HISTORICAL SALT MARSH RESTORATION IN MASSACHUSETTS:

A COMPARATIVE STUDY OF PRE-RESTORATION AND POST-RESTORATION BIOLOGICAL MONITORING DATA

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Massachusetts Office of Coastal Zone Management
Executive Office of Energy and Environmental Affairs
Commonwealth of Massachusetts

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1. Introduction

Salt marshes are among the most productive ecosystems on earth, providing important habitat for various life stages of fish, shellfish, and other wildlife and critical protections against flooding, water quality impairments, storm surge, and sea level rise. Tidal flow is essential for the health and productivity of the marsh, but is often altered, or restricted, by the construction of roads and other features. Restrictions can reduce or eliminate tidal flooding – necessary for marsh ecological processes – and can reduce drainage of fresh water upstream, leading to the replacement of native halophytes by less salt tolerant species such as the non-native reed, *Phragmites australis* (Burdick and Roman 2012). The widespread impacts recognized as a result of tidal restrictions have led to a push towards removal and restoration of tidal flow and salt marsh condition.

For close to twenty years, the U.S. Environmental Protection Agency (EPA) has been encouraging states to develop monitoring and assessment methods for wetlands and to begin reporting on wetland condition, however because of the complexity of wetland systems, no systematic approach exists to measure, document, and describe the condition of coastal and inland wetlands. The Massachusetts Office of Coastal Zone Management (CZM) has been actively working since 1995 on projects to advance wetland assessment methods and approaches for coastal systems and to assist the Massachusetts Department of Environmental Protection (MassDEP) with the development and implementation of a statewide wetlands monitoring and assessment program.

To identify effective approaches for assessing wetland condition, particularly within salt marshes with restricted and restored tidal flow, CZM and partners completed several projects during 1995-2004 as part of the North Shore Wetland Assessment Project and Cape Cod Salt Marsh Assessment Project. These efforts generated a wealth of data on plant and animal communities and composition both prior to and after restoration. CZM revisited the same sample locations at these project sites in 2013, using similar collection methods to resample upstream and downstream areas. The goals of the study were to: (1) examine trends in plant and animal populations through time and (2) assess changes in condition as a result of tidal flow restoration. We hope the results of this study provide important information not only on status and trends, but also a path forward to effective wetland condition assessment.

2. Methods

Five salt marsh locations originally sampled prior to tidal flow restoration during the 1999-2003 time period were re-sampled in 2013 as part of this study (Table 1). In addition, two reference salt marsh sites located in relatively undisturbed watersheds of Cape Cod were re-sampled in 2013 for comparison--Great Island Creek in Barnstable, originally sampled in 1999, and Coast Guard Beach in Eastham, originally sampled in 2003. Vegetation and macroinvertebrates were collected at each site according to a standard protocol at locations upstream and downstream of areas where tidal flow was once restricted for pre-restoration data, and at the same locations again in 2013 after restorations had been completed. Locations upstream of restrictions (or former restrictions) were test sites, while locations downstream acted as control sites in this design. Vegetation transects and macroinvertebrate sampling locations were relocated by maps, aerial photos, GPS coordinates, and field measurements. Original staff of the previous effort were also consulted to verify transect locations as necessary.

Table 1. Month and year of first and second sample collection with date of restoration.

Site	1st data collection	Restoration	2nd data collection
Mary Chase	September 2003	October 2003	September 2013
Bike Path	September 2001	April 2002	September 2013
Sage Lot Pond	August 2001	2008	September 2013
Conomo Point	July 2000	December 2000	August 2013
Little Neck	August 1999	April 2001	August 2013

2.1. Vegetation Surveys

At each salt marsh site, vegetation was surveyed along six transects established in 1999-2003 (see Table 1). The locations of transects were originally determined by first dividing the evaluation area into three sections, located at 100-foot intervals along a primary transect set parallel to the tidal creek. Then, in each of the sections, two transects were placed, for a total of six transects, with spacing determined by random number generation. The transects were oriented to run from the creek bank (primary transect) to the upland edge, on a consistent compass bearing (Figure 1).

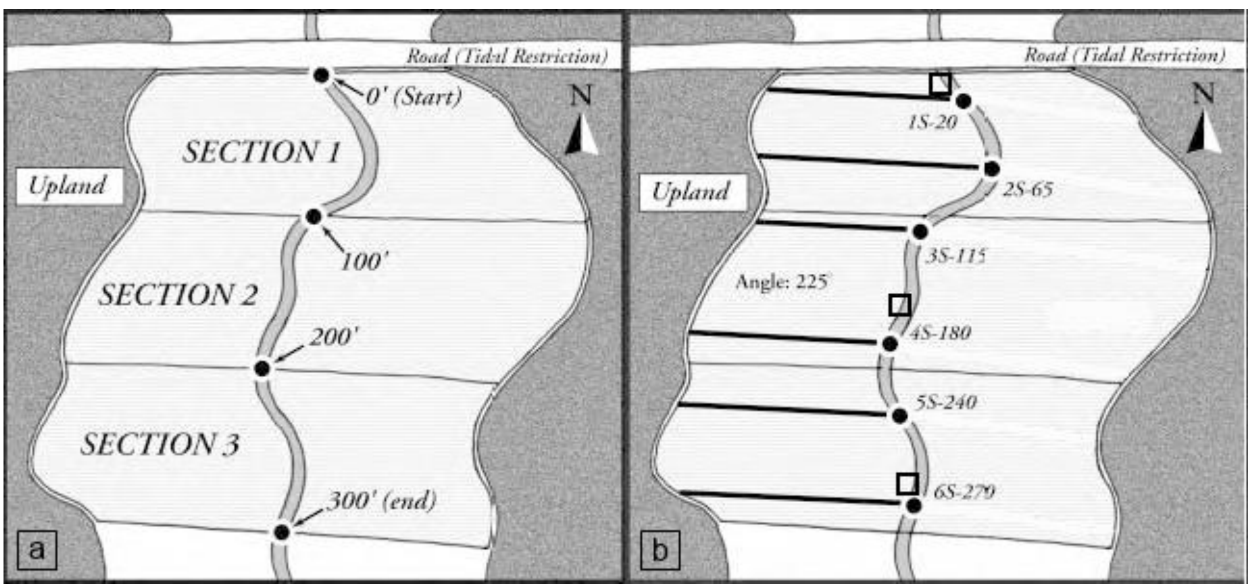

Figure 1. (a) Example of a salt marsh site divided into three sections for preliminary sampling design. (b) Overview of typical sampling plot with vegetation transects and macroinvertebrate sampling locations (squares). Adapted from Carlisle et al. 2002.

Vegetation was sampled along each transect within 1 x 1 m plots placed at 60 ft intervals, starting at the creek edge and progressing along the entire length of the transect up to the upland edge. The last plot was always located in the salt marsh border/fringe community, so if the regular plot interval occurred in the upland above this community, it was moved back on the transect until it was located in the border and that distance on the transect was noted on the data sheet. In each plot, every plant was identified to species and denoted on the field data sheet. For each species within the plot, the abundance was determined by comparing the visual estimates of at least two investigators and then applying a standard cover class value for nine coverage ranges. The community type (low marsh, high marsh, or fringe) for each plot was also recorded. Coverage estimates also included areas within the 1 x 1 m plot that were not occupied by living, rooted plants, including wrack, inorganic matter, bare ground, and open water.

2.2. Macroinvertebrate Surveys

The sampling protocol was designed to survey representative populations of macroinvertebrates from the sub- or inter-tidal open water feature (channel, bay, pond) and the inter-tidal salt marsh bank (generally characterized by the tall form *Spartina alterniflora*). Within the salt marsh evaluation area, sampling stations were located along the primary transect or spine located adjacent to the marsh creek at the following three intervals from the starting point: 0 to 20 feet, 140 to 160 feet, and 280 to 300 feet (Figure 1). At each of the three invertebrate stations, the following discrete samples were collected: one D-Net sweep along the edge of the bank, one approx 3 inch diameter auger sample from top of substrate to a depth of approximately 6 inches, and one half meter survey plot on the marsh surface adjacent to the bank of the creek. Species in the quadrat samples were identified on site where possible. Auger samples were sieved through .5mm mesh on site, and then along with the D-net samples, placed in sealed and labeled bags, preserved in 70% ethanol, and stored in a cooler during travel and refrigerator for longer term storage prior to post-processing and identification in the laboratory. For past surveys, all samples were pooled into a composite and identified to the lowest possible taxon, with the exception of insects which were identified to phyla. Current samples were identified to the lowest possible taxon, however the data were pooled together similar to the past data collection to enable comparisons of the data through time.

2.3. Comparative Study

To compare the response of plant and macroinvertebrate communities through time, pre- and post-restoration, we are primarily interested in the community upstream of the former tidal restriction changes or becomes more similar to the community downstream as tidal flow and salinity is restored to upper portions. To examine this we used paired t-tests of difference in means to avoid violating assumptions of data independence as the upstream/downstream pairs are correlated in space and time. Means were log (x+1) transformed for normalization purposes as necessary. Similarity (or dissimilarly) tests of community composition both upstream and downstream of the restored area were also calculated. For vegetation and macroinvertebrates separately Jaccard dissimilarities were calculated for each upstream/downstream pair sampled and for reference and sample sites overall. In addition, general trends were examined in the data by constructing abundance metrics for both the plant and macroinvertebrate community as described in Table 2.

Table 2. Abundance and species richness metrics calculated to describe plant and macroinvertebrate communities through time.

Group	Metric	Description
Macroinvertebrates	Taxa richness	total of number taxa found per site (or mean for multiple sites)
	Annelid abundance	total number of annelids collected per site (or mean for multiple sites)
	Insect abundance	total number of insects collected per site (or mean for multiple sites)
Plants	Species richness	total number of species found per site (or mean for multiple sites)
	Halophytes	relative abundance of halophytes (salt tolerant plants) calculated by
	Low marsh species	relative abundance of low marsh species (defined as short-form *Spartina alterniflora*)
	High marsh species	relative abundance of high marsh species (example species include *Distichlis spicata*, *Spartina patens*, and *Symphyotrichum tenuifolium*)*
	Salt marsh border species	relative abundance of salt marsh border species (example species include *Baccharis halimifolia*, *Iva frutescens*, and *Solidago sempervirens*)*
	Brackish border species	relative abundance of brackish border species (example species include *Ammaranthus cannabinis*, *Festuca rubra*, and *Schoenoplectus robustus*)*
	Phragmites australis	relative abundance of *Phragmites australis*

* A complete list of plant species and their corresponding classes/metrics can be found in Appendix A.

3. Results

Results of the comparative study are presented for each site sampled. Information on each site, including year of restoration, acreage of tidal marsh restored, and project funding are provided when available. This is followed by results of metric and similarity analyses.

Flooded marsh at the Parker River National Wildlife Refuge, Newbury, MA.
Credit: Adrienne Pappal, CZM

3.1. Study Sites

The following five sites were each sampled prior to restoration of tidal flow and after in 2013. Both the upstream and downstream sides of the restriction/former restriction were sampled for each site.

Mary Chase, Eastham (EMC)

Description

The Mary Chase salt marsh is located within the Nauset Marsh embayment system on the outer arm of Cape Cod in the town of Eastham (Figure 2). A historic stone and earthen dike bisected the marsh, restricting tidal flows from Abelino Creek until a portion was removed in October of 2003. This significantly increased tidal flows to the marsh, however as the dike is considered a historic structure, complete removal was not permitted. As a result, areas upstream of the dike do not drain completely during ebb tide. The two sample pairs are located upstream and downstream of the historic dike, with an evaluation area of 8,623 m^2 and 12,601 m^2 respectively. For this analysis macroinvertebrate and vegetation data collected just prior to the restoration in August 2003 were compared to contemporary data collected in August 2013.

