Evaluation of Mill Creek Salt Marsh Restoration Project
Chelsea, Massachusetts
Final Report

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Contents

Introduction

On June 8, 2000, the *T/V* Posavina was rammed and punctured by its own tug, spilling approximately 59,000 gallons of oil in the lower Chelsea River (Figure 1), Chelsea, Massachusetts. Although most of the oil was recovered, a substantial amount of local shoreline was oiled, including salt marsh. A restoration plan was drafted in response to the spill by resource Trustees (NOAA et al. 2003). The Trustees evaluated a range of mitigation activities that could compensate for the spill injury (NOAA et al. 2003). One preferred alternative was to restore a degraded salt marsh bordering Mill Creek, located on the upper reach of the Chelsea River.

The restoration site is surrounded by residential apartments, a shopping mall, and two intersecting highways (Rte 1 and Rte 16). Impacts from historic filling and subsequent stormwater drainage from the surrounding and upriver developments had led to invasion and dominance of the remaining salt marsh by the exotic form of *Phragmites australis* (common reed, hereafter *Phragmites*). Restoration, as outlined by the Trustees, involved removal of *Phragmites* roots and rhizomes and associated sediments (6-18 inches) from a large portion of the 1.5 acre site (Figure 2; NOAA et al. 2003). As indicated in Figure 2, a shallow perimeter ditch was planned for the southwestern portion. Following physical modifications, the excavated area was planted with *Spartina alterniflora* (smooth cordgrass) and *Spartina patens* (salt hay) at appropriate elevations. Prior to the restoration work, the Massachusetts Highway Department set up sediment retention structures and a maintenance plan to reduce sedimentation of the marsh in the future. The approach to restoration at this site was based on successes at similar marshes invaded by *Phragmites* (Burdick et al. 1999, 2007). The Chelsea Open Space and Recreation Committee led the restoration construction and planting (NOAA et al. 2003).

The Trustees indicated the restoration ". . . project will have substantive beneficial effects to restoring the natural resources that were injured as a result of the oil spill . . . by increasing the aquatic functions and values of this one acre marsh" (NOAA et al. 2003). Specific objectives included propagation of native species, invasive species control, and appropriate hydrology. To restore aquatic function, the physical work removed the sediment build-up from stormwater deposition and most of the invasive *Phragmites*, but more importantly, the restoration effort reestablished regular tidal flooding. In addition, native *Spartina* species (*S. alterniflora* and *S. patens*) were planted to reestablish native salt marsh vegetation. This report examines changes in vegetation over a three-year monitoring period to determine whether restoration activities have made a significant positive impact on the marsh towards meeting restoration project objectives.

Pre-restoration data were collected by EA Engineering, Science and Technology, Inc. (EA) on September 1 2005 (EA 2006) to characterize the vegetation at the site and an adjacent reference marsh prior to restoration. The presence, abundance and height of vascular plant species were recorded at approximately 20 stations for each area. The site construction for the restoration was completed in fall, 2005. In 2007, we revisited the sampling stations established and mapped by EA and collected data on the vegetation of the restored and reference sites using their methodology (EA 2006). Our report evaluates the vegetation using a before-after-control-impact (BACI) design to determine whether restoration activities have decreased *Phragmites* cover and increased the cover of native plants.

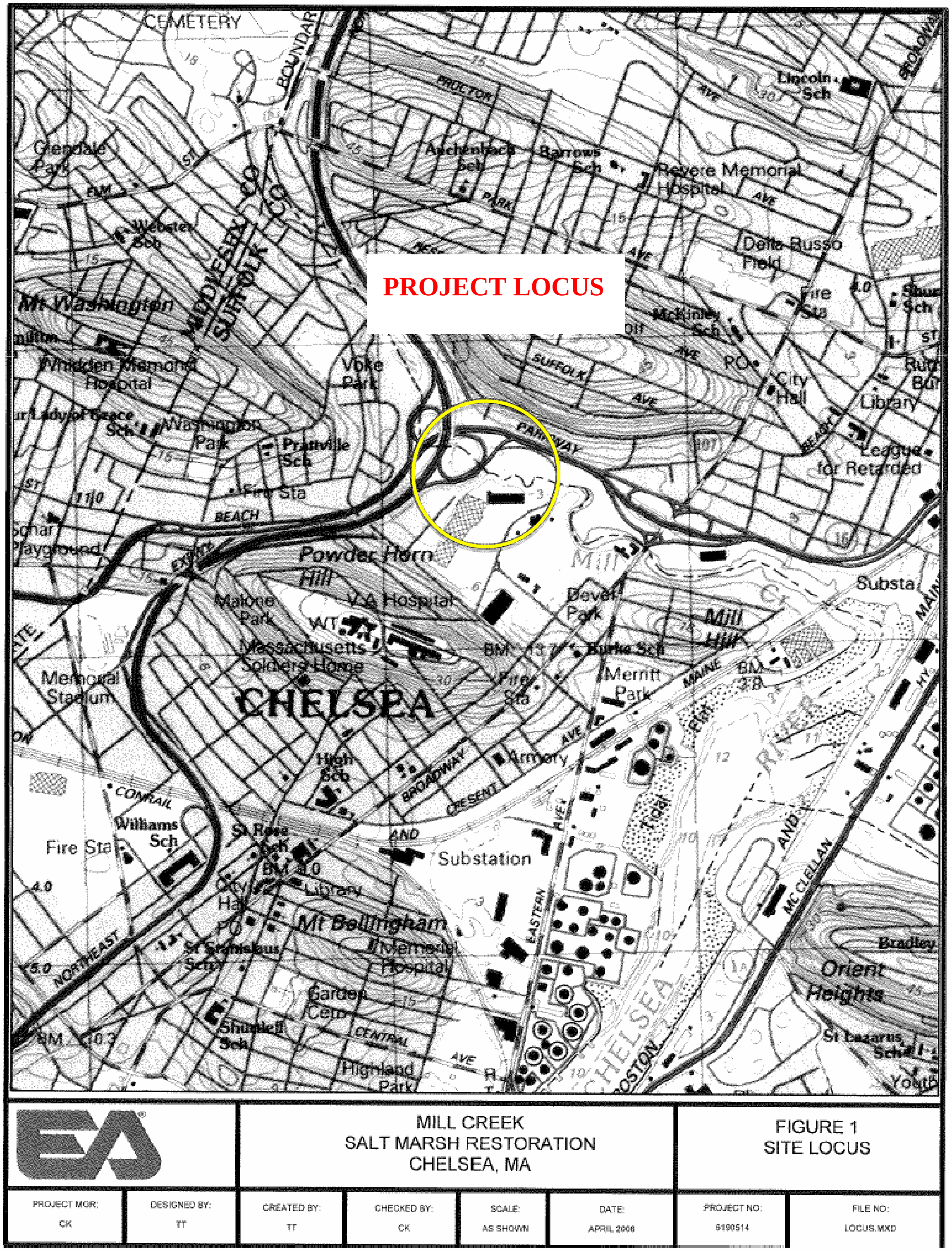

Figure 1. Locus map for Mill Creek Salt Marsh Restoration, Chelsea, Massachusetts (from EA 2006).

