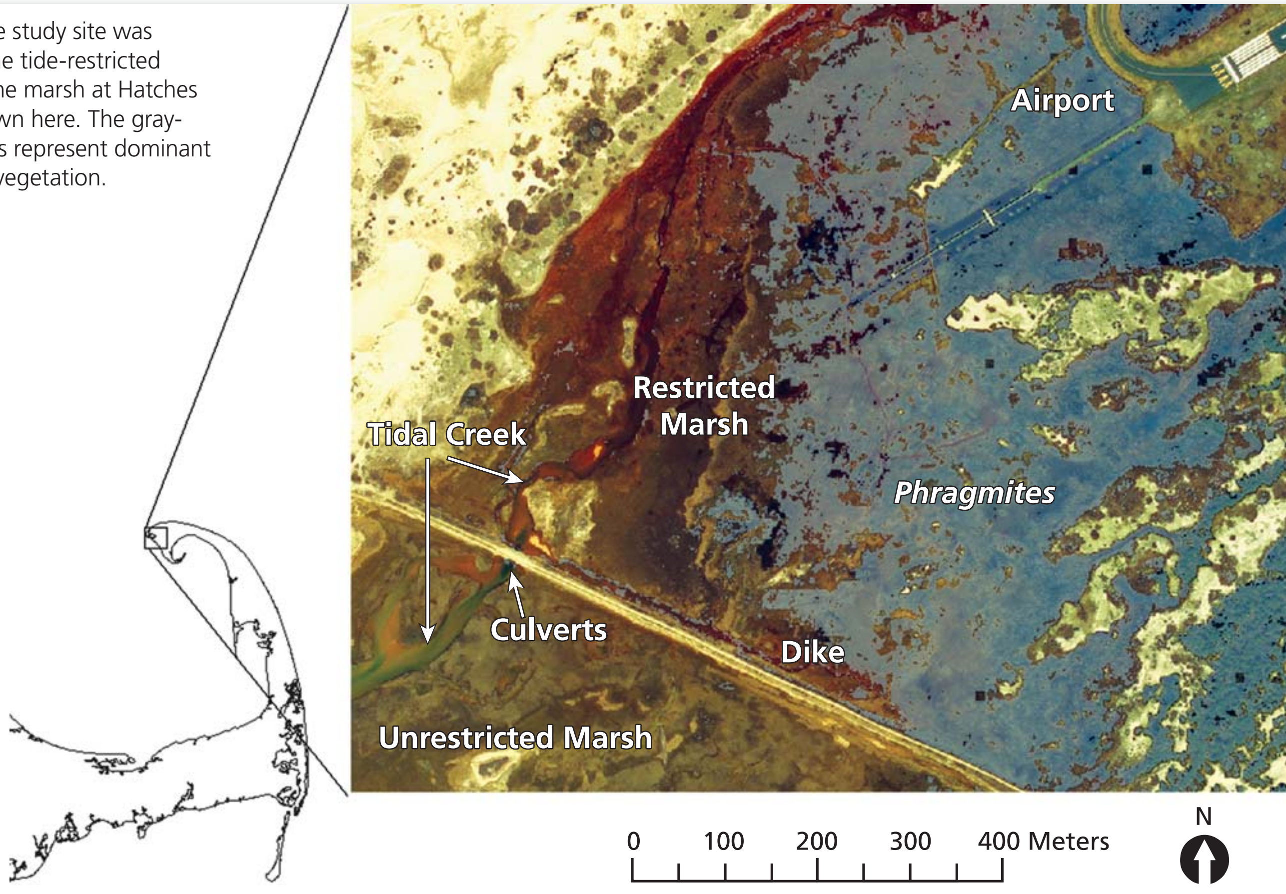

Figure 1. The study site was located in the tide-restricted portion of the marsh at Hatches Harbor, shown here. The gray-shaded areas represent dominant *Phragmites* vegetation.