Restoration Snapshot

Year: 2003	**Size:** 7.8 acres of tidal wetland	**Funding:** $40,000	**Source:** NOAA Restoration Atlas

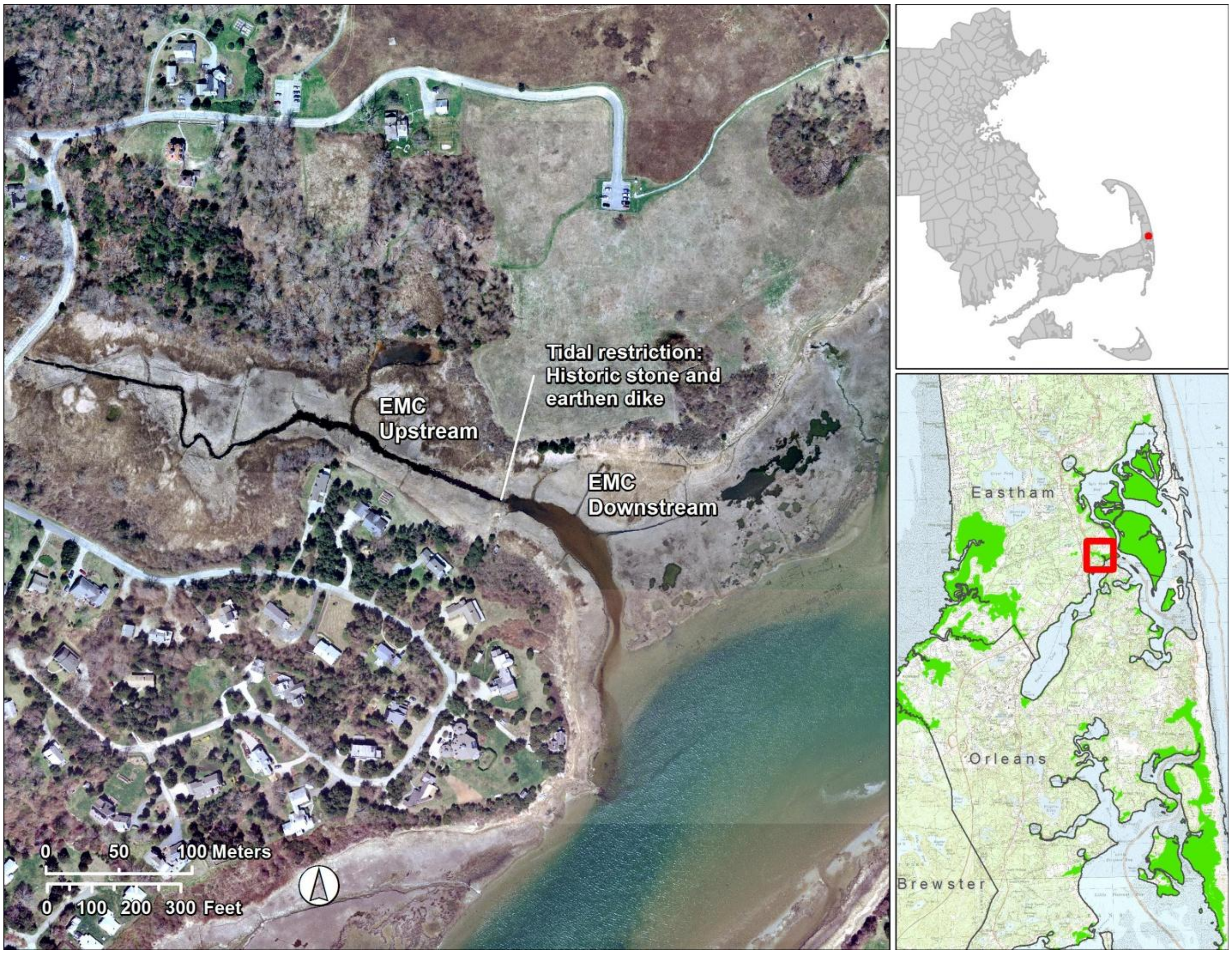

Figure 2. Overview map of the Mary Chase salt marsh sampling area.

Mary Chase salt marsh pre-restoration and during removal of the stone dike. *Credit: CZM*

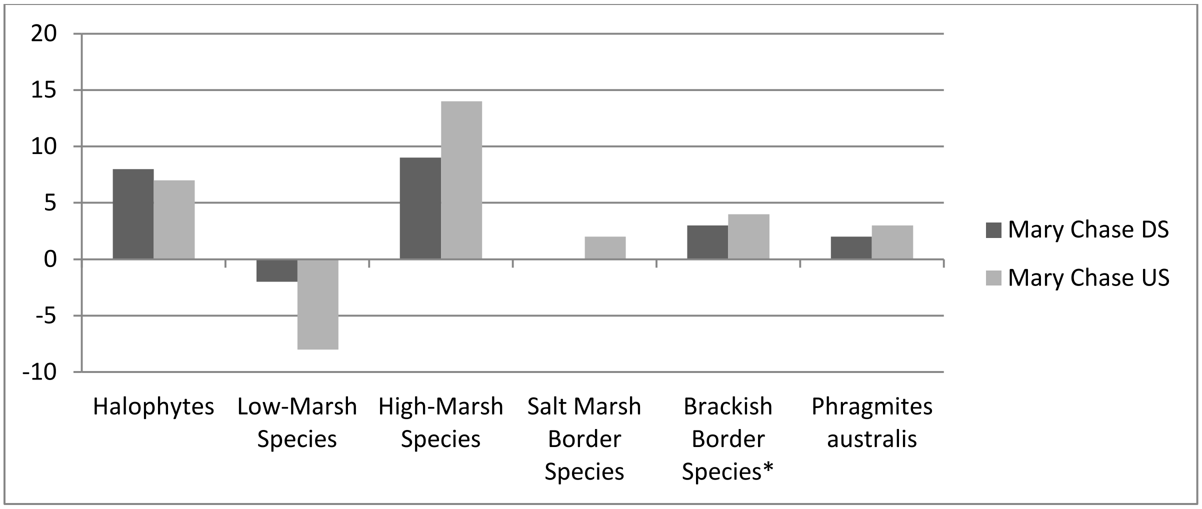

Figure 3. Change in vegetation metrics measured as relative (%) abundance from pre-restoration to post-restoration at the Mary Chase site for downstream (DS) and upstream (US) sample locations.

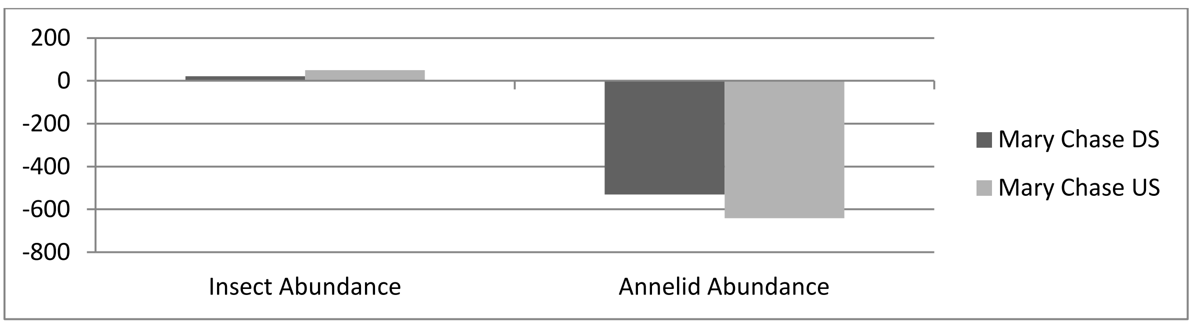

Figure 4. Change in macroinvertebrate metrics measured by number of individuals from pre-restoration to post-restoration at the Mary Chase site for downstream (DS) and upstream (US) sampling locations.

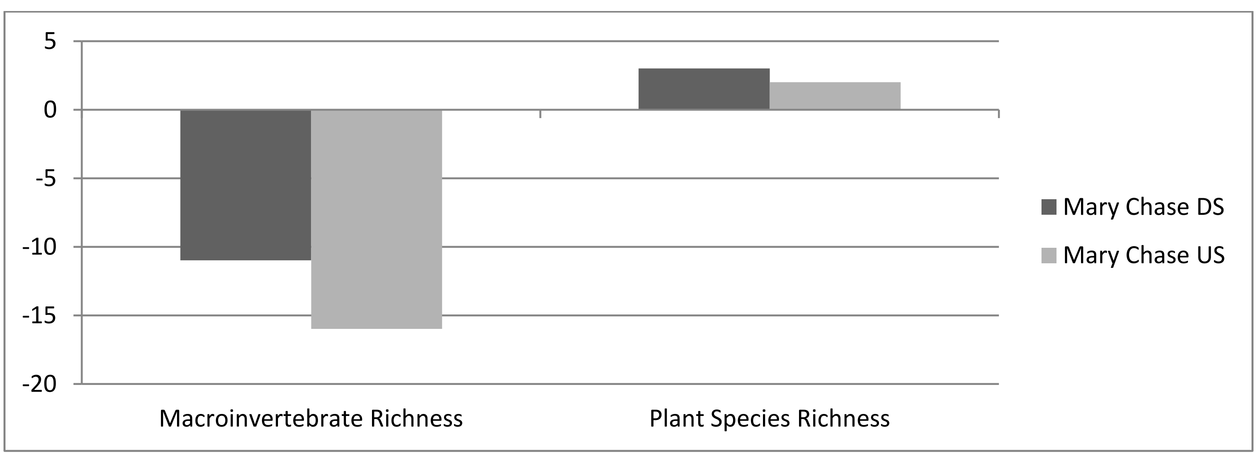

Figure 5. Change in richness measured by number of taxa (macroinvertebrates) or number of species (vegetation) from pre-restoration to post-restoration at the Mary Chase site for downstream (DS) and upstream (US) sampling locations.

Bike Path, Eastham/Orleans (EOBP)

Description

This marsh study area is located at the top of Boat Meadow Creek, in the towns of Eastham and Orleans (Figure 6). The Cape Cod Rail Trail, located on a former railroad causeway, bisects the marsh. The two sample areas, one upstream and one downstream from the bike path, are 13,188 m^2 and 17,335 m^2 respectively. In April 2002, tidal flow was restored under the causeway by removing an undersized culvert that was in a state of disrepair and replacing it with a new 4 x 6 ft pre-cast concrete box culvert. For this analysis, macroinvertebrate and vegetation data collected prior to the restoration in 2001 are compared to data collected in 2013.

Restoration Snapshot

Year: 2002 | **Size:** 7 acres of tidal wetland | **Funding:** $194,000 | **Source:** NOAA Restoration Atlas