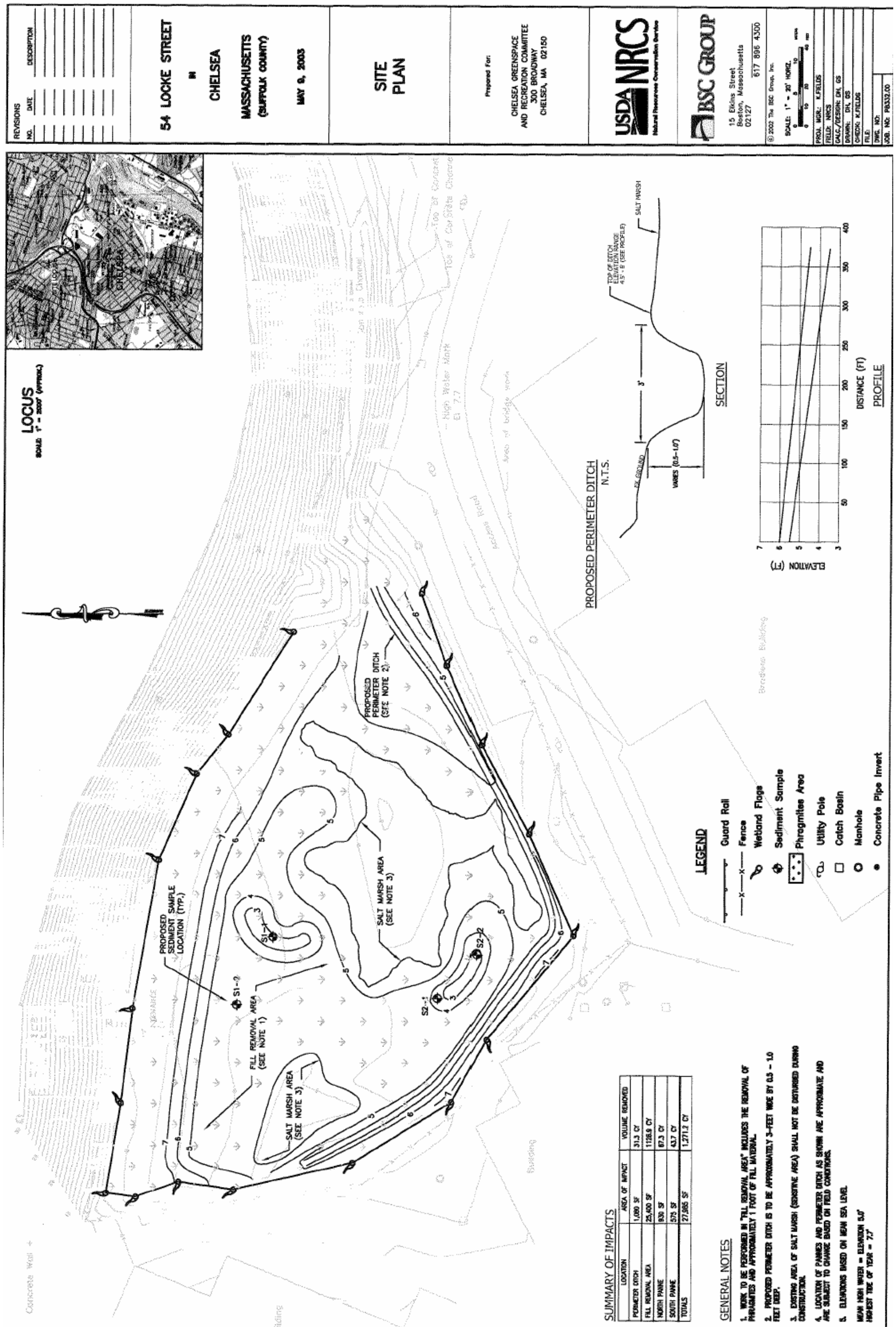

Figure 2. Site plan for Mill Creek Salt Marsh Restoration (from NOAA et al. 2003).

Methods

EA established five transects perpendicular to the main axis of the tidal creek in each of the impact and reference marshes in 2005 (EA 2006). Transects were separated by 18 meters (60 feet) and sample plot locations were separated by a minimum of 10 meters (33 feet). Three to six sample locations were marked with an oak stake on each transect and mapped using GPS (Figure 3), resulting in 20 stations in the impact marsh (data was available for only 19 of the 20 stations), and 23 stations in the reference marsh. EA stated they used the Gulf of Maine Salt Marsh Restoration Monitoring Protocol (Neckles et al. 2002) to assess abundance and height of plant species within 1.0 m^2 plots. However the actual percentage cover was not recorded, rather the standard cover class developed by the Massachusetts Office of Coastal Zone Management was used (Nedeau 2002). Instead of recording the height of the three tallest individuals for each species of concern, they recorded the average height of the three tallest individuals of each species found in each plot. Each plot was photographed by EA, except those plots where *Phragmites* dominated the vegetation (EA 2006).

Using the station map (Figure 3) and waypoint coordinates pre-loaded into a differential GPS, we relocated EA's original 2005 sampling stations in September 2007, two growing seasons following construction and planting activities. We collected data at 21 stations in the restoration marsh (two stations were sampled near the station EA missed in 2005), and 23 stations at the reference marsh. We collected year-two data on plant abundance by species using visual estimates of percent cover. We also recorded the heights of the three tallest individuals and the stem number of the species of concern (*Phragmites)*, at each plot as described by the protocol (Neckles et al. 2002). Species richness is the total number of species found within all the plots at each marsh. Species frequency was calculated as the number of plots with a specific species divided by the total number of plots. To compare our data with pre-restoration data, we later coded our percentage cover to the Mass CZM cover classes (0-1% = 1%; 2-4% =3%; 5-10% = 7%; 11-19% = 15%; 20-30% = 25%; 31-45% = 38%; 46-64% = 55%; 65-87% = 76%; 88-100% = 94%). Cover class data from 2005 and 2007 were presented and analyzed as relative abundance (Sum % cover for each species divided by Sum % cover for all species).

Data were input to Excel spreadsheets and analyzed using JMP statistical software (v. 6.0). For statistical comparisons, plants were grouped into native salt marsh plants, *Spartina* species, and invasive species (*Phragmites* at both restored and reference sites). We used Two-Way ANOVA for the BACI design. Statistical tests were considered significant if $P<0.05$ (alpha = 0.05). Analyses of plant abundance were examined for deviations from the assumptions of ANOVA. Although error was distributed evenly, the distribution of residuals failed tests for normality with raw and transformed data (log-transformed and odd logs-transformed), producing non-normal distributions of residuals. However, all the transformations produced the same conclusions regarding native, invasive and *Spartina* species abundance. Therefore, results from analyses using the raw data are presented. *Spartina* species planted for the project (*S. alterniflora* and *S. patens*) were combined with *Distichlis spicata* due to the differences between years at the reference marsh (EA may have had difficulty in distinguishing between *S. patens* and *D. spicata)*.