Table 1. Halophyte abundance within study plots of the halophyte- (H) and Phragmites-dominated (P) areas of the restricted marsh at Hatches Harbor

		2008				2009				2008 + 2009			
Common Name	**Scientific Name**	**H**	**(SE[1])**	**P**	**(SE)**	**H**	**(SE)**	**P**	**(SE)**	**H**	**(SE)**	**P**	**(SE)**
salt marsh hay	*Spartina patens*	563	310	406	198	304	171	300	1	433	177	353	97
Virginia glasswort	*Salicornia depressa*	350	212	0		15	6	4		182	107	2	
slender glasswort	*Salicornia maritima*	243	78	0		27	11	<1	3	135	41	<1	1
salt marsh cordgrass	*Spartina alterniflora*	40	16	5	5	33	12	0	150	37	10	2	78
salt sandspurry	*Spergularia salina*	59	56	0		3	2	0		31	28	0	
seepweed	*Suaeda spp.*	13	7	2	2	3	2	1		8	4	2	1
sea lavender	*Limonium carolinianum*	1		0		0		0		1		0	
marsh spikegrass	*Distichlis spicata*	0		0		<1		0		<1		0	
spear saltbush	*Atriplex patula*	0		0		0		<1	22	0		<1	11
eastern baccharis	*Baccharis halimifolia*	0		9	9	0		32	150	0		20	79

Note: Halophyte abundance is the total (mature and seedlings) of stems per plot (i.e., stems/10.76 ft^2 [1.00m^2]). The perennial salt marsh hay *Spartina patens* and annual glassworts (*Salicornia* spp.) were the most abundant halophytes in both halophyte- and *Phragmites*-dominated areas of the salt marsh; however, the annual species were rarely seen within *Phragmites*-dominated areas of the higher marsh.

[1]SE = Standard Error


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Figure 2. Halophyte seedlings grow in a 10.76 ft^2 (1.00 m^2) study plot in a halophyte-dominated area of Hatches Harbor salt marsh in 2008.


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Figure 3. Located in a *Phragmites*-dominated area of Hatches Harbor salt marsh, this plot (flags) has manually been cleared of Phragmites and includes a buffer to allow sunlight to reach the plot.

Simpson's diversity index (Simpson 1949) on a plot-by-plot basis for both 2008 and 2009. Simpson's diversity index measures the probability that two individual stems selected at random from one plot will belong to the same species.

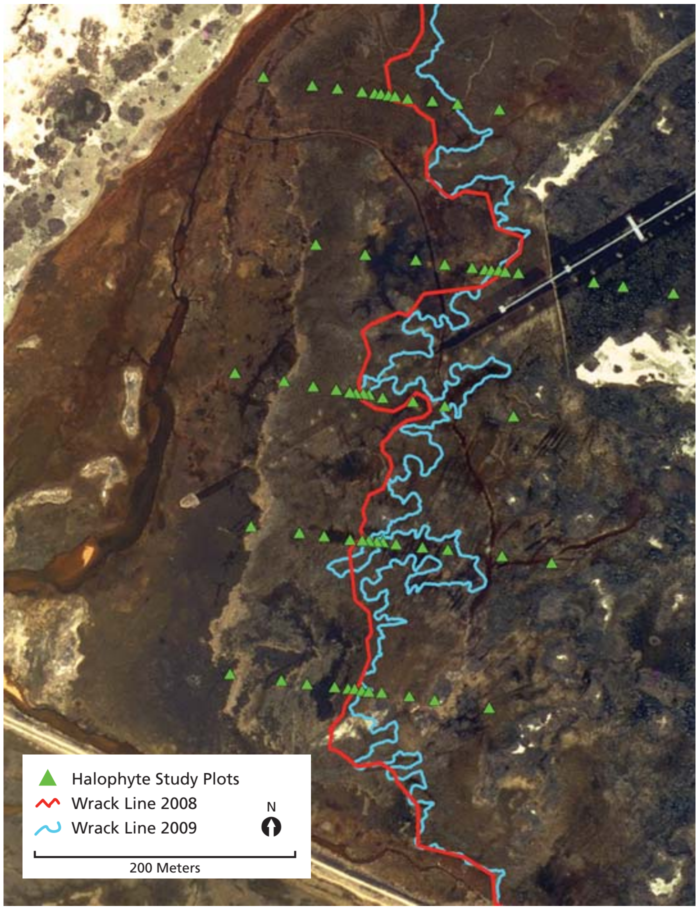
We located plots along five transects spaced 410 feet (125 m) apart and running perpendicular to the 2008 wrack line (the zone where wrack and debris accumulate). We placed plots on each transect at distances of 10 ft (3 m), 26 ft (8 m), 59 ft (18 m), 124 ft (38 m), 190 ft (58 m), and 321 ft (98 m) toward the upland and in the direction of the tidal creek, perpendicular to the wrack line (fig. 4). In mechanical removal plots, we cut *Phragmites* stems to a height of 4 inches (10 cm) with garden shears and kept plots clear of new *Phragmites* growth, as well as leaf and stem litter, to expose the soil throughout the growing seasons of 2008 and 2009. We also established a cleared buffer around each plot to reduce shading of halophyte seedlings by surrounding *Phragmites* (fig. 5). Mature and emergent halophyte seedlings were counted four times from June through August 2008 and three times in 2009. In plots where salt marsh hay (*Spartina patens*) was too dense to count, we estimated abundance using 1.6 in^2 (10 cm^2) subplots. On each visit, halophyte seedlings were identified to species, removed, and discarded. In addition, any advancing *Phragmites* vegetative shoots were cut and removed. Distances from vegetation plots to halophyte seed sources (wrack line or established halophyte populations) were measured to the nearest meter and analyzed with ArcGIS 9.2 (Geographic Information System [GIS] mapping software), using vegetation-cover raster imagery.