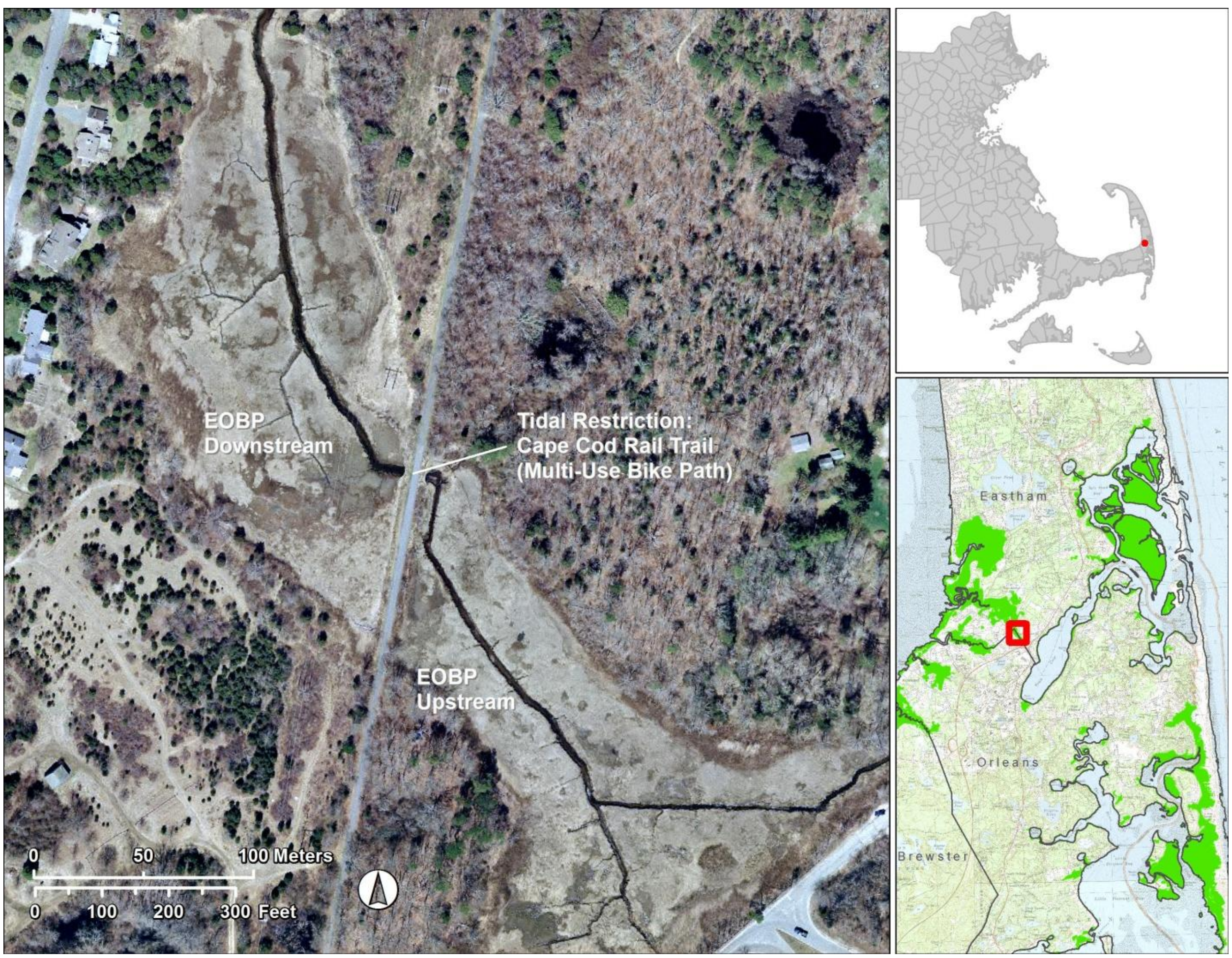

Figure 6. Overview map of the Bike Path salt marsh sampling area.

Conditions before and after culvert replacement at the Eastham Bike Path site. *Credit: CZM*

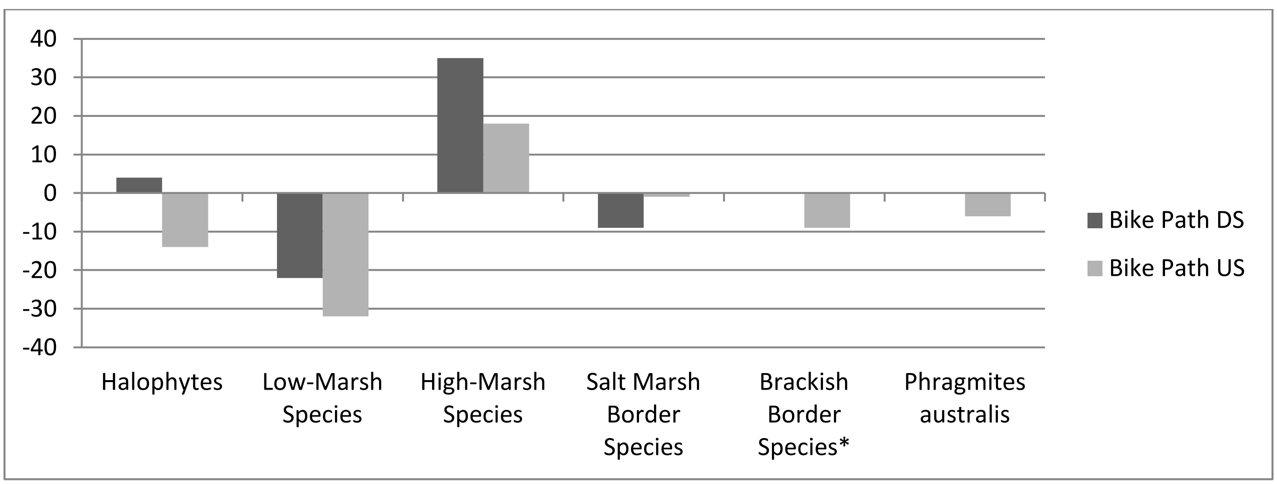

Figure 7. Change in vegetation metrics measured as relative (%) abundance from pre-restoration to post-restoration at the Bike Path Site for downstream (DS) and upstream (US) sample locations.

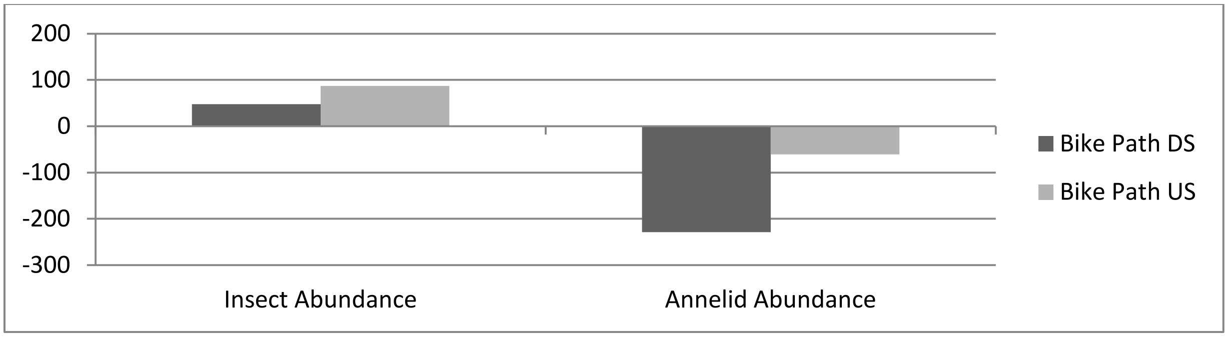

Figure 8. Change in macroinvertebrate metrics measured by number of individuals from pre-restoration to post-restoration at the Bike Path site for downstream (DS) and upstream (US) sampling locations.

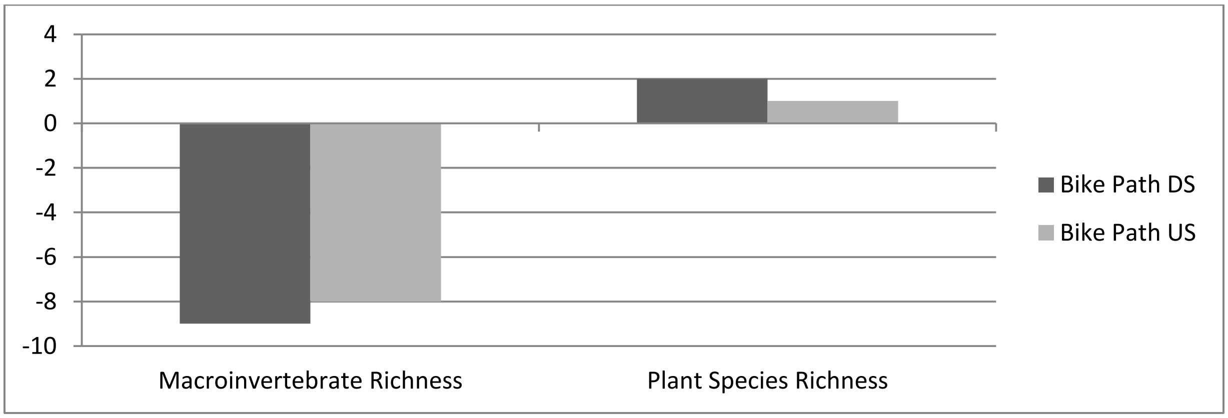

Figure 9. Change in richness measured by number of taxa (macroinvertebrates) or number of species (vegetation) from pre-restoration to post-restoration at the Bike Path site for downstream (DS) and upstream (US) sampling locations.

Sage Lot Pond, Mashpee (MSLP)

Description

Sage Lot Pond is located within the Waquoit Bay National Estuarine Research on land owned and managed by the Massachusetts Department of Conservation and Recreation. Tidal water flows into the marsh via Waquoit Bay and Sage Lot Pond, which is bisected by two roadway causeways. The two sample areas, upstream and downstream of these restrictions are 21,528 m^2 and 18,038 m^2 respectively. In 2008 tidal hydrology was restored to the site by removing two undersized culverts and replacing them with a larger box culvert and light duty bridge. For this analysis data collected in 2001 is compared with macroinvertebrate and vegetation data collected in 2013.

Restoration Snapshot

Year: 2008 | **Size:** 15 acres of tidal wetland | **Funding:** $349,360 | **Source:** NOAA Restoration Atlas

Figure 10. Overview map of the Sage Lot Pond salt marsh sampling area.

Culvert at Sage Lot Pond prior to replacement.
Credit: Jeremy Bell, Source: NOAA Restoration Atlas

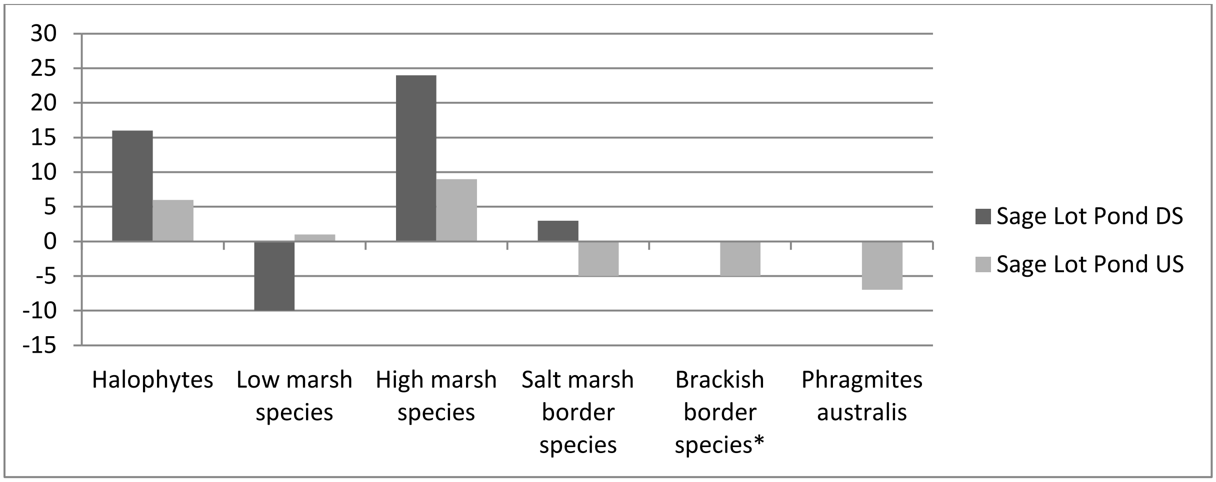

Figure 11. Change in vegetation metrics measured as relative (%) abundance from pre-restoration to post-restoration at the Sage Lot Pond site for downstream (DS) and upstream (US) sample locations.

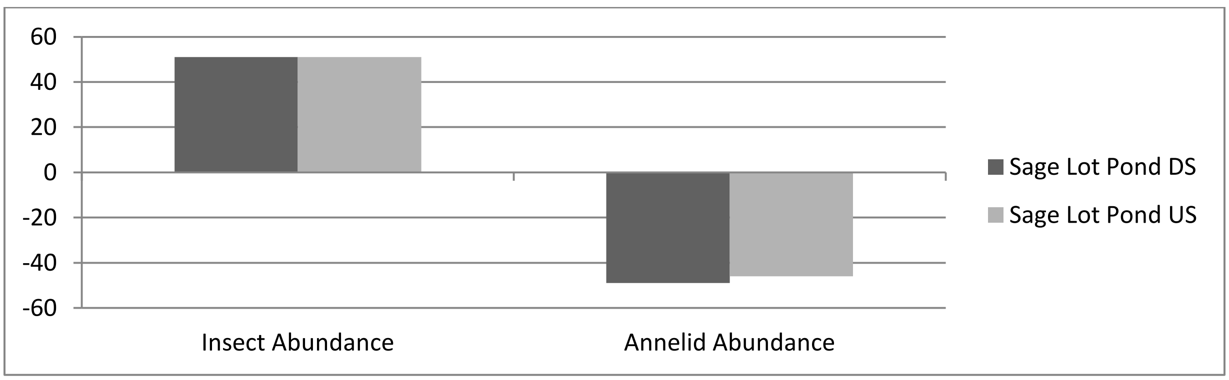

Figure 12. Change in macroinvertebrate metrics measured by number of individuals from pre-restoration to post-restoration at the Sage Lot Pond site for downstream (DS) and upstream (US) sampling locations.