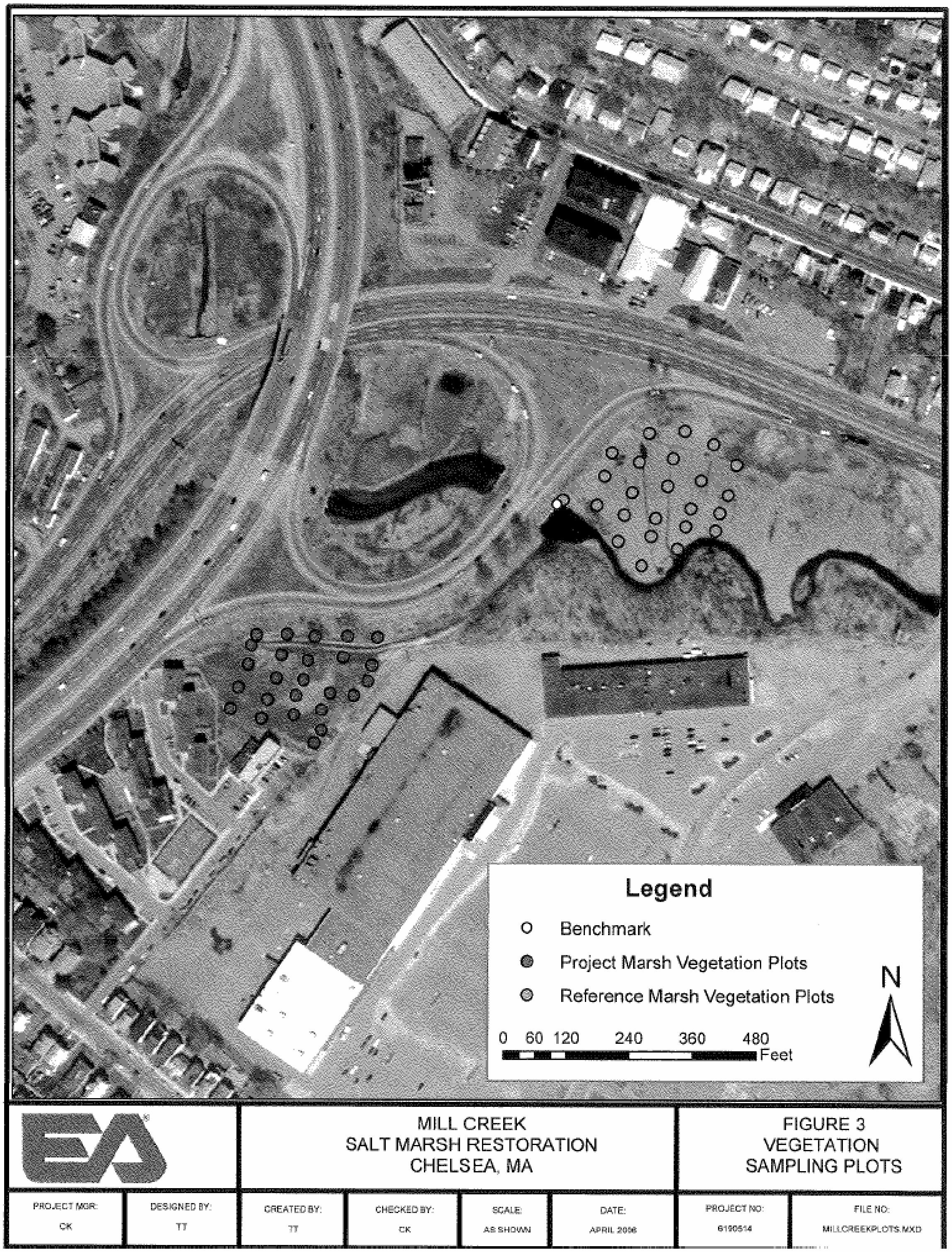

Figure 3. Location of vegetation stations in the impacted and reference marshes of Mill Creek. (from EA 2006).

Results

A summary of plant data is shown in Table 1. Prior to restoration activities at the impacted marsh, *Phragmites* was the plant most frequently found in plots (95%) and dominated the landscape with over 67% cover. *Spartina patens* (salt hay) *and Solidago sempervirens* (seaside goldenrod) were the next most frequently observed plants, each appearing in about 25% of samples, but together making up only 13% cover. Figure 4 is a photo collage of the site, showing the dominance of *Phragmites*, and conditions following its removal. Two growing seasons following the restoration, *Phragmites* was less dominant, but remained the most frequently observed plant (57%). *Spartina alterniflora* (smooth cordgrass) *and Salicornia europaea* (saltwort), which were not found in the 2005 samples, were the next most frequently observed plants (52% each). We found both smooth cordgrass and salt hay planted at the site, and the plot average of cover class midpoints was 16% and 6%, respectively. The remaining *Phragmites* still showed the greatest cover of an individual species at the restoration site (29%). If the restoration is successful, we would expect the *Spartina* species to increase in cover in the future. However, the success of the restoration will hinge on whether native grasses will continue to recolonize the area and, together with the influence of tidal flooding, prevent re-establishment of a dominant *Phragmites* community.

The number of plant species observed in the restoration marsh plots increased from five to fourteen taxa between 2005 and 2007 (Table 1). Salt marsh species increased from three to ten species. *Spartina alterniflora* (smooth cordgrass) existed at the site but was not observed within the plots (its abundance was increased by planting). Other additions can be ascribed to the restoration activities.

At the reference marsh in 2005 and 2007, *Distichlis spicata* (spike grass) and *S. patens* were the co-dominants, contributing to about 75% cover. *Phragmites* is invading the marsh along the upper edge along the highway verge and made up about 11% cover in the reference marsh (Figure 4). In 2005, seven species were found in the 23 plots, whereas ten species were found in these plots in 2007. The choice of reference site was not ideal for two reasons. First, the restoration area was excavated to a low marsh elevation that should support *S. alterniflora*, while the reference area is primarily high marsh supporting *S. patens* and *D. spicata*. Second, the reference area lies downstream of the restoration area and since the conditions in an upper reach may not be similar to those of a lower reach, it cannot be expected to replicate the reference marsh.

We also examined the cover data after grouping native marsh species (dominated by *Spartina* species) and invasive species (primarily *Phragmites*). Results show dramatic changes in the impacted marsh pre-restoration compared to post- restoration, but little change in the reference marsh (Figure 5). When the BACI design was tested statistically, a significant Marsh by Year interaction was found for invasive species cover (Table 2). Figure 5 shows this interaction as a loss of invasives over time at the restored site, but not at the reference site. Interestingly, the changes in the native species, including the planted *Spartina* species, were not as one might have expected. Excavation of the site to remove the *Phragmites* also removed substantial amounts of *S. patens* (cover fell from 12% to 6%). Even though the planting of the *S. alterniflora* replaced much of that lost (from 0% to 16%), the gains in *Spartina* and the other natives colonizing the site were not enough to show significant increases in native species cover (Table 2). Therefore for native plants and *Spartina* species the interactions were not significant, underlining the importance of continued monitoring at this site to show success not only in removing *Phragmites,* but in restoring native grass cover.

Table 1. Results from vegetation surveys in 2005 and 2007.