We used nonparametric Wilcoxon rank-sum tests to compare total and dominant halophyte species abundance and diversity in plots from which *Phragmites* was mechanically removed against their abundance and diversity in undisturbed control plots. Halophyte abundance (log-transformed) and diversity were analyzed using Wilcoxon rank-sum correlations with distance from wrack line. Halophyte abundance results are reported for combined years. Halophyte diversity results are reported for 2008, 2009, and 2008 and 2009 combined. JMP version 7 (SAS Institute 2007) was used for all statistical tests, and statistical significance was determined at $\alpha \leq 0.05$ except where otherwise noted.

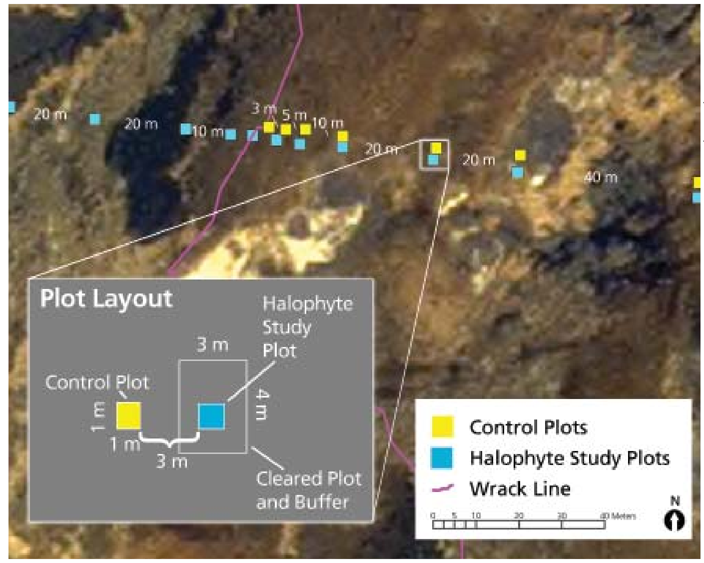
Results

Halophyte composition

A total of eight species (2008 and 2009 combined) were recorded in plots within the halophyte-dominated (i.e., non-*Phragmites*) portion of the marsh, and seven in undisturbed (control) plots in *Phragmites*-dominated areas (table 1). Four species (salt marsh hay [*Spartina patens*], slender glasswort [*Salicornia maritima*], salt marsh cordgrass [*Spartina alterniflora*], and herbaceous seepweed [*Suaeda maritima*]) were found in both halophyte- and *Phragmites*-dominated areas. Spear saltbush (*Atriplex patula*), eastern baccharis (*Baccharis halimifolia*), and common threesquare (*Schoenoplectus pungens*) were found only in the *Phragmites*-dominated area, while sea lavender (*Limonium carolinianum* [formerly *L. nashii*]), salt sandspurry (*Spergularia salina*), and Virginia glasswort (*Salicornia depressa* [formerly *S. virginica*]) were observed only in the halophyte-dominated area. Abundance of mature and seedling halophytes was significantly greater in plots from which *Phragmites* was mechanically removed than in control plots (Wilcoxon rank-sum Z = 6.50, p <0.001) in



JESSE WHEELER, 2010; IMAGERY ARCVIEW 9.2



JESSE WHEELER, 2010; IMAGERY ARCVIEW 9.2

Figure 4 (left). The halophyte study plots (green triangles) were established along the five transects in Hatches Harbor. Wrack line locations for 2008 and 2009 are indicated by red and blue lines, respectively; transect origins were based on the 2008 wrack line.