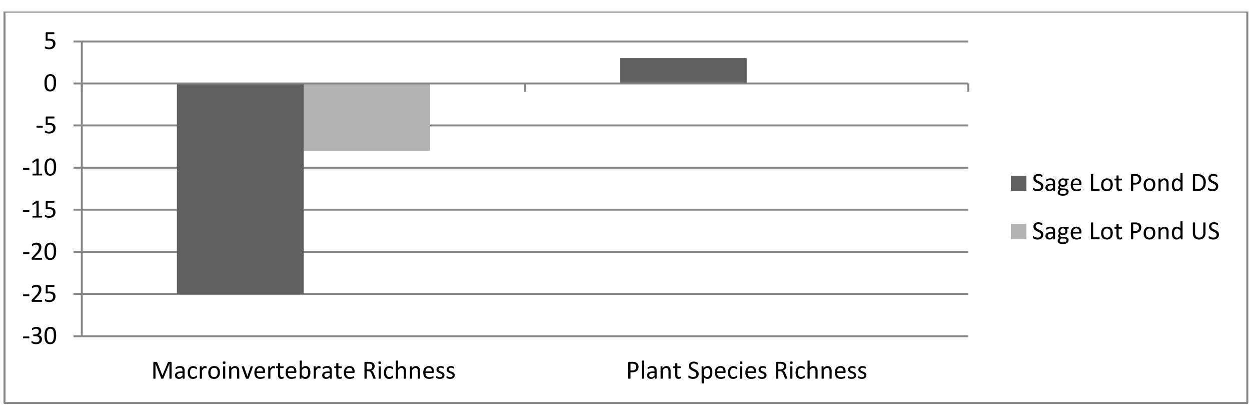

Figure 13. Change in richness measured by number of taxa (macroinvertebrates) or number of species (vegetation) from pre-restoration to post-restoration at the Sage Lot Pond site for downstream (DS) and upstream (US) sampling locations.

Conomo Point, Essex (ESS)

Description

The Conomo Point wetland is located on Conomo Point Road in Essex, MA. Prior to restoration a significant tidal restriction existed from a partially collapsed stone culvert under the two-lane paved road that bisects the marsh. The culvert was replaced in late 2000 with a 3 x 4 ft box culvert to increase tidal flow into the restricted 1.2 acre portion of the marsh. For this analysis, macroinvertebrate and vegetation collected in July 2000 prior to the restoration are compared to data collected in 2013.

Restoration Snapshot

Year: 2000 | **Size:** 1.2 acres of tidal wetland | **Funding:** $29,529 | **Source:** NOAA Restoration Atlas

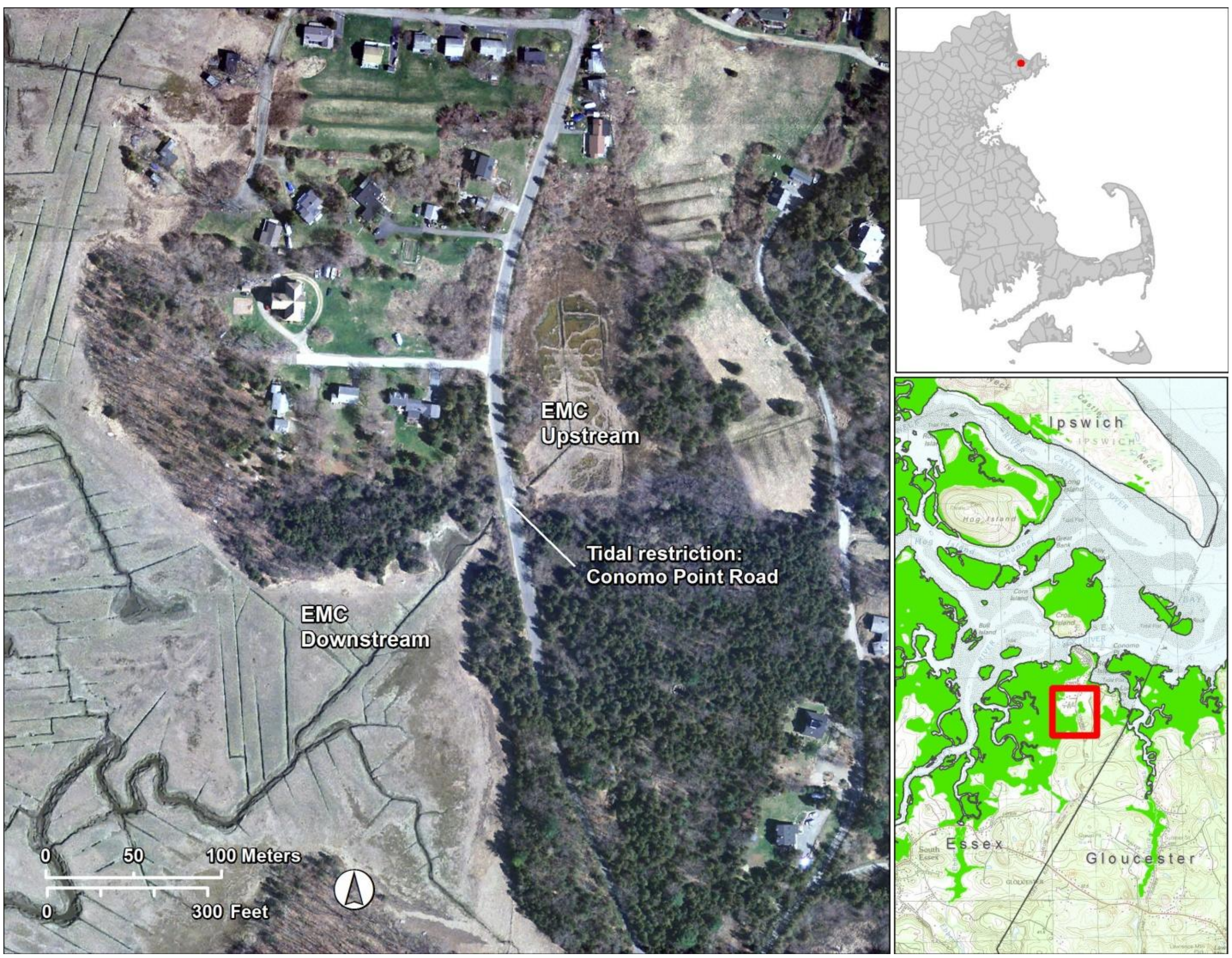

Figure 14. Overview map of the Conomo Point salt marsh sampling area.

Installation of the new box culvert at Conomo Point.
Source: NOAA Restoration Atlas

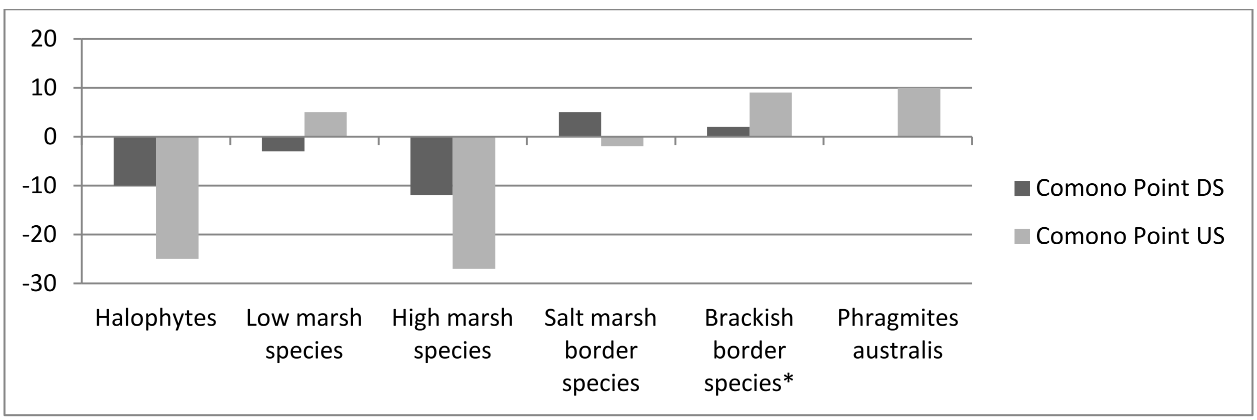

Figure 15. Change in vegetation metrics measured as relative (%) abundance from pre-restoration to post-restoration at the Conomo Point site for downstream (DS) and upstream (US) sample locations.

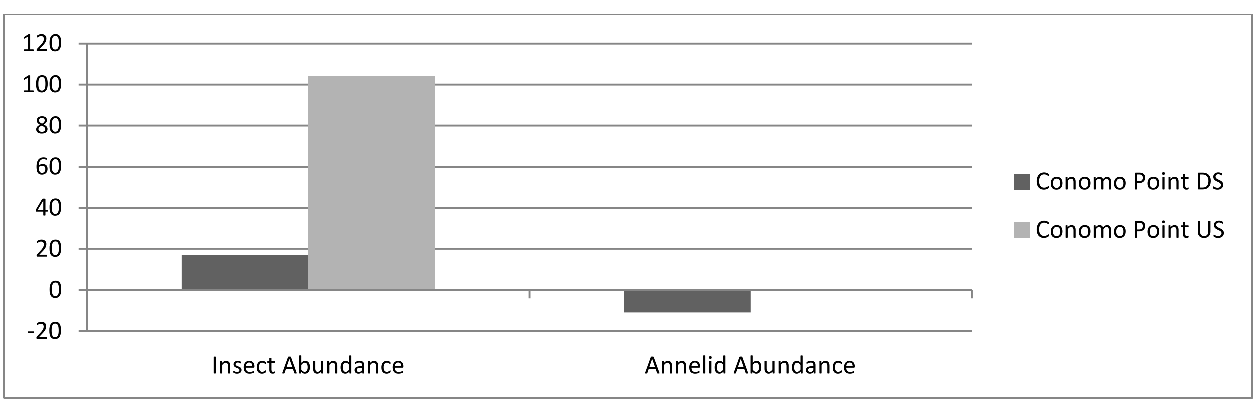

Figure 16. Change in macroinvertebrate metrics measured by number of individuals from pre-restoration to post-restoration at the Conomo Point site for downstream (DS) and upstream (US) sampling locations.

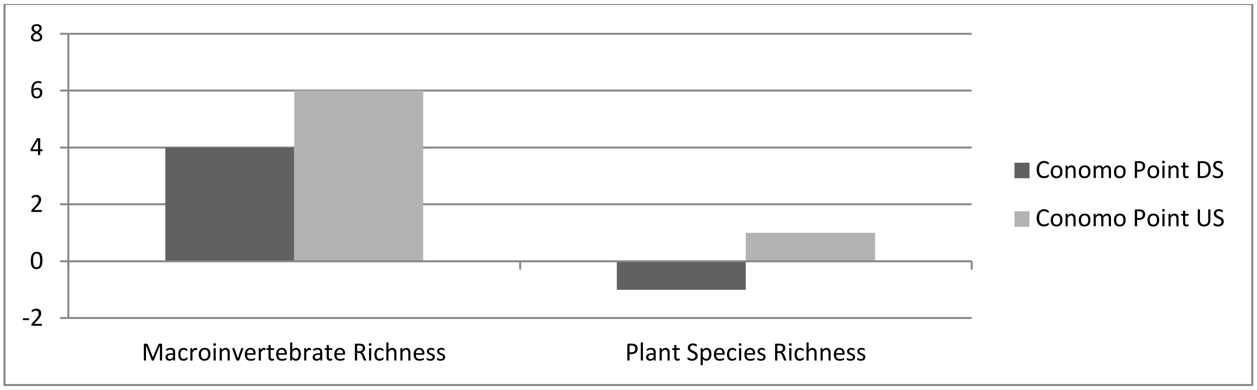

Figure 17. Change in richness measured by number of taxa (macroinvertebrates) or number of species (vegetation) from pre-restoration to post-restoration at the Conomo Point site for downstream (DS) and upstream (US) sampling locations.