	Frequency (%)		**Relative Abundance (%)**	
	RESTORATION MARSH			
Species	2005 (n=19)	2007 (n=21)	2005 (n=19)	2007 (n=21)
Phragmites australis	94.7	57.1	66.9	29.4
Spartina patens	26.3	23.8	12.2	5.6
Bare	78.9	71.4	12.2	32.3
Distichlis spicata	5.3	14.3	4.0	4.6
Dead	10.5	57.1	3.3	5.4
Solidago sempervirens	21.1	23.8	1.1	2.5
Artemisia vulgaris	5.3	4.8	0.4	0.1
Spartina alterniflora	0.0	52.4	0.0	15.5
Salicornia europaea	0.0	52.4	0.0	3.3
Atriplex patula	0.0	23.8	0.0	0.5
Agrostis stolonifera	0.0	4.8	0.0	0.3
Limonium nashii	0.0	4.8	0.0	0.1
Festuca rubra	0.0	4.8	0.0	0.1
Suaeda linearis	0.0	9.5	0.0	0.1
Solanum dulcamara	0.0	4.8	0.0	0.1
Agalinas maritima	0.0	4.8	0.0	0.1
Species Richness	**5**	**14**		
	REFERENCE MARSH			
Species	2005 (n=23)	2007 (n=23)	2005 (n=23)	2007 (n=23)
Distichlis spicata	82.6	82.6	53.7	21.2
Spartina patens	56.5	95.7	19.0	55.1
Phragmites australis	17.4	13.0	12.1	10.7
Bare	78.3	52.2	6.8	3.9
Atriplex patula	21.7	30.4	3.7	0.6
Spartina alterniflora	8.7	8.7	3.6	1.4
Solidago sempervirens	8.7	4.3	0.8	0.7
Dead	7.7	56.5	0.2	5.7
Salicornia europaea	4.3	8.7	0.1	0.1
Agalinas maritima	0.0	17.4	0.0	0.3
Scripus pungens	0.0	4.3	0.0	0.3
Suaeda linearis	0.0	4.3	0.0	0.1
Species Richness	**7**	**10**		

Figure 4. a) Pre-restoration site visit (2005) with project partners Eric Hutchins (NOAA), Chuck Katuska (EA), David Burdick (UNH) and representatives from local community partners, including T.J. Hellmann and volunteer of the Chelsea Open Space and Recreation Committee; b) Post-restoration view showing same areas, now excavated (2006); c) View of reference marsh (2005); and d) View of restoration area interior during monitoring visit (2006).

Table 2. Results from Two-Way ANOVA of BACI monitoring design using several dependent variables. *Spartina* species includes cover of *Distichlis spicata*. Sample number, n, equals 86 for all variables but *Phragmites* Height, where n=33.

	Native Species	**Invasive Species**	**Species Richness**	***Spartina* Species**	***Phragmites* Height**
	R^2 / F / *P*	**R^2 / F / *P***	**R^2 / F / *P***	**R^2 / F / *P***	**R^2 / F / *P***
Whole Model	.47/23/.0001	.33/14/.0001	.18/5.8/.0011	.43/21/.0001	.22/2.7/.0647
Marsh	0.0001	0.0001	0.5354	0.0001	0.6766
Year	0.3466	0.0048	0.0001	0.3182	0.2990
Marsh * Year	0.2608	0.0087	0.2089	0.7953	0.0123

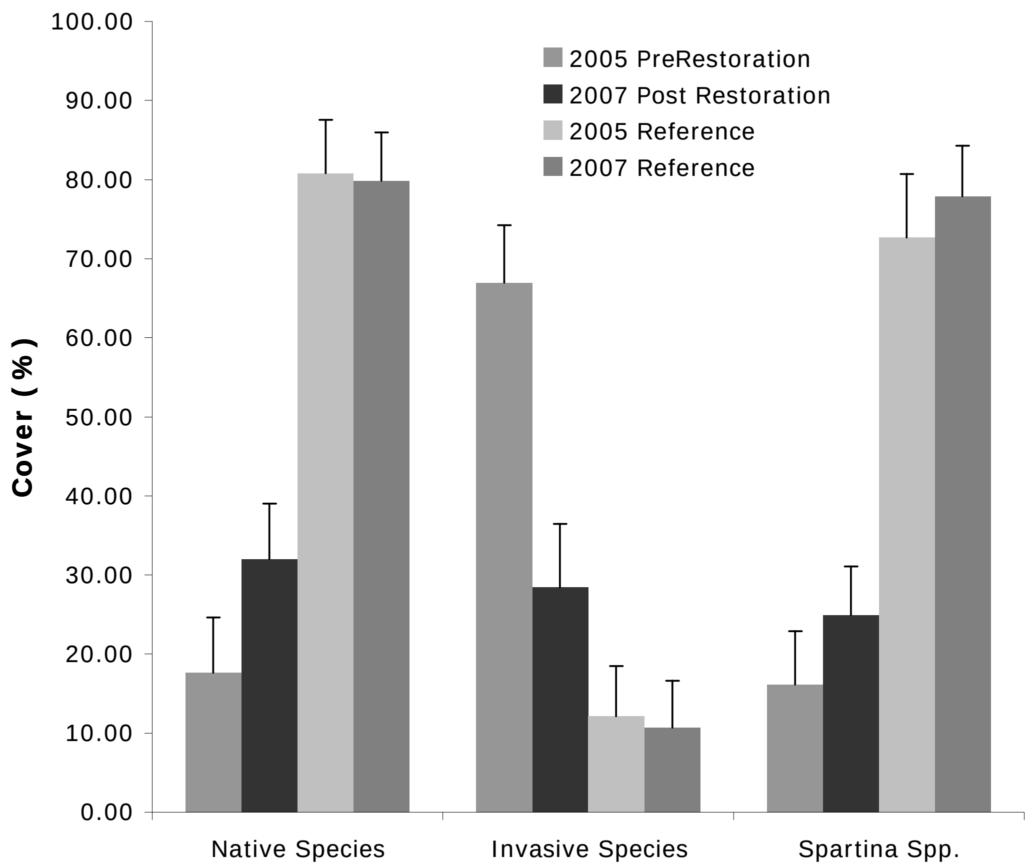

Figure 5. Cover class averages of native salt marsh plants, invasive species *(Phragmites australis*) and *Spartina* species (including *Distichlis spicata*), at restoration and reference marshes in 2005 (pre restoration) and 2007 (year two post restoration).

The average height of the three tallest *Phragmites* plants decreased in the restoration area from 240 cm (8 feet) in 2005 to 195 cm (6.5 feet) in 2007 (Figure 6). In addition, the number of plots where stem heights of *Phragmites* could be measured declined from 16 to 11 plots at the restoration marsh. At the reference marsh, sampling in 2007 included three plots in *Phragmites* stands that averaged 260 cm, whereas in 2005 these plots showed heights averaging only 140 cm. When a Two-Way ANOVA was used to analyze the data, the interaction term was significant (Table 2). The height and vigor of *Phragmites* at the restoration marsh was significantly reduced compared to the reference marsh.