Figure 5 (above). The diagram shows an example of halophyte study and control plots along a transect in Hatches Harbor; the inset describes specific plot layouts.

2008, 2009, and 2008 and 2009 combined. However, the increase in abundance was slight, with just 13% more seedlings than in the control plots. Mechanical removal plots yielded an average of 400 (± 142) individual halophytes per plot (i.e., 10.76 ft^2 [1.00 m^2]) while control plots averaged 353 (129) per plot (table 2, next page).

Although only one-third of the mechanically cleared plots contained a high abundance of mature and seedling halophytes (>100), most of the plots appeared to have a viable seed bank, as evidenced by the presence of emerging seedlings and mature halophytes in 74% of plots. *Spartina patens* abundance was slightly lower in mechanical removal plots than in control plots (Wilcoxon rank-sum Z = 1.70, $p < 0.09$, $\alpha = 0.10$). However, abundance of the annuals *Suaeda* spp. (Wilcoxon rank-sum Z = 3.74, $p < 0.001$) and *Salicornia maritima* (Wilcoxon rank-sum Z = 8.24, $p < 0.00$) was significantly higher in mechanical removal plots than in control plots (table 2, next page).

Halophyte abundance (both mature and seedling) was not significantly correlated with distance from wrack line (Spearman's $r_s = 0.21$, $p < 0.11$). Plots where halophytes were present averaged 15.0 ft (4.6 m) in distance from seed source populations. However, halophyte presence was not significantly different ($p = 0.83$) with regard to distance from already established seed source populations or open pathways for seed dispersal.

Halophyte (mature and seedling) diversity

Halophyte plant diversity was significantly higher in halophyte-dominated areas than in *Phragmites*-dominated areas of Hatches Harbor in 2008, 2009, and 2008 and 2009 combined (fig. 6, page 47). Diversity was significantly higher in plots from which *Phragmites* was mechanically removed than in control plots (Wilcoxon rank-sum Z = 2.94, $p < 0.001$) (fig. 7, page 47). Diversity was not significantly correlated with distance from wrack line in 2008 (Spearman's $r_s = 0.01$, $p = 0.59$), 2009 (Spearman's $r_s = 0.04$, $p = 0.33$), or 2008 and 2009 combined (Spearman's $r_s = 0.06$, $p = 0.64$).

Discussion

We observed few halophytes, either mature plants or seedlings, in undisturbed (i.e., noncleared) *Phragmites*-dominated areas upslope from where wrack accumulates. In contrast, we observed a greater abundance and diversity (particularly in annuals) in

Table 2. Mean (± SE) abundance of halophyte species in control (C) and mechanically removed (MR) plots in the restricted marsh at Hatches Harbor

		2008				2009				2008 + 2009			
Common Name	**Scientific Name**	**C**	**(SE)**	**MR**	**(SE)**	**C**	**(SE)**	**MR**	**(SE)**	**C**	**(SE)**	**MR**	**(SE)**
salt marsh hay	*Spartina patens*	406	198	380	231	268	156	255	167	340	127	309	137
slender glasswort	*Salicornia maritima*	0	0	36	13	<1	0	24	10	<1	0	29	8
seepweed	*Suaeda* sp.	2	2	6	3	1	1	6	3	2	1	6	2
Virginia glasswort	*Salicornia depressa*	0	5	6	0	4	0	8	0	2	3	7	0
common threesquare	*Schoenoplectus pungens*	0	0	2	2	0	3	1	2	0	2	2	2
salt marsh cordgrass	*Spartina alterniflora*	5	0	<1	0	0	0	1	0	3	0	1	0
marsh spikegrass	*Distichlis spicata*	0	0	0	1	0	0	1	1	0	0	<1	1
sea lavender	*Limonium carolinianum*	0	0	<1	0	0	0	<1	0	0	0	<1	0
salt sandspurry	*Spergularia salina*	0	0	0	0	0	0	<1	1	0	0	<1	0
spear saltbush	*Atriplex patula*	0	0	0	0	0	0	0	0	0	0	0	0
eastern baccharis	*Baccharis halimifolia*	9	9	0	0	3	2	0	0	6	5	0	0
All species		**422**	**202**	**430**	**230**	**277**	**156**	**377**	**182**	**353**	**129**	**400**	**142**