Little Neck, Ipswich (IPS)

Description

The Little Neck salt marsh area is located on Great Neck in Ipswich, MA (Figure 18). Prior to restoration tidal flow was restricted by a small culvert beneath Little Neck Road, which bisects the marsh. In the spring of 2000, the culvert collapsed, undermining the road and resulting in reduced tidal flow and freshwater flooding of and ponding on the marsh surface. In June of 2001, the culvert was replaced with twin 43-inch wide by 27-inch high corrugated aluminum arch culverts to restore tidal flow to the area. For this analysis, macroinvertebrate and vegetation collected in August 1999 prior to the restoration are compared to data collected in 2013.

Restoration Snapshot

Year: 2001	**Size:** approximately 6 acres of tidal wetland	**Funding:** details not immediately available	**Source:** CZM

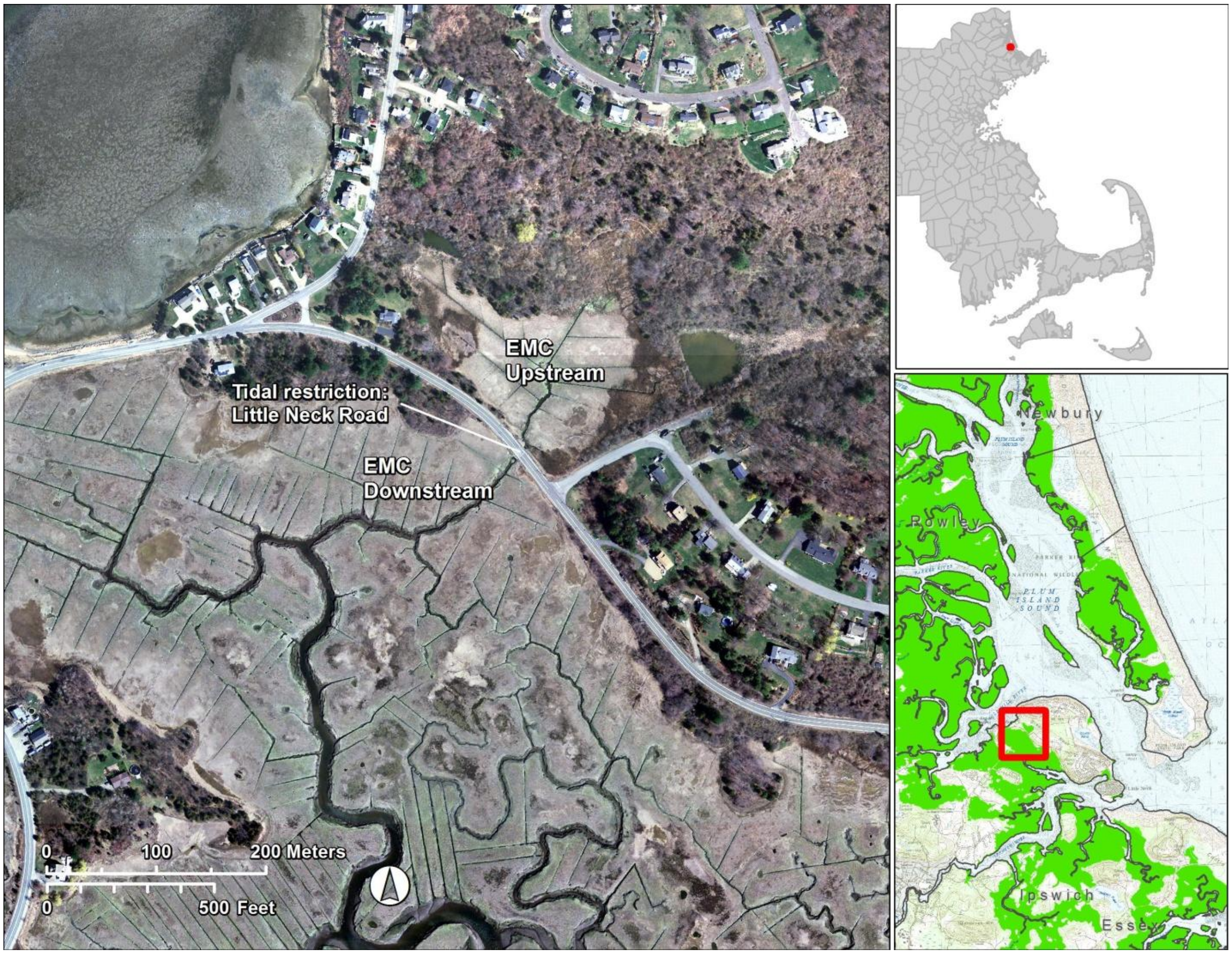

Figure 18. Overview map of the Little Neck salt marsh sampling area.

Vegetation and macroinvertebrate sampling in a salt marsh. *Credit: Chris Garby, CZM*

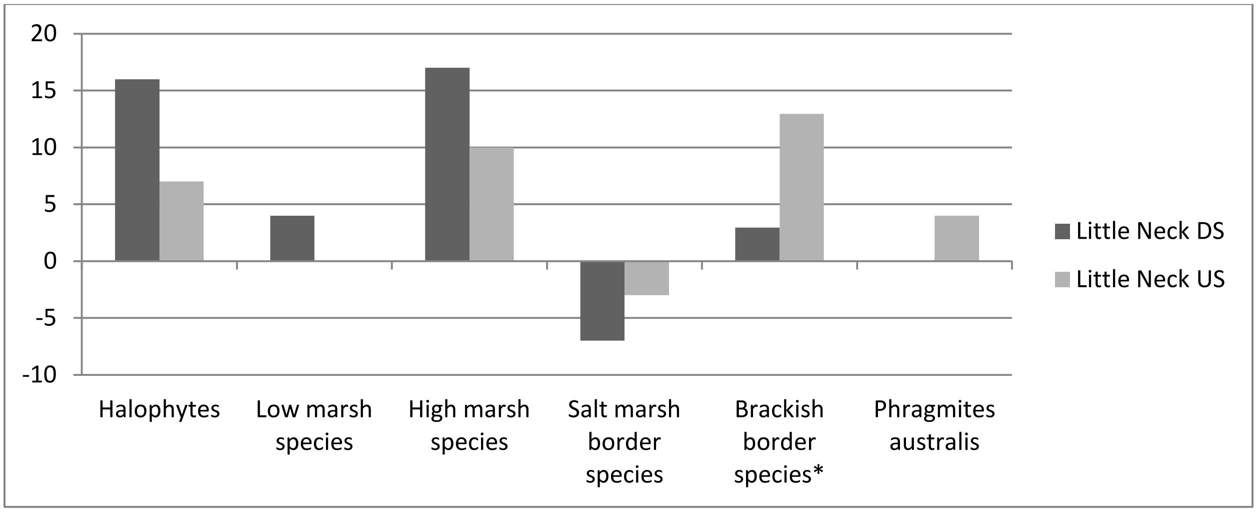

Figure 19. Change in vegetation metrics measured as relative (%) abundance from pre-restoration to post-restoration at the Little Neck Site for downstream (DS) and upstream (US) sample locations.

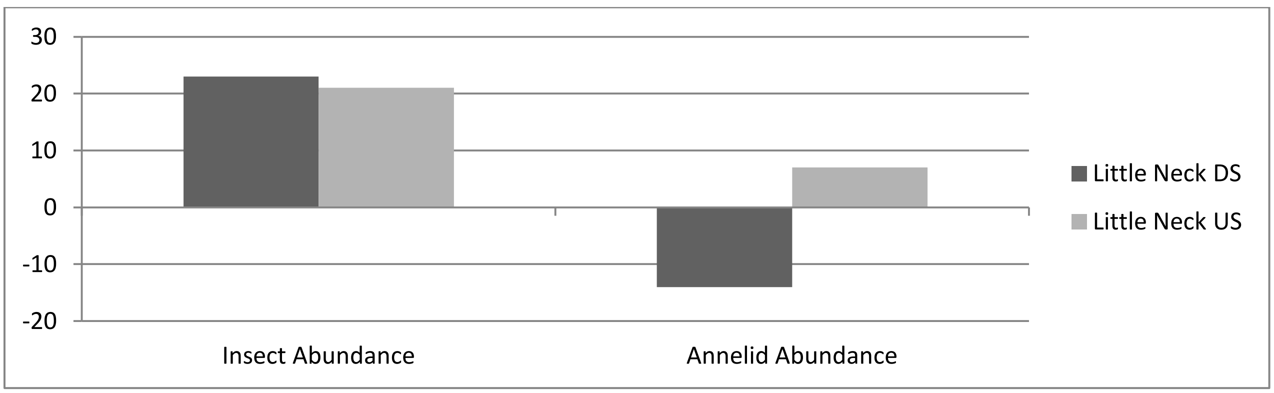

Figure 20. Change in macroinvertebrate metrics measured by number of individuals from pre-restoration to post-restoration at the Little Neck site for downstream (DS) and upstream (US) sampling locations.

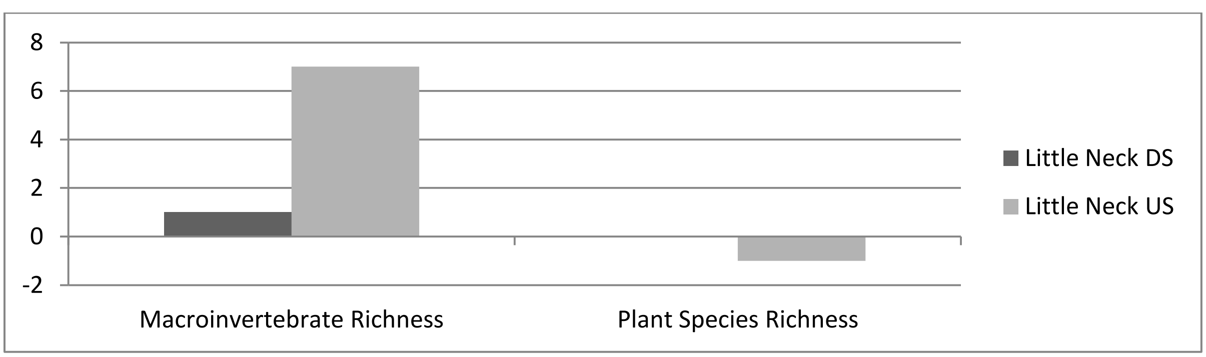

Figure 21. Change in richness measured by number of taxa (macroinvertebrates) or number of species (vegetation) from pre-restoration to post-restoration at the Little Neck site for downstream (DS) and upstream (US) sampling locations.

3.2. Reference Sites

These two locations were selected as representative areas of low disturbance and good condition. Both reference sites were sampled in the pre-restoration time period (although no restoration actions were taken at these sites) and in 2013 at one location on the marsh.

Great Island Creek, Barnstable (BGIC)

This site is located within the extensive salt marsh complex in the Sandy Neck conservation complex, owned by the Commonwealth of Massachusetts and managed by the town of Barnstable. The 21,597 m^2 site is surrounded by natural land cover and open water. Data were collected in 1999 and compared with contemporary data collected in 2013.