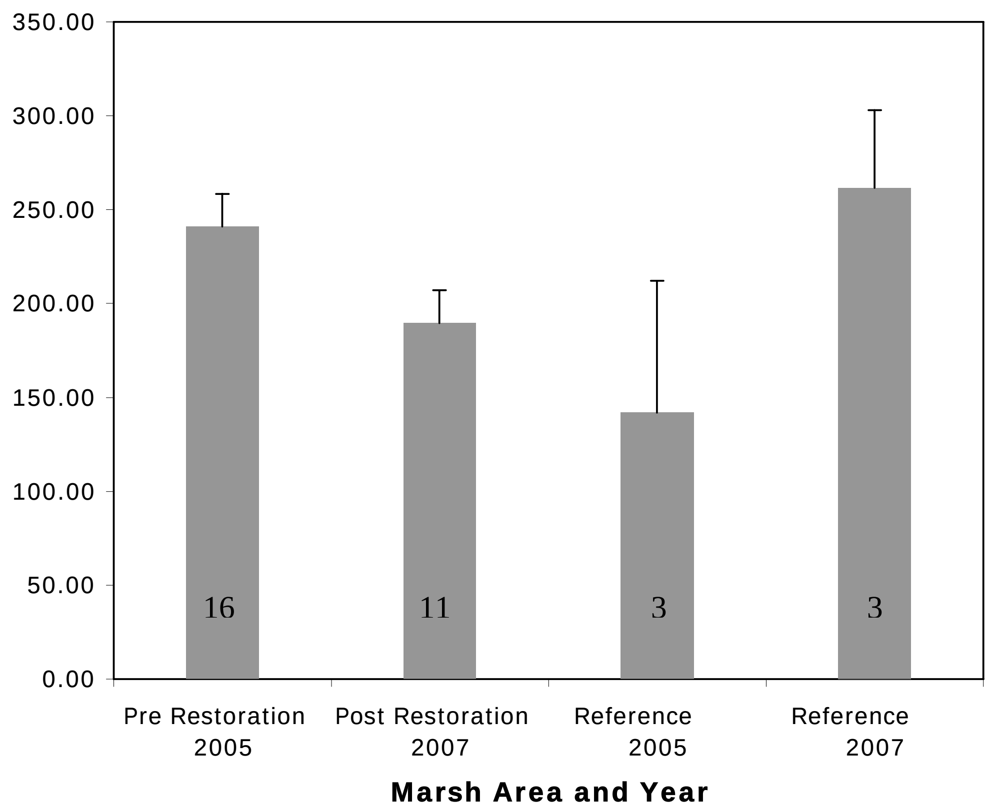

Figure 6. Average height and standard error of three tallest *Phragmites* plants within plots of the reference and restoration marshes. The sample number, n, is shown on each bar.

Discussion

The degraded marsh chosen for restoration was impacted for many years by stormwater flows and sediments, building up the marsh surface with coarse-grained inorganic sediments which has been shown to promote establishment and spread of the invasive, exotic form of *Phragmites australis* (Saltonstall 2002, Bart et al. 2006). Once established, *Phragmites* itself can alter sediment chemistry to favor its dominance until it becomes a monoculture (Windham and Lathrop 1999, Bart and Hartman 2000, Burdick and Konisky 2003). The restoration planners considered these factors and incorporated efforts by the Massachusetts Highway Department to retrofit stormwater drainage to prevent further sediments from flooding into the marsh on a regular basis into their restoration and management plan for the site. They also designed the restoration to excavate sediments and *Phragmites*. By removing the sediments and underground rhizomes of *Phragmites*, a substantial amount of reproductive capacity was removed. Furthermore, the area floods more often, increasing pore water salinity and sulfides. The increased flooding should stress *Phragmites* as it attempts to recolonize the area through heightened salinity and sulfide concentrations and decreased redox potential within the root zone (Chambers 1997, Burdick et al. 2001). If increased flooding conditions were achieved, plant height would be expected to decrease in response to physiological stress as we found (Table 2, Figure 6).

In the restored marsh, six species (perhaps excluded by the *Phragmites* prior to restoration) appear to have naturally colonized the exposed soils. The removal of *Phragmites* and greater tidal influence may have helped plants recolonize the marsh from the seed bank or from seed brought in by the tides (four of the new species were found in the nearby reference marsh).

Replanting the excavated area with *Spartina* plants was essential to the success of the restoration effort. Recent studies have shown that *Phragmites* trying to recolonize a similar excavated marsh had reduced success (increased mortality, decreased biomass and height) when *Spartina* species and other native plants were planted in an experiment in New Hampshire (Peter 2007). Planting is also a good idea because without planting, the period needed to naturally revegetate with native species in Gulf of Maine marshes can exceed eight years (Burdick et al. 1999).

While it is difficult to predict how successful this restoration project will be in the long term, it is clear that the major objectives (removal of the exotic variety of *Phragmites*, sediment excavation with partial perimeter ditch, increased and regular flooding by tidal waters) were achieved. One exception to positive results was for native plant cover, which was not found to increase significantly in the restoration marsh (Table 2). However, the planted *Spartina alterniflora* (smooth cordgrass) did survive at the site, increasing to 16% cover. We recommend consideration of integrated vegetation management plans at the site, such as use of manual (hand cutting) and chemical (herbicide) techniques, to build upon the progress documented at the site. Funding from regional and federal programs or non-government agencies could be obtained to support the effort, along with volunteer assistance and participation from local groups (such as the Friends of Chelsea Creek). We recommend further vegetation and fish assessment for the site. Research on east coast marshes has shown that fish are strongly influenced by *Phragmites* (Able et al. 2003), and in New England, fish and hydrology have played a key role in the assessment of restoration success (Dionne et al. 1999, Boumans et al. 2002). Nekton and hydrologic results collected from the site will be available soon (Burdick et al., in preparation) and may provide important information to help assess the restoration and guide adaptive management.

Acknowledgements

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References

Able, K. W., S. M. Hagan, and S.A. Brown. 2003. Mechanisms of marsh habitat alteration due to *Phragmites*: Response of young-of-the-year Mummichog (*Fundulus heteroclitus*) to treatment for *Phragmites* removal. *Estuaries* 26(2B): 484-494.

Bart, D., D. Burdick, R. Chambers and J. M. Hartman. 2006. Human facilitation of *Phragmites australis* invasions in tidal marshes: A review and synthesis. *Wetlands Ecology and Management* 14:53-65.

Bart, D. and J. M. Hartman. 2000. Environmental determinants of *Phragmites australis* expansion in a New Jersey salt marsh: an experimental approach. *Oikos* 89:59-69.

Boumans, R. M. J., D. M. Burdick, and M. Dionne. 2002. Modeling habitat change in salt marshes following tidal restoration. *Restoration Ecology* 10: 543-555.

Burdick, D. M., R. Buschbaum and E. Holt. 2001. Variation in soil salinity associated with expansion of *Phragmites australis* in salt marshes. *Environmental and Experimental Botany* 46: 247-261.

Burdick, D. M., R. M. Boumans, M. Dionne and F. T. Short. 1999. Impacts to salt marshes from tidal restrictions and ecological responses to tidal restoration. Final Report, NOAA, Sanctuaries and Reserves Division, Silver Spring, MD. 98 pp.

Burdick, D. M., R. Vincent, A. Eberhardt and C. Peter. 2007. Evaluation of post restoration conditions Awcomin Marsh, Rye, New Hampshire. Final Report, New Hampshire Coastal Program, NH DES, Portsmouth, NH. 56 pp.