Note: Halophyte abundance is measured by stems per plot (stems/10.76 ft^2 [1.00/m^2]). The most abundant halophyte in *Phragmites*-dominated areas, *Spartina patens*, was found in slightly fewer numbers in mechanically removed plots, not indicating much change from areas cleared of *Phragmites*. However, whereas a significant increase of most annuals was noticed in response to removed *Phragmites*, control plots with standing *Phragmites* saw very few annuals.

plots from which we mechanically removed *Phragmites*. When we looked at annual and perennial halophytes separately, we found that the abundance of the perennial *Spartina* grasses actually declined slightly in plots where *Phragmites* was removed, whereas the annual halophytes experienced modest gains in abundance. The annual halophytes *Salicornia maritima* and *Suaeda* spp. responded favorably to *Phragmites* cutting, growing among the majority (66%) of cleared plots but in only 7% of neighboring control plots. We observed fewer perennial halophyte species (e.g., *Spartina*) in areas kept clear of *Phragmites*, likely because of differences in germination or seed dispersal characteristics between annual and perennial halophyte species. Annual plants such as *Salicornia* spp. produce small, round seeds as opposed to the seeds of *Spartina* spp., which are much larger and oblong with sharp ends. The latter tend to disperse less easily (Rand 2000). Once established, many perennial salt-marsh species, like *Spartina* grasses, also spread through vegetative growth.

The *Phragmites* stands at Hatches Harbor also contain patchy, isolated populations of halophytes dominated by *Spartina patens* and wrack piles; thus, we hypothesized that these "halophyte islands" might provide seeds to *Phragmites*-dominated areas devoid of these species. However, we observed no significant correlation between halophyte germination and distance from these potential seed sources, likely because seeds from potential seed sources could not disperse through the surrounding *Phragmites* stems.

Clearing *Phragmites* has the potential to enhance dispersal and germination from an existing seed bank (Smith 2007). The majority of the *Phragmites* plots we cleared at Hatches Harbor were isolated from adjacent halophyte communities—that is, they were not connected to these areas by tidal channels or clearings through which halophyte seeds could be dispersed. Monitoring these plots gave us an opportunity to observe whether the existing seed bank would respond favorably to increased light and soil temperature when *Phragmites* is removed (Smith 2007). We observed that halophyte abundance and diversity increased in these cut plots. However, seedling density in these plots was still only about 50% of the average plant density in halophyte-dominated areas of the marsh (average 400 seedlings versus 827 seedlings per plot). Further, halophyte seedlings germinated in only 30% of cleared plots. Either growing conditions were unfavorable for seed germination or viable seeds were not present in those areas. The few seeds that did germinate in cleared plots likely germinated from the extant seed bank because of increased light levels and temperatures at the soil surface following *Phragmites* removal.

In a recent seed bank study, Boyle (2011) found little halophyte germination in sediments collected from *Phragmites*-dominated

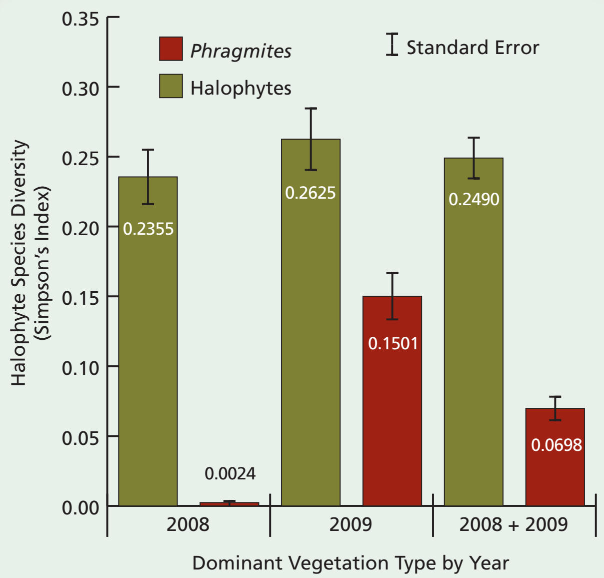


Figure 6. Mean (±SE) halophyte diversity (Simpson's index) was significantly higher in areas dominated by halophytes than in areas dominated by *Phragmites* in Hatches Harbor in 2008, 2009, and 2008 and 2009 combined. The dominant vegetation types are halophyte-dominated areas, defined as lying between the tidal creek and wrack line, and *Phragmites*-dominated areas, the section of marsh that runs from the wrack line to the upland edge of the marsh.