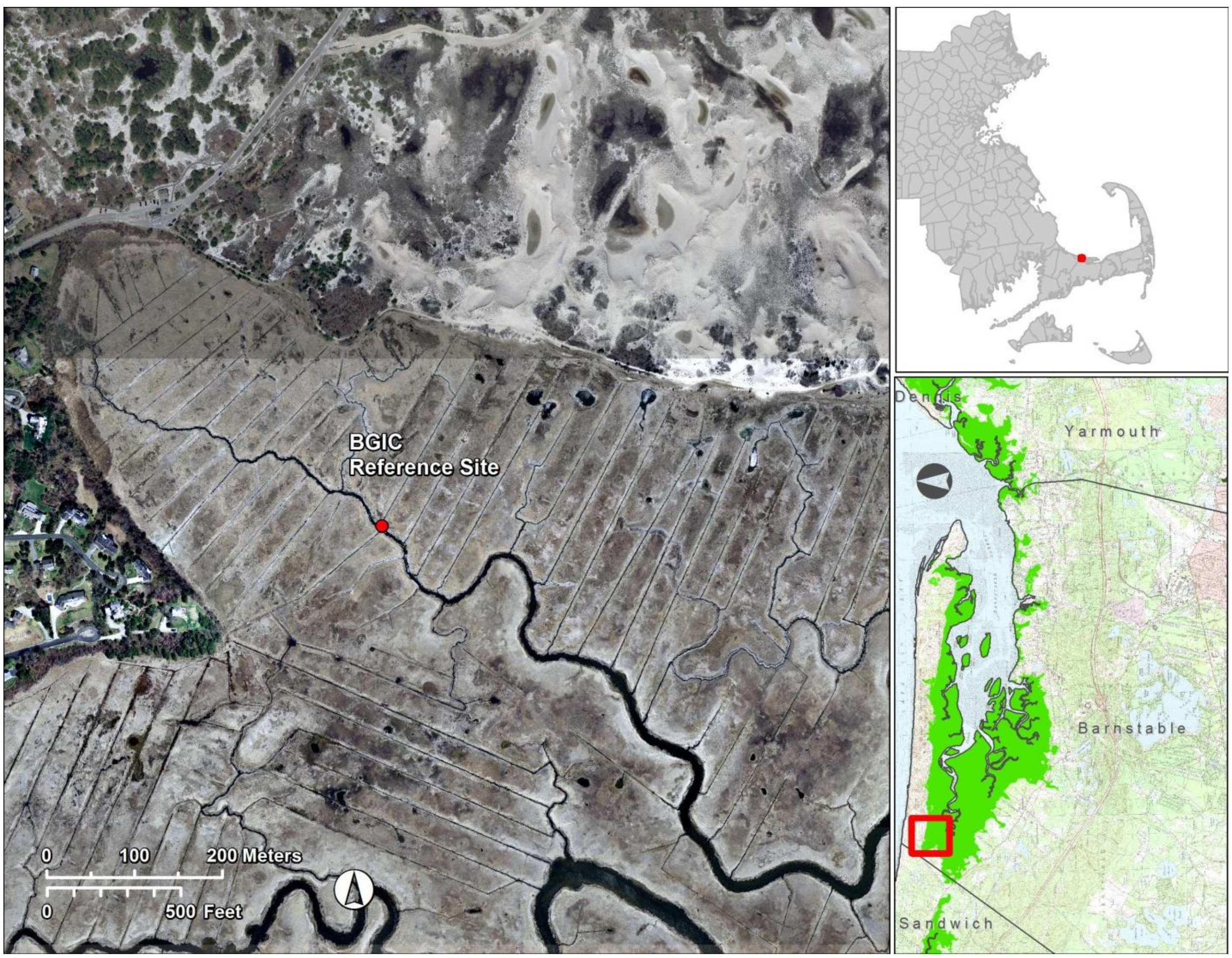

Figure 22. Overview map of the Great Island Creek sampling area, part of the Sandy Neck Barrier Beach System.

A salt marsh in Barnstable, MA.
Credit: Chris Slinko, CZM

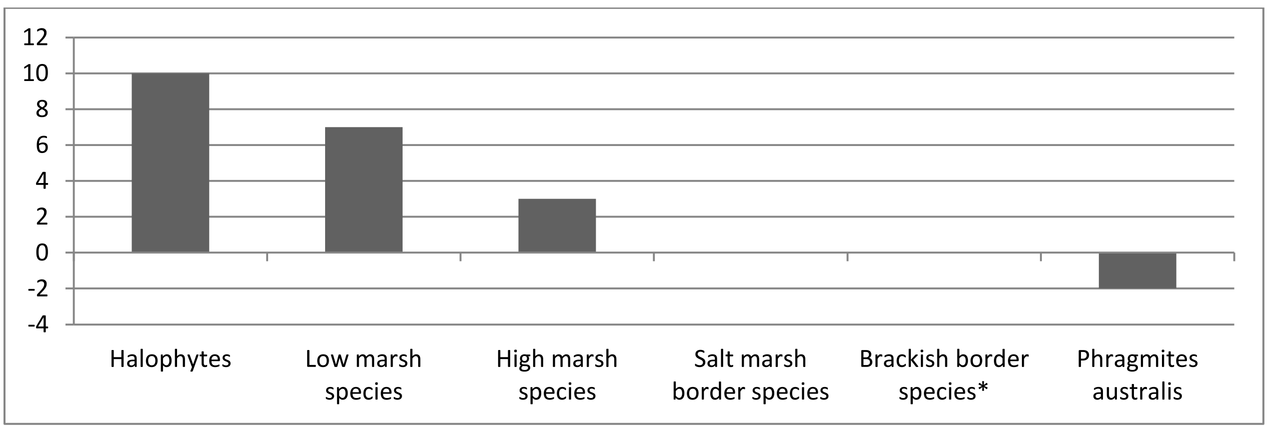

Figure 23. Change in vegetation metrics through time measured as relative (%) abundance at the Great Island Creek reference site.

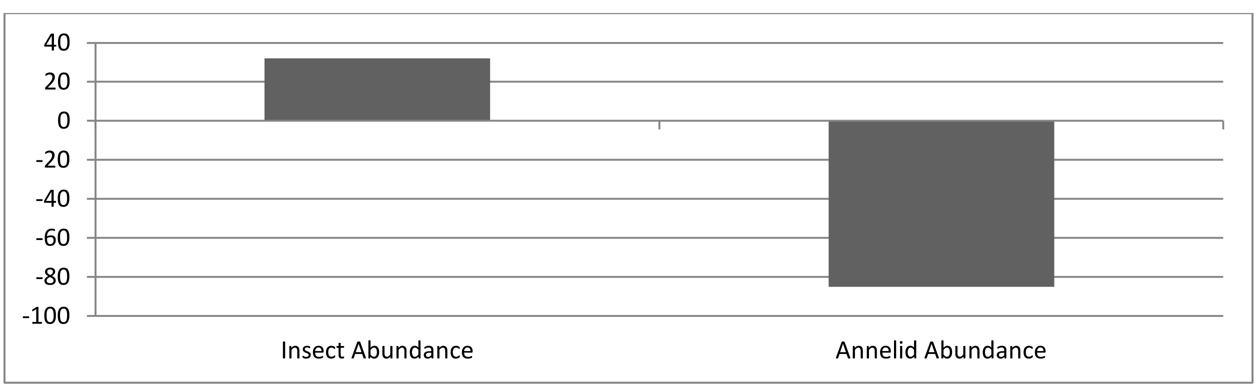

Figure 24. Change in macroinvertebrate metrics through time measured by number of individuals at the Great Island Creek reference site.

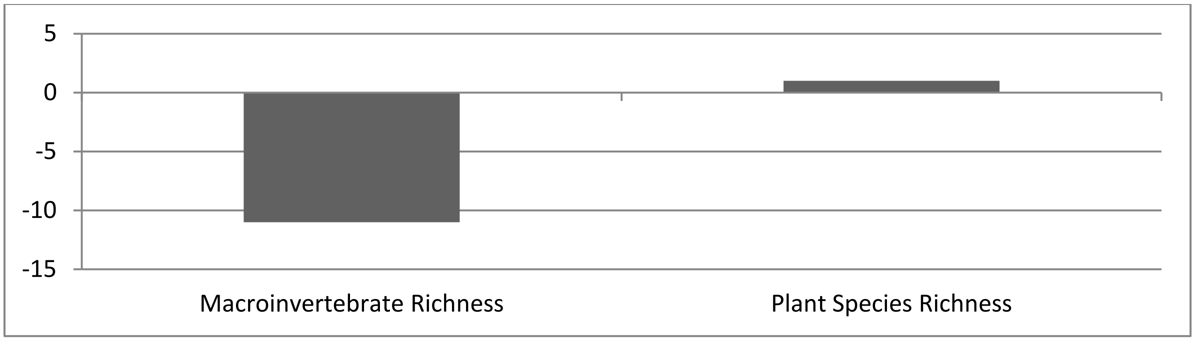

Figure 25. Change in richness measured by number of taxa (macroinvertebrates) or number of species (vegetation) through time at the Great Island Creek reference site.

Coast Guard Beach, Eastham (ECG2)

The Eastham wetland reference site is located within the Nauset Marsh embayment system, and is part of the Cape Cod National Seashore (Figure 26). The site is surrounded by natural land cover and open water in addition to low density development and a former U.S. Coast Guard station. Data were collected in 2003 and compared with contemporary data collected in 2013.

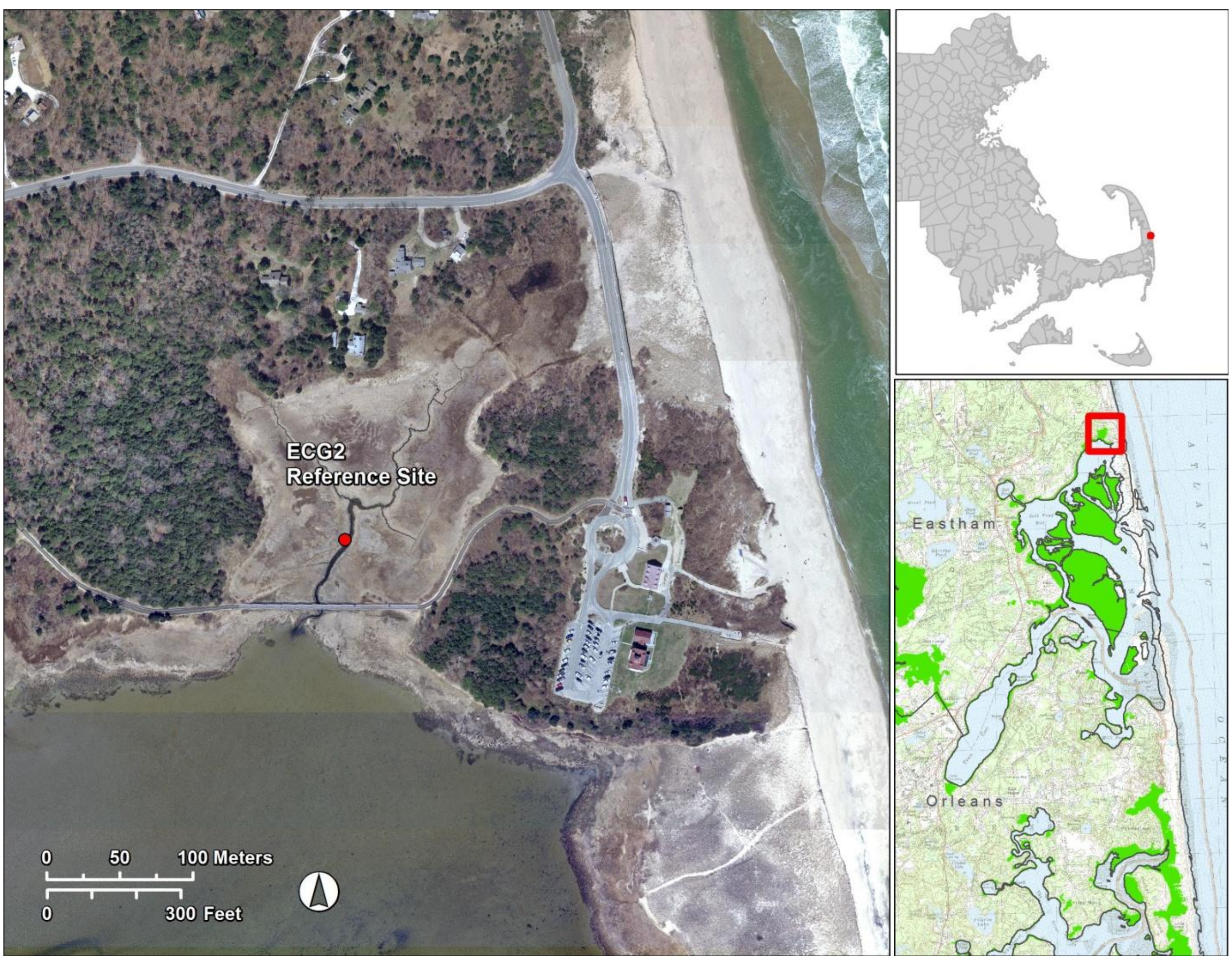

Figure 26. Overview map of the Coast Guard Beach sampling area.