Burdick, D. M., and R. A. Konisky. 2003. Determinants of expansion for *Phragmites australis*, common reed, in natural and impacted coastal marshes. *Estuaries* 26:407-416.

Chambers, R. M. 1997. Porewater chemistry associated with *Phragmites* and *Spartina* in a Connecticut tidal marsh. *Wetlands* 17:360-367.

Chambers, R. M., L. A. Meyerson, and K. Saltonstall. 1999. Expansion of *Phragmites australis* into tidal wetlands of North America. *Aquatic Botany* 64:261-273.

Dionne, M., F. T. Short and D. M. Burdick. 1999. Fish utilization of restored, created, and reference salt-marsh habitat in the Gulf of Maine. *American Fisheries Society Symposium* 22:384-404.

EA Engineering, Science and Technology, Inc. 2006. Pre-restoration vegetation monitoring Mill Creek Salt Marsh Restoration Project, Chelsea, Massachusetts. Memorandum to Eric Hutchins, NOAA Restoration Center, Gloucester, MA. 5 pp.

Neckles, H. A., M. Dionne, D. M. Burdick, C. T. Roman, R. Buchsbaum, and E. Hutchins. 2002. A monitoring protocol to assess tidal restoration of salt marshes on local and regional scales. *Restoration Ecology* 10:556-563.

Nedeau, E. J. (ed.). 2002. A Volunteer's Handbook For Monitoring New England Salt Marshes. Office of Coastal Zone Management, EOEA, Boston, MA. 151 pp.

National Oceanic and Atmospheric Administration, U.S. Department of the Interior (USF&WS), Massachusetts Executive Office of Environmental Affairs. 2003. Damage assessment and restoration plan / environmental assessment for the June 8, 2000 *T/V Posovina* oil spill. Draft. NOAA Restoration Center, Gloucester, MA. 39 pp.

Peter, C. 2007. Can Plant Competition and Diversity Reduce the Success of Exotic *Phragmites australis* invading a salt marsh? M.S. Thesis. University of New Hampshire, Durham, NH. 136 pp.

Saltonstall, K., 2002: Cryptic invasion by a non-native genotype of the common reed, *Phragmites australis*, into North America. *Proceedings of the National Academy of Sciences* 99:2445-2449.

Windham, L. and R. G. Lathrop, Jr. 1999. Effects of *Phragmites australis* (common reed) invasion on aboveground biomass and soil properties in brackish tidal marsh of the Mullica River, New Jersey. *Estuaries* 22:927-935.

Appendix 1. Station locations

Type of Marsh	TRANSECT #	EA plot #	GPS Coordinates
Excavation	1	1	N42 24.297 W71 01.542
Excavation	1	2	N42 24.293 W71 01.543
Excavation	1	3	N42 24.288 W71 01.548
Excavation	2	1	N42 24.298 W71 01.559
Excavation	2	2	N42 24.287 W71 01.563
Excavation	2	3	N42 24.282 W71 01.567
Excavation	2	4	N42 24.276 W71 01.565
Excavation	2	5	N42 24.271 W71 01.568
Excavation	3	1	N42 24.297 W71 01.572
Excavation	3	2	N42 24.292 W71 01.574
Excavation	3	3	N42 24.285 W71 01.578
Excavation	3	4	N42 24.279 W71 01.579
Excavation	4	1	N42 24.300 W71 01.584
Excavation	4	2	N42 24.294 W71 01.585
Excavation	4	3	N42 24.287 W71 01.588
Excavation	4	4	N42 24.277 W71 01.591
Excavation	5	1	N42 24.304 W71 01.595
Excavation	5	2	N42 24.298 W71 01.597
Excavation	5	3	N42 24.289 W71 01.602
Excavation	5	4	N42 24.283 W71 01.605
Reference	1	1	N42 24.345 W71 01.448
Reference	1	2	N42 24.354 W71 01.444
Reference	1	3	N42 24.360 W71 01.441
Reference	2	1	N42 24.333 W71 01.439
Reference	2	2	N42 24.341 W71 01.436
Reference	2	3	N42 24.349 W71 01.434
Reference	2	4	N42 24.359 W71 01.429
Reference	2	5	N42 24.367 W71 01.428
Reference	3	1	N42 24.325 W71 01.429
Reference	3	2	N42 24.332 W71 01.426
Reference	3	3	N42 24.337 W71 01.423
Reference	3	4	N42 24.351 W71 01.419
Reference	3	5	N42 24.360 W71 01.416
Reference	3	6	N42 24.369 W71 01.413
Reference	4	1	N42 24.331 W71 01.415
Reference	4	2	N42 24.338 W71 01.411
Reference	4	3	N42 24.343 W71 01.409
Reference	4	4	N42 24.354 W71 01.403
Reference	4	5	N42 24.363 W71 01.400
Reference	5	1	N42 24.337 W71 01.399
Reference	5	2	N42 24.342 W71 01.397
Reference	5	3	N42 24.349 W71 01.393
Reference	5	4	N42 24.358 W71 01.390

Appendix 2. Vegetation Data, Mill Creek, Chelsea, MA. Type of marsh is Excavated (restored) and Reference; Habitat types include high marsh (H), low marsh (L) and upland edge (UE). A) Pre-restoration data collected by EA (2006) as cover classes (Nedeau 2002) and adjusted to 100% cover by adding bare cover.

Site	DATE ASSESSED	Type of Marsh	TRANSECT #	EA plot #	Habitat	Bare Mud	Dead	Water	*Atriplex patula*	*Ambrosia artemisiifolia*	*Distichlis spicata*	*Phragmites australis*	Height 1	*Salicornia europaea*	*Solidago sempervirens*	*Spartina alterniflora*	*Spartina patens*	SA+SP+DS	% Native	% Invasive	Species Richness
Mill Cr	9/2/05	Ex	5	1	HIGH	6						94	290					0	0	94	1.0
Mill Cr	9/2/05	Ex	5	2	HIGH	6						94	312					0	0	94	1.0
Mill Cr	9/2/05	Ex	5	3	HIGH	6						94	312					0	0	94	1.0
Mill Cr	9/2/05	Ex	5	4	HIGH	6						94	254					0	0	94	1.0
Mill Cr	9/2/05	Ex	4	1	HIGH	7	55					38	300					0	0	38	1.0
Mill Cr	9/2/05	Ex	4	2	HIGH	6						94	310					0	0	94	1.0
Mill Cr	9/2/05	Ex	4	4	HIGH	6						94	241					0	0	94	1.0
Mill Cr	9/2/05	Ex	3	1	HIGH	6						94	284					0	0	94	1.0
Mill Cr	9/2/05	Ex	3	2	HIGH	6						94	330					0	0	94	1.0
Mill Cr	9/2/05	Ex	3	3	HIGH							35	163		10		55	55	65	35	3.0
Mill Cr	9/2/05	Ex	3	4	HIGH							25	173		3		72	72	75	25	3.0
Mill Cr	9/2/05	Ex	2	1	HIGH	82						15	130		3			0	3	15	2.0
Mill Cr	9/2/05	Ex	2	2	HIGH	9					76						15	91	91	0	2.0
Mill Cr	9/2/05	Ex	2	3	HIGH							56	229		5		39	39	44	56	3.0
Mill Cr	9/2/05	Ex	2	4	HIGH							50	135				50	50	50	50	2.0
Mill Cr	9/2/05	Ex	2	5	HIGH	17				7		76	168					0	7	76	2.0
Mill Cr	9/2/05	Ex	1	1	HIGH	38	7					55						0	0	55	1.0
Mill Cr	9/2/05	Ex	1	2	HIGH	24						76						0	0	76	1.0
Mill Cr	9/2/05	Ex	1	3	HIGH	6						94	229					0	0	94	1.0
Mill Cr	9/2/05	Ref	1	1	LOW	24										76		0	76	0	1.0
Mill Cr	9/2/05	Ref	1	2	HIGH						50						50	100	100	0	2.0
Mill Cr	9/2/05	Ref	1	3	HIGH						24						76	100	100	0	2.0
Mill Cr	9/2/05	Ref	2	1	HIGH	2	4		3		76						15	91	94	0	3.0
Mill Cr	9/2/05	Ref	2	2	HIGH	6					94							94	94	0	1.0
Mill Cr	9/2/05	Ref	2	3	HIGH	8					76			1			15	91	92	0	3.0
Mill Cr	9/2/05	Ref	2	4	HIGH	9					15						76	91	91	0	2.0