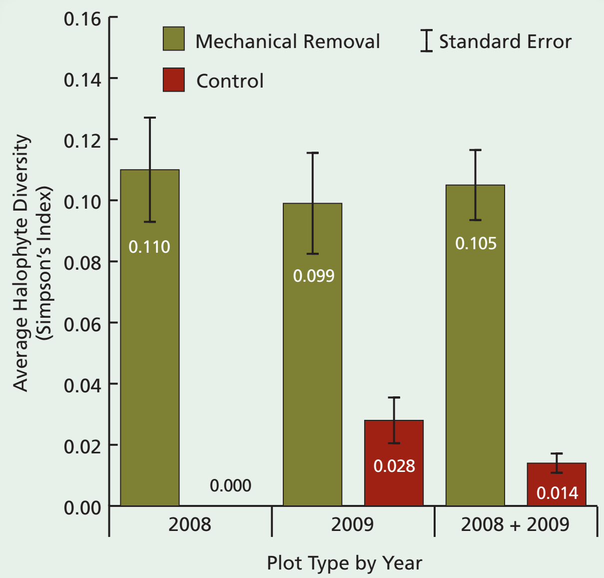


Figure 7. Mean (±SE) halophyte diversity (Simpson's index) was significantly higher in mechanically removed *Phragmites* plots than in control plots in Hatches Harbor for 2008, 2009, and 2008 and 2009 combined. Zero Simpson's diversity was recorded in control plots of 2008 because only one halophyte species was present at any given time.

areas of Hatches Harbor, suggesting that there may be few viable seeds in dense *Phragmites* stands. These findings, combined with our observation that halophyte seed germination from the seed bank in cleared plots occurs but is minimal, suggest that managers may need to cut *Phragmites* from large areas of the marsh to see substantial halophyte germination and reestablishment. In fact, cleared pathways that connect any artificial openings with existing halophyte vegetation would reduce impediments to dispersal into these areas and enhance seed supply to *Phragmites* zones. Boyle (2011) observed that transplanted mature plugs of *Spartina patens* had very high (99.5%) survivorship after one year in *Phragmites*-dominated areas of Hatches Harbor, suggesting that halophytes can persist in *Phragmites* stands if they are able to establish and reach maturity. Thus, sowing seeds collected directly into areas where *Phragmites* is cleared may increase seedling abundance substantially.

In addition to seed dispersal limitations, recruitment of halophyte taxa into *Phragmites* stands is likely inhibited by direct competition with *Phragmites* plants. We found no correlation between mature or seedling halophyte abundance and distance from the wrack line, suggesting that competition and obstructed seed dispersal severely limit halophyte expansion into *Phragmites*-dominated areas. *Phragmites* forms dense root mats, covers soil surfaces with leaf and shoot litter, casts shade, and alters the physicochemical conditions of the soil, making growing conditions for other species difficult (Minchinton et al. 2006). Very few noncleared *Phragmites* plots at our study site supported any halophytes at all. Given the limitations to seed dispersal and the dominance of Phragmites at this site, halophyte seeds deposited on bare soil surfaces completely devoid of *Phragmites*, or where *Phragmites* is mechanically cleared and connected with halophyte communities, will have the best chance of germinating.

Conclusions and management suggestions

Management of *Phragmites* at Hatches Harbor and other similarly affected sites in the National Park System could accelerate the process of vegetation restoration by (1) allowing halophyte seeds to disperse more easily, and (2) improving conditions for seed germination. At some salt-marsh sites, burning may not be an effective management tool to create clearings and conduits for seed dispersal because of public concern or insufficient fuel continuity. Burning also may destroy the resident seed bank (Boyle 2011). Creating new tidal channels, along with mechanical removal of *Phragmites*, could provide conduits for seed dispersal and result in increased halophyte establishment from incoming seed and from the existing seed bank. Alternatively, active seeding and transplanting of salt-marsh taxa to areas cleared of *Phragmites* (or areas naturally clear but that do not receive halophyte seeds because of limits on dispersal) may enhance establishment. Repeated clearing of *Phragmites* may be needed to create optimal conditions for seed dispersal, germination, and seedling establishment. The use of herbicides may be particularly effective in keeping areas clear of dense *Phragmites* for longer periods of time. Once stable native halophyte populations are established, clearing *Phragmites* may no longer be necessary, assuming that salinities in the restored marsh are high enough to limit *Phragmites* encroachment. The most effective adaptive management efforts will likely depend on land use history and local site conditions, including the proximity of established halophyte communities that serve as seed sources.

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