Nauset Marsh with a view of the dunes of Nauset Beach in the distance.
Credit: Marc Carullo, CZM

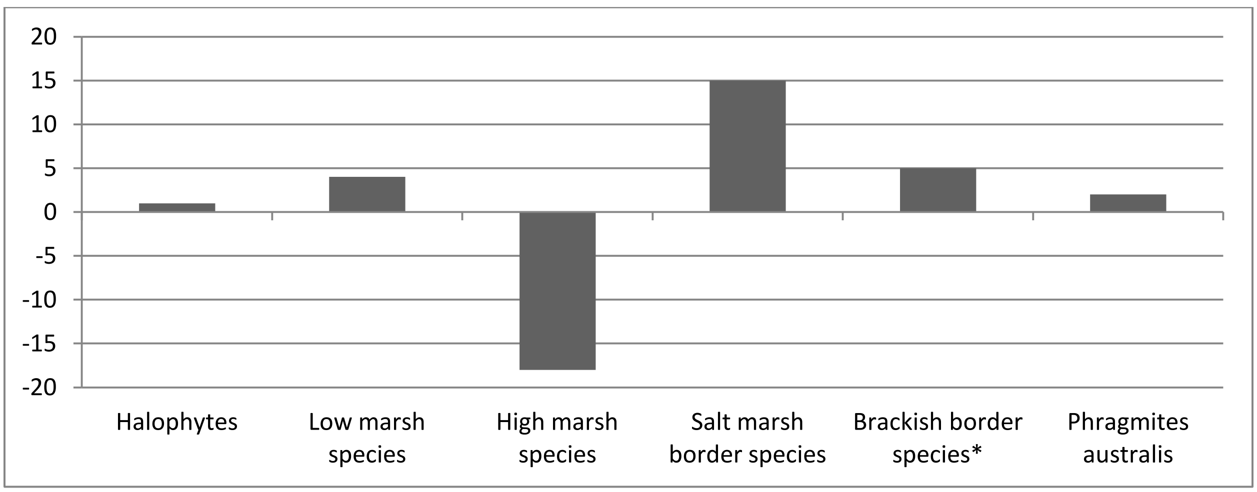

Figure 27. Change in vegetation metrics through time measured as relative (%) abundance at the Coast Guard Beach reference site.

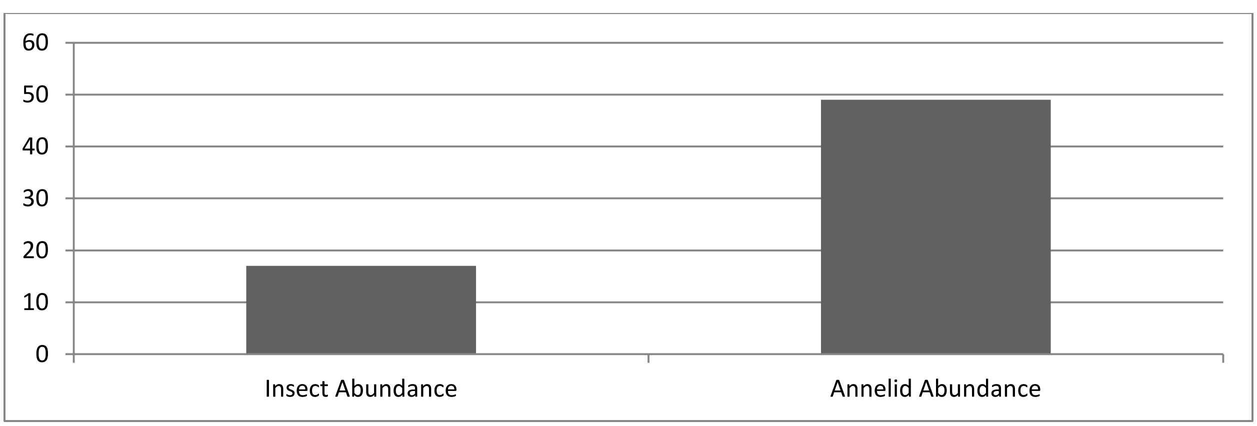

Figure 28. Change in macroinvertebrate metrics through time measured by number of individuals at the Coast Guard Beach reference site.

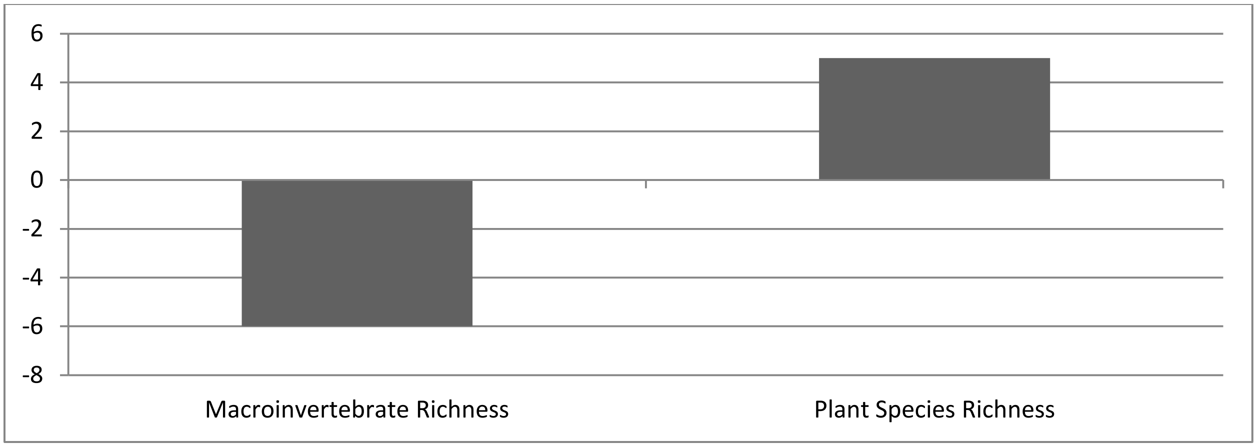

Figure 29. Change in richness measured by number of taxa (macroinvertebrates) or number of species (vegetation) through time at the Coast Guard Beach reference site.

3.3. Comparative Study

The following are results of the comparative study of sites through time and between reference and restored sites. Vegetation and macroinvertebrate data are reported separately.

3.3.1. Vegetation

The average number of plant species increased at sites downstream of former restrictions after restoration and decreased at sites upstream (Table 3). Similarly, the relative abundance of halophytes on average increased at downstream sites and decreased slightly at sites formerly upstream of a restriction. The relative abundance of the invasive reed *Phragmites australis* increased slightly at both sites downstream and upstream of restrictions through time.

There was also a slight increase in species richness through time at reference sites, however these results were not significant (average increase of 3 species). The relative abundance of *P. australis* at the reference sites remained at a very low level (0-2%) through time. There was no *P. australis* detected at the Great Island Creek site (originally at 2%) and a 2% abundance at Coast Guard beach where originally none was detected. There was a slight and significant increase in halophyte relative abundance through time (5%, p= .02 from one-tailed paired T-test).

Table 3. Average values (rounded) of upstream and downstream metrics, for sampling periods pre- and post-restoration, with average difference in values and standard error between upstream and downstream sites and associated p values.

		Pre-Restoration				Post-Restoration			
Taxa Group	**Metric**	**US**	**DS**	**Difference***	**P***	**US**	**DS**	**Difference***	**P***
Macro-invertebrates	Taxa richness	21	18	5 (SE 1.5)	.01	13	14	4 (SE 2.3)	.07
	Insect abundance	9	15	7 (SE 3.1)	.04	41	78	37 (SE .67)	.01
	Annelid abundance	176	157	72 (SE 33)	.05	10	8	12 (SE 4.4)	.03
Vegetation	Species richness	13	11	2 (SE .98)	.03	15	11	3 (SE 1)	.02
	Halophyte abundance†	64	60	8 (SE 2.1)	.01	71	57	15 (SE 5.3)	.02
	Phragmites abundance†	14	27	12 (SE 2.0)	.002	17	29	11 (SE 3.4)	.02

*Average difference calculated by absolute value of the difference between upstream and downstream pairs; this value was tested against the hypothesized value of zero using a one-tailed paired t-test.

†Relative abundance expressed as a percentage.

There were several apparent differences on a site level basis of upstream and downstream site pair similarities in vegetation species composition pre- and post-restoration: at the Mary Chase and Little Neck sites, the upstream and downstream pairs were slightly less similar after the restoration while the upstream and downstream sites were slightly more similar after restoration at the Bike Path site (Table 4). There were no appreciable differences in upstream/downstream similarity at the Conomo Point or Sage Lot Pond sites after restoration (Table 4).

Table 4. Jaccard dissimilarity calculation of plant taxa at upstream and downstream site pairs pre- and post-restoration. Higher values indicate more dissimilarity in the site pairs.

Site	Pre-Restoration	Post-Restoration
Mary Chase	0.3125	0.4444
Bike Path	0.5238	0.4167
Conomo Point	0.5217	0.5295
Little Neck	0.4286	0.5882
Sage Lot Pond	0.3600	0.3500
Mean	*0.42932*	*0.46576*

Dissimilarity of vegetation assemblages between restoration and reference sites varied among sites and by time period. Prior to restoration, the assemblages at Little Neck and Sage Lot Pond were most similar to the assemblage at the Great Island reference site, and Mary Chase had the most similar assemblage to the reference site at Coast Guard Beach. Conomo Point was least similar to Great Island, and Sage Lot

Pond was least similar to Coast Guard Beach prior to restoration. After restoration, the vegetation assemblage at the Bike Path site is now most similar to both reference sites, followed by Conomo Point. The vegetation community at several restoration sites were overall less similar to reference sites after restoration than they had been before: assemblages at Little Neck and Mary Chase were less similar to both reference sites. Vegetation at Sage Lot Pond was more similar to the Coast Guard reference site, but less similar to the Great Island Creek site after restoration.

3.3.2. Macroinvertebrates

Taxa richness declined slightly at both downstream and upstream sites through time (Table 3). There was a five-fold increase of insects at sites both downstream and upstream of former restrictions, however upstream sites had twice the level of increase (average of 15 insects pre-restoration vs. 78 post-restoration). The trend of a difference in insect abundance at sites as a whole between pre-restoration and post-restoration was strong although not statistically significant (one-tailed paired t-test P = .06). A 18:1 reduction in annelids at downstream and upstream sites between the time periods was seen, with both downstream and upstream sites showing a similar decline in annelids post-restoration (166 less and 151 less respectively). While the majority of the macroinvertebrate metrics showed significant differences between upstream and downstream sites both prior to and after restoration, caution must be taken when interpreting these results as the differences come close to the sampling precision of various collection methods used (roughly +/- 1-6 individuals, Pappal unpublished work).

Reference sites reflected the trend of decreased overall macroinvertebrate taxa richness, an increase in insects and a decrease in annelid abundance through time. Macroinvertebrate taxa richness decreased at these sites from 20 vs. 11 on average, whereas there was more than a two-fold increase in insect abundance from 19 to 43. Annelids decreased on average at reference sites, from 51 to 33. Four out of five of the restoration sites trended toward greater similarity in the macroinvertebrate community between the upstream and downstream pairs after restoration (Table 5). Sage Lot Pond was the exception, demonstrating less similarity between upstream and downstream macroinvertebrate taxa composition after restoration (Table 5).

Table 5. Jaccard dissimilarity calculation of macroinvertebrate taxa at upstream and downstream site pairs pre- and post-restoration. Higher values indicate more dissimilarity in the site pairs.