Site	DATE ASSESSED	Type of Marsh	TRANSECT #	EA plot #	Habitat	Bare Mud	Dead	Water	*Atriplex patula*	*Ambrosia artemisiifolia*	*Distichlis spicata*	*Phragmites australis*	Height 1	*Salicornia europaea*	*Solidago sempervirens*	*Spartina alterniflora*	*Spartina patens*	SA+SP+DS	% Native	% Invasive	Species Richness
Mill Cr	9/2/05	Ref	2	5	UE	21						76	64		3			0	3	76	2.0
Mill Cr	9/2/05	Ref	3	1	HIGH		1				92						7	99	99	0	2.0
Mill Cr	9/2/05	Ref	3	2	HIGH	6					94							94	94	0	1.0
Mill Cr	9/2/05	Ref	3	3	HIGH						75						25	100	100	0	2.0
Mill Cr	9/2/05	Ref	3	4	HIGH	5					95							95	95	0	1.0
Mill Cr	9/2/05	Ref	3	5	HIGH	4			5		76						15	91	96	0	3.0
Mill Cr	9/2/05	Ref	3	6	HIGH	15					55	15			15			55	70	15	3.0
Mill Cr	9/2/05	Ref	4	1	LOW						94					6		94	100	0	2.0
Mill Cr	9/2/05	Ref	4	2	HIGH	6			1		55						38	93	94	0	3.0
Mill Cr	9/2/05	Ref	4	3	HIGH	6			76		3						15	18	94	0	3.0
Mill Cr	9/2/05	Ref	4	4	HIGH	9					76						15	91	91	0	2.0
Mill Cr	9/2/05	Ref	4	5	UE	6						94	80					0	0	94	1.0
Mill Cr	9/2/05	Ref	5	1	HIGH	10					76						14	90	90	0	2.0
Mill Cr	9/2/05	Ref	5	2	HIGH	6					94							94	94	0	1.0
Mill Cr	9/2/05	Ref	5	3	HIGH	8			1		15						76	91	92	0	3.0
Mill Cr	9/2/05	Ref	5	4	UE	6						94	282					0	0	94	1.0

Appendix 2, continued. B) Post restoration data collected at restoration (excavation treatment) and reference marshes on September 19, 2006. Data coded to cover classes using Nedeau (2002) and adjusted to 100% using dead and bare cover, proportionally.

Type of Marsh	TRANSECT #	EA plot #	Habitat	Bare Mud	Dead	Water	*Agalinas maritima*	*Agrostis stolonifera*	*Atriplex patula*	*Artemisia vulgaris*	*Atrope belladonna*	*Distichlis spicata*	*Festuca rubra*	*Limonium nashii*	*Phragmites australis*	Total stems	*Salicornia europaea*	*Solidago sempervirens*	*Spartina alterniflora*	*Spartina patens*	*Suaeda linearis*	*Scirpus pungens*	*Vaucherria spp.*	% Native	SA+SP+DS	% Invasive	Species Richness	Phrag mean ht.
Ex	5	1	UE		24										76	27								0	0	76	1.0	310
Ex	5	2	H	22	2										76	137								0	0	76	1.0	210
Ex	5	2a	H	36											7	10	1		55				1	56	55	7	3.0	129
Ex	5	3	H	13	3												1		76				7	77	76	0	2.0	
Ex	5	4	H	54													1		38				7	39	38	0	2.0	
Ex	4	1	H	26	5												7		55				7	62	55	0	2.0	
Ex	4	2	H	96													1		3					4	3	0	2.0	
Ex	4	3	H	16													38		1	38			7	77	39	0	3.0	
Ex	4	4	UE	8	15				1						76	52								1	0	76	2.0	267
Ex	3	1	H		7				1			3		1	15	24	7	25	3	38			3	78	44	15	8.0	126
Ex	3	2	H						7			15			38	53		15		25				62	40	38	5.0	151
Ex	3	3	H	43													7		25				25	32	25	0	2.0	
Ex	3	4	H	96													1		3				1	4	3	0	2.0	
Ex	2	1	H	35													3		55				7	58	55	0	2.0	
Ex	2	2	H		16				1			76								7				84	83	0	3.0	
Ex	2	3	H	96											1		1	1	1					3	1	1	4.0	
Ex	2	4	UE	26	20			7	1	3			1		38	37		3			1			16	0	38	7.0	146
Ex	1	1	H	81	3		1								7	53				7	1			9	7	7	4.0	154
Ex	1	2	UE		3						3				94	61								3	0	94	2.0	188
Ex	1	3	UE	10	7										76	168		7						7	0	76	2.0	176
Ex	2	5	UE		4										94	50								0	0	94	1.0	226
Ref	1	1	H	3	15		1					25					1			55				82	80	0	4.0	
Ref	1	2	H		6		1					55								38				94	93	0	3.0	
Ref	1	3	H	5	19							38								38				76	76	0	2.0	
Ref	2	1	H	19			1					25								55				81	80	0	3.0	
Ref	2	2	H	0			3					25								72				100	97	0	3.0	

Type of Marsh	TRANSECT #	EA plot #	Habitat	Bare Mud	Dead	Water	*Agalinas maritima*	*Agrostis stolonifera*	*Atriplex patula*	*Artemisia vulgaris*	*Atrope belladonna*	*Distichlis spicata*	*Festuca rubra*	*Limonium nashii*	*Phragmites australis*	Total stems	*Salicornia europaea*	*Solidago sempervirens*	*Spartina alterniflora*	*Spartina patens*	*Suaeda linearis*	*Scirpus pungens*	*Vaucherria spp.*	% Native	SA+SP+DS	% Invasive	Species Richness	Phrag mean ht.
Ref	2	3	H	20								25								55				80	80	0	2.0	
Ref	2	4	H	5								7								88				95	95	0	2.0	
Ref	2	5	H	18								3			76	103				3				6	6	76	3.0	179
Ref	3	6	UE												76	47		15		3		7		25	3	76	4.0	300
Ref	3	1	H						3			24								73				100	97	0	3.0	
Ref	3	2	H		10				3			25							7	55				90	87	0	4.0	
Ref	3	3	H						1			25								76				102	101	0	3.0	
Ref	3	4	H		1							66								34				100	100	0	2.0	
Ref	3	5	L			3						25					1			72	3			101	97	0	4.0	
Ref	4	1	L	5	20							25							25	25				75	75	0	3.0	
Ref	4	2	H		6				3			15								76				94	91	0	3.0	
Ref	4	3	H	4	15				1			25								55				81	80	0	3.0	
Ref	4	4	H	9	15															76				76	76	0	1.0	
Ref	4	5	H	2	7							15								76				91	91	0	2.0	
Ref	5	1	H	1	7				1			15								76				92	91	0	3.0	
Ref	5	2	H									25								76				101	101	0	2.0	
Ref	5	3	H		5				1											94				95	94	0	2.0	
Ref	5	4	H		6										94	61								0	0	94	1.0	306

Appendix 2, continued. C) Post restoration data collected at restoration (excavation treatment) and reference marshes on September 19, 2006. Data uncoded.

Type of Marsh	TRANSECT #	EA plot #	Habitat	Bare Mud	Dead	Water	*Agalinas maritima*	*Agrostis stolonifera*	*Atriplex patula*	*Artemisia vulgaris*	*Atrope belladonna*	*Distichlis spicata*	*Festuca rubra*	*Limonium nashii*	*Phragmites australis*	Total stems	*Salicornia europaea*	*Solidago sempervirens*	*Spartina alterniflora*	*Spartina patens*	*Suaeda linearis*	*Scirpus pungens*	*Vaucheria sp.*	% Native	SA+SP+DS	% Invasive	Species Richness	Phragmites mean ht.
Ex	5	1	UE		15										85	27								0	0	85	1.0	310
Ex	5	2	H	18	2										80	137								0	0	80	1.0	210
Ex	5	2a	H	28											10	10	1		60				1	61	60	10	3.0	129
Ex	5	3	H	20	4												1		70				5	71	70	0	2.0	
Ex	5	4	H	50													1		45				5	46	45	0	2.0	
Ex	4	4	UE		15				0.5						85	52								0.5	0	85	2.0	267
Ex	4	3	H	14													45		1	35			5	81	36	0	3.0	
Ex	4	2	H	97													1		2					3	2	0	2.0	
Ex	4	1	H	30	5												5		50				10	55	50	0	2.0	
Ex	3	4	H	96													1		2				1	3	2	0	2.0	
Ex	3	3	H	40													10		30				20	40	30	0	2.0	
Ex	3	2	H						5			15			43	53		12		25				57	40	43	5.0	151
Ex	3	1	H	4	10				1			3		1	12	24	5	20	2	40			2	72	45	12	8.0	126
Ex	2	1	H	40													2		50				8	52	50	0	2.0	
Ex	2	2	H		19.5				0.5			70								10				80.5	80	0	3.0	
Ex	2	3	H	98											1		0.5	0.5	0.5					1.5	0.5	1	4.0	
Ex	2	4	UE	30	20			7	1	3			0.5		35	37		3			0.5			15	0	35	7.0	146
Ex	2	5	UE		5										95	50								0	0	95	1.0	226
Ex	1	3	UE	5	5										85	168		5						5	0	85	2.0	176
Ex	1	2	UE		7						3				90	61								3	0	90	2.0	188
Ex	1	1	H	80	1		0.5								10	53				8	0.5			9	8	10	4.0	154
Ref	1	3	H		10							45								45				90	90	0	2.0	
Ref	1	2	H		9.5		0.5					50								40				90.5	90	0	3.0	
Ref	1	1	H		13.5		1					25					0.5			60				86.5	85	0	4.0	
Ref	2	1	H	20			0.5					30								50				80.5	80	0	3.0	
Ref	2	2	H	5			3					22								70				95	92	0	3.0	
Ref	2	3	H	20								20								60				80	80	0	2.0	

Type of Marsh	TRANSECT #	EA plot #	Habitat	Bare Mud	Dead	Water	*Agalinas maritima*	*Agrostis stolonifera*	*Atriplex patula*	*Artemisia vulgaris*	*Atrope belladonna*	*Distichlis spicata*	*Festuca rubra*	*Limonium nashii*	*Phragmites australis*	Total stems	*Salicornia europaea*	*Solidago sempervirens*	*Spartina alterniflora*	*Spartina patens*	*Suaeda linearis*	*Scirpus pungens*	*Vaucheria sp.*	% Native	SA+SP+DS	% Invasive	Species Richness	Phragmites mean ht.
Ref	2	4	H	5								5								90				95	95	0	2.0	
Ref	2	5	H	9								3			85	103				3				6	6	85	3.0	179
Ref	3	6	UE												77	47		15		3		5		23	3	77	4.0	300
Ref	3	5	L	8		4						23					1			66	2			92	89	0	4.0	
Ref	3	4	H		1							65								34				99	99	0	2.0	
Ref	3	3	H		10				0.5			24.5								65				90	89.5	0	3.0	
Ref	3	2	H		10				2			28							10	50				90	88	0	4.0	
Ref	3	1	H		5				3			22								70				95	92	0	3.0	
Ref	4	1	L		20							30							20	30				80	80	0	3.0	
Ref	4	2	H		10				2			18								70				90	88	0	3.0	
Ref	4	3	H		15				1			30								54				85	84	0	3.0	
Ref	4	4	H		15															85				85	85	0	1.0	
Ref	4	5	H		5							15								80				95	95	0	2.0	
Ref	5	4	H		5										95	61								0	0	95	1.0	306
Ref	5	3	H		9.5				0.5											90				90.5	90	0	2.0	
Ref	5	2	H		10							25								65				90	90	0	2.0	
Ref	5	1	H		10				1			19								70				90	89	0	3.0	

Appendix 2, continued. D) Post restoration data on *Phragmites australis* collected at restoration (excavation treatment) and reference marshes on September 19, 2006.

Type of Marsh	TRANSECT #	EA plot #	Habitat	*Phragmites australis*	Total stems	Height 1	Height 2	Height 3	*Phragmites* mean ht. (cm)
Ex	5	1	UE	85	27	331	297	302	310
Ex	5	2	H	80	137	207	202	221	210
Ex	5	2a	H	10	10	141	121	126	129
Ex	4	4	UE	85	52	259	257	286	267
Ex	3	2	H	43	53	152	150	150	151
Ex	3	1	H	12	24	144	114	121	126
Ex	2	3	H	1	0				
Ex	2	4	UE	35	37	143	148	148	146
Ex	2	5	UE	95	50	215	220	244	226
Ex	1	3	UE	85	168	176	174	179	176
Ex	1	2	UE	90	61	188	195	180	188
Ex	1	1	H	10	53	200		107	154
Ref	2	5	H	85	103	180	183	173	179
Ref	3	6	UE	77	47	292	296	313	300
Ref	5	4	H	95	61	314	302	301	306