Site	Pre-Restoration	Post-Restoration
Mary Chase	0.5000	0.1000
Bike Path	0.3913	0.2500
Conomo Point	1.0000	0.4737
Little Neck	0.7778	0.5000
Sage Lot Pond	0.5278	0.7727
Mean	*0.6394*	*0.4193*

The macroinvertebrate assemblage at restoration sites differed variably from reference plots both prior to and after restoration. Prior to restoration, macroinvertebrates at Mary Chase were most similar to both reference sites out of all the study sites. The macroinvertebrate community at the Bike Path site was most similar to the Great Island Creek site, and macroinvertebrates at Conomo Point were most similar to Coast Guard Beach. The Little Neck site showed the most dissimilarity to either reference site prior to restoration.

Overall, the macroinvertebrate communities at three of the five restored sites (Mary Chase, Bike Path, and Little Neck) were more similar to both reference communities after restoration. After restoration, the invertebrate community of Mary Chase remained the most similar to both reference sites and Conomo Point became more similar to the Coast Guard Beach reference macroinvertebrate community. All but two of the restoration sites (Conomo Point and Sage Lot Pond) were more similar to the Great Island Creek reference site after restoration.

Interesting patterns are seen when the results of the sites are compared overall (Table 6). In general, when the relative abundance of low marsh plant species decreased after restoration, the number of macroinvertebrate taxa decreased at all study sites. When the relative abundance of low marsh species increased after restoration, there was an increase in macroinvertebrate taxa seen. For reference sites this result was mixed as both had a reduced number of invert taxa through time while each gaining abundance of low marsh plant species. For vegetation, plant species richness increased at all sites except the Conomo Point site, where no change was seen, and the Little Neck site which had an overall loss in the number of plant species seen. *Phragmites australis* had gains in relative abundance at three of the study sites, while two had reductions.

Table 6. Comparison chart of selected metrics calculated for restored and reference sites overall. "+" signifies an increase in the abundance or richness metric, and "-" signifies a decrease. "N/C" represents no change.

Site	**Invert. Taxa**	**Insect Abundance**	**Annelid Abundance**	**Plant Species Richness**	**Low Marsh Plants**	**High Marsh Plants**	***Phragmites* Abundance**
Mary Chase	-	+	-	+	-	+	+
Bike Path	-	+	-	+	-	+	-
Sage Lot Pond	-	+	-	+	-	+	-
Conomo Point	+	+	-	N/C	+	-	+
Little Neck	+	+	-	-	+	+	+
Great Island Creek (Ref)	-	+	-	+	+	+	-
Coast Guard Beach (Ref)	-	+	+	+	+	-	+

4. Discussion

The goals of tidal flow restoration in salt marsh systems are twofold--there is the immediate goal of restoring tidal flow and a more longer term goal of a return to pre-disturbance condition. In the ecological community, we would expect that as tidal flow returns to restricted portions of the marsh, brackish species will decrease and more salt tolerant species will increase. In the plant community this equates to an increase in halophyte abundance (*Spartina alterniflora* and *S. patens* for example) and a reduction in less salt tolerant species such as the non-native reed *Phragmites australis* upstream of formerly restricted areas (Burdick and Roman 2012; Roman et. al 2002; Warren et al. 2002). Responses in the macroinvertebrate community tend to be variable given the patchiness of communities and differences in individual taxa abundance and ecological preferences and thus are more difficult to pinpoint (Warren et al. 2002).

Two of the restored sites (Sage Lot Pond and Bike Path) examined as part of this study demonstrated a positive response to tidal restoration in the vegetation community with an increase in halophytes abundance, a decrease in brackish species and a decrease in *P. australis* upstream of former restrictions. The vegetation community at upstream and downstream sites were slightly more similar after restoration at the Bike Path site and the vegetation community as a whole became more similar to the Great Island Creek reference site. The similarity of the vegetation community upstream and downstream of the former restriction at Sage Lot Pond remained unchanged, however the community became more similar to the vegetation community at the Great Island Creek reference site.

Responses from the other sites were mixed. Two locations had an increase in halophytes upstream but also had an overall increase in brackish species and *P. australis* (Mary Chase and Little Neck). At the Conomo Point site, a decrease in halophytes was seen both upstream and downstream of the former restriction along with an increase in brackish species and *P. australis*. Plant species richness increased at all sites except the Conomo Point site, which had no change and the Little Neck site which had an overall loss in the number of plant species.

Overall, the macroinvertebrate communities at three of the five restored sites (Mary Chase, Bike Path, and Little Neck) were more similar to reference communities after restoration. All sites, reference and restored, had an increase in insect taxa through time and the majority had a decrease in annelid taxa with the exception of the Coast Guard Beach reference site. Interestingly there was also a relationship between low marsh plant abundance and the number of macroinvertebrates sampled after restoration. Sites with average declines in relative abundance of low marsh species had a decrease in macroinvertebrates after restoration (Sage Lot Pond, Mary Chase, Bike Path) whereas sites with an increase in low marsh species abundance (Little Neck, Conomo Point) had overall gains in macroinvertebrate species richness.

The Sage Lot Pond and the Bike Path site were among the largest marsh systems to be restored in this comparison study (15 and 7 acres respectively), each utilizing large box culverts to restore tidal flow from the former undersized culverts. The Sage Lot Pond and Bike Path sites also tended to have highest taxa richness for both vegetation and macroinvertebrates both prior to and after restoration. The Conomo

Point location in contrast is a relatively small marsh area (1.2 acres) with a smaller box culvert utilized for restoration. The relative size of the marsh system may indicate its resiliency to disturbances in tidal flow and a more rapid response to pre-disturbance conditions after restoration. Individual characteristics present at each salt marsh restoration site may also impact the relative response of the ecological community. For example, salt marshes characterized by lower elevations, greater hydroperiods, and higher soil water tables, had a more rapid recovery of the ecological community after restoration in a long term study of restored marshes in Connecticut (Warren et al. 2002).

Response times for a measurable response in the ecological community after restoration is also variable. In Connecticut, tracking of six restored salt marsh systems indicated a trend toward a restored ecological community within time periods of 5 to 21 years (Warren et al. 2002). A compilation of salt marsh monitoring datasets from over thirty restoration projects across the Gulf of Maine during 1995-2003 found vegetation response times to be 3 + years after restoration (Konisky et al. 2006). While in some salt marshes, the process of a return to a pre-disturbance community can occur quickly, within one growing season or year after restoration (Raposa 2008; Roman et al. 2002). The sites in this study where a response in the vegetation and macroinvertebrate community are unclear after restoration may require longer sampling periods to track changes.

One of the benefits and indicators of tidal marsh restoration is a reduction of the non-native brackish species *P. australis* as salinities increase with restored tidal flow. However in this study, three out of the five sites showed overall increases in *P. australis* abundance. As *P. australis* is a habitat modifier, it could be that the restoration of tidal flow alone is not enough to control populations at these sites (Burdick and Roman 2012). For example, high abundance of *P. australis* was noted at the Mary Chase site in 2001-2003 time period and a high abundance of *P. australis* remained (and increased) after tidal flow was restored in 2003.

One of the reference sites (Coast Guard Beach) and restoration sites (Conomo Point) demonstrated a loss in high marsh species abundance through the time period. Climatic changes, sea level rise in particular, is predicted to increase the level of subsidence in marshes unable to maintain enough sediment supply to keep pace with rising sea levels. One of the indicators of this is a decline in high marsh and an increase low marsh species – eventually to tidal flats as marshes become more and more saturated. While it is unclear if this is the case here, it is a reminder of changing conditions and variables through time which can make linking a cause and effect relationship to tidal restoration difficult.

While community changes were recorded in the restored marshes as part of this study, caution must be taken when broadly interpreting these results. Data collected provide a snapshot for a limited collection area and may not reflect all changes occurring in the ecological community as part of tidal flow restoration. In addition, as the sampling plots were not permanently established, there may have been position errors which occurred in the relocation of the transects and sampling station within the marsh. While a careful review of the methods were conducted to ensure sampling compatibility between the two sample time periods, variations may have occurred which impacted the results. Macroinvertebrate sampling in particular, is subject to variations given the patchiness of these communities. In addition slight alterations in the sampling apparatus between samplers can lead to differences in the macroinvertebrate population ultimately sampled. For example, placement of the D-net closer to the bottom of the creek in the past sampling efforts would have collected more annelids in contrast with current methods at the water/bank interface which would target more insects. In addition, the original sampling methods used for the northern Massachusetts sites (Little Neck, Conomo Point) may have been slightly different than those used at the Cape Cod sites (Mary Chase, Sage Lot Pond, Bike Path) as these were sampled by two different teams.

Given this limited dataset, it is difficult to evaluate definitively the results of restoration activities in these five marshes. However, clearly for some locations such as the Bike Path and Mary Chase site ecological changes are occurring which are indicative of a restored tidal regime and a return to pre-disturbance conditions. It is not our intent, however, to indicate the success of one restoration project over another. Clearly more information is needed to monitor the responses of the ecological community of salt marshes to restoration through time, particularly as impacts from climate change continue to threaten.

Restoration activities in tidal marshes go beyond restoration in the ecological community. In 2012 and 2014, the Massachusetts Department of Fish and Game, Division of Ecological Restoration released documents examining the success and benefits of wetland restoration in the Commonwealth. The documents *Economic Impacts of Ecological Restoration in Massachusetts* and *Estimates of Ecosystem Service Values from Ecological Restoration Projects in Massachusetts* highlight DER's effectiveness in coastal wetland restoration, specifically salt marshes. Some of the highlights of wetland restoration include: leveraging of state dollars and attraction of federal funds into the Massachusetts economy, creation of jobs, support of a number of economic sectors, "ripple effects" through the economy, increased flood protection, improved water quality, carbon sequestration, and increased property values. It is clear that restoration activities are and will continue to be critical for the health and function of salt marshes today and into the future.

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Appendix A

Table A-1. A complete list of plant species and their corresponding salinity and assigned community classes.

Taxa	Salinity Class	Assigned Community Class
Achillea millefolium	Brackish	Brackish terrestrial border
Agalinis maritima	Halophyte	High marsh
Agrostis stolinifera	Brackish	Brackish terrestrial border
Amaranthus cannabinis	Brackish	Brackish terrestrial border
Ammophila breviligulata	Brackish	Brackish terrestrial border
Argentina anserina	Halophyte	High marsh
Atriplex sp.	Halophyte	High marsh
Baccharis halimifolia	Halophyte	Salt marsh terrestrial border
Carex sp.	Brackish	Brackish terrestrial border
Cuscuta sp.	Brackish	Brackish terrestrial border
Distichlis spicata	Halophyte	High marsh
Festuca rubra	Brackish	Brackish terrestrial border
Glaux maritima	Halophyte	High marsh
Iva frutescens	Halophyte	Salt marsh terrestrial border
Juncus effusus	Brackish	Brackish terrestrial border
Juncus gerardii	Halophyte	High marsh
Juniperus virginiana	Brackish	Brackish terrestrial border
Limonium carolinianum	Halophyte	High marsh
Morella caroliniensis	N/A	Upland
Phragmites australis	Brackish	Invasive
Plantago maritima	Halophyte	High marsh
Pluchea odorata	Brackish	Brackish terrestrial border
Rosa virginiana	Brackish	Brackish terrestrial border
Ruppia maritima	Brackish	Pannes and pools
Salicornia depressa	Halophyte	High marsh
Schoenoplectus sp.	Brackish	Brackish terrestrial border
Schoenoplectus pungens	Brackish	Brackish terrestrial border
Schoenoplectus robustus	Brackish	Brackish terrestrial border
Smilax sp.	N/A	Upland
Solidago sempervirens	Halophyte	Salt marsh terrestrial border
Spartina alterniflora-short	Halophyte	High marsh
Spartina alterniflora-tall	Halophyte	Low marsh
Spartina patens	Halophyte	High marsh
Spartina pectinata	Brackish	Brackish terrestrial border
Symphyotrichum sp.	Halophyte	High marsh
Symphyotrichum tenuifolium	Halophyte	High marsh
Thinopyrum pycnanthum	Halophyte	Salt marsh terrestrial border
Toxicodendron radicans	Brackish	Brackish terrestrial border
Triglochin maritima	Halophyte	High marsh