Cape Cod Salt Marsh Assessment Project:
Developing Measures of Condition

Grant Report Volume 2, August 2004

Investigation 2:
Response of selected salt marsh indicators
to tide restriction 2000-2003




Prepared by:
Massachusetts Office of Coastal Zone Management

CZM

Prepared for:
US Environmental Protection Agency, Region I

EPA United States Environmental Protection Agency

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Prepared by:
Massachusetts Office of Coastal Zone Management
251 Causeway Street, Suite 900
Boston, MA 02114

Prepared for :
US Environmental Protection Agency, Region I
1 Congress Street, Suite 1100
Boston, MA 02114

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CZM INFORMATION LINE (617) 626-1212
CZM WEB SITE www.mass.gov/czm

Table of Contents

List of Figures

List of Tables

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Background

Massachusetts Office of Coastal Zone Management (MA-CZM), in cooperation with project partners, has completed the U.S. Environmental Protection Agency (EPA) funded portion of a salt marsh assessment project in Cape Cod, Massachusetts. The project is comprised of two different investigations:

1. A single season comparison of salt marsh indicators from sites with varying surrounding land uses (Final Report Volume 1), and
2. A multi-year comparison of indicators from tide restricted salt marsh sites (Final Report Volume 2).

Coastal salt marsh wetlands are unique, valuable and highly productive ecosystems that provide vital habitat and refuge for fish, shellfish, and wildlife and perform important physical and chemical functions such as shoreline stabilization, sediment trapping, organic production and export, flood attenuation, and water quality maintenance. Urban development, agriculture, water-control actions and other legacies of human activities in coastal areas have resulted in the direct loss and alteration of a significant portion of this Nation's salt marsh wetlands. Loss estimates from the mid 1950s to the mid 1970s are as much as 400,000 acres (Tiner, 1984). While the direct destruction of salt marshes has been dramatically curtailed with regulatory protection, adverse effects from indirect sources such as nonpoint source pollution (including onsite waste disposal and stormwater runoff), oil and other toxic spills, and subsurface water withdrawal continue to degrade these unique systems (Kennish, 2001). Ecological criteria are needed to assess the condition of protected and restored coastal wetlands and their capability to provide aquatic life use support and other designated uses.

With the 1972 passage of the Clean Water Act, Congress mandated that states report on the condition of their waters and wetlands every two years for the National Water Quality Inventory Report. In the 2000 report, the US EPA summarized on the status of wetlands in the United States:

> *In their 2000 reports, only nine states and tribes reported the designated use support status for some of their wetlands. EPA cannot draw national conclusions about…conditions in all wetlands because the states used different methodologies to survey only 8% of the total wetlands in the nation. Additionally, only one state used random sampling techniques and two used a targeted approach (monitoring where problems were known or suspected).*

Clearly, there is a distinct lack of information currently available or being generated to assess the quality and condition of wetlands across the Nation. This issue will gain more attention, though, as States develop their Comprehensive Monitoring Program Strategy plans by 2004 as a contingent for their CWA §106(e)(1) funding. The recent US EPA guidance to states for the development of these plans, *Elements of a State Water Monitoring and Assessment Program (August 2002)*, cite wetlands as core indicators in a state plan.

To date, there has been little systematic effort to measure, document, and describe the condition of wetlands — both coastal and inland. Work by the USFWS National Wetland Inventory has enabled Federal and State governments to report on the status and trends of wetland acreage in some regions of the United States (Dahl, 2000). There have also been some isolated efforts to document wetland losses and changes in condition, largely through the analysis of historical and current maps and aerial photographs.

Much of the bio-assessment work in the United States has been associated with the development of biological water quality criteria for streams, rivers, and lakes (Gibson et al., 2000; Plafkin et al., 1989). In the last 10 years there has been significant effort focused on wetlands (US EPA, 2002; US EPA 1996; Brinson, 1993). Of particular note in this area is the work of the National Wetland Monitoring and Assessment Work Group administered by the U.S. Environmental Protection Agency (US EPA). Through technical and programmatic support, the Work Group helps states and tribes build their capacity to implement and sustain wetland monitoring and assessment programs that support wetland restoration and protection.

The goal of wetland biological assessment (bio-assessment) is to evaluate a wetland's ability to support and maintain a balanced, adaptive community of organisms having a species composition, diversity, and functional organization comparable with that of minimally disturbed wetlands within a region. Although there has been abundant research and published literature on various aspects of salt marsh ecology (Bertness, 1999; Bertness and Ellison, 1987; Nixon, 1982; Whitlatch, 1982), the use of bio-assessment frameworks in salt marshes are still in the design and protocol development.

In the past four years, the review, evaluation, and discussion of standardized salt marsh survey protocols has been an area of focus for two regional forums: the Global Programme of Action / Coalition (GPAC) for the Gulf of Maine, coordinated by the Wells National Estuarine Research Reserve and the Great Marsh Working Group, coordinated by Massachusetts Audubon Society. Through these forums there has been active interaction and debate among researchers and investigators from state and federal agencies, universities, and regional nonprofits as to the most appropriate techniques and methods for surveying or monitoring salt marsh endpoints. Regional standardized protocols (in the form of guidelines) for the identification and evaluation of tide-restricted salt marshes have been released by the GPAC group (Neckles and Dionne, 2000). Other examples of regional efforts to develop standardized protocol, include shallow water monitoring for nekton (Raposa and Roman, 2001), monitoring salt marsh plants (Roman et al. 2001), and guidance for volunteers to monitor various salt marsh end points (Carlisle et al., 2002).

MA-CZM has been actively engaged in the development of wetland condition indicators since 1996, including four applied research projects, wetland mapping projects, and ongoing volunteer training and education. MA-CZM is an active member of both the

National Wetlands Monitoring and Assessment Workgroup and the New England Biological Assessment of Wetlands Workgroup.

The primary goal of the Cape Cod Salt Marsh Assessment Project was to advance and improve the salt marsh assessment approach and indicators developed by MA-CZM in previous projects through its application to two separate investigations.

The first investigation, conducted in the 1999 field season (May to October index period), examined salt marsh indicators from six sites on the Cape Cod Bay coast; these sites had varying types and intensities of human land use or disturbance. Volume 1 of the final report covers the first investigation.

The second investigation is a long-term comparison of indicators from selected tide restricted and reference salt marshes. Volume 2 reports on the second investigation. The focus of this work was to examine selected indicators at tide restricted salt marshes and at reference salt marshes and to determine if differences exist between the two groups of salt marshes and to examine indicator response to tidal restoration actions. The working hypothesis is that there will be differences in certain indicators between sites with normal tide regimes and sites with tide restrictions but that other factors, such as site-specific habitat availability or trophic interactions, will affect indicator status and response.

Through the implementation of these two investigations, additional objectives will be realized. The collection and compilation of data on the condition of relatively undisturbed salt marshes is of critical importance to the evaluation and determination of impaired sites. This project will serve to expand the salt marsh reference site database. Another important aspect of this project will be to further examine the suite of indicators used for biological comparison and to explore new ones, based on the project data and literature/information base. The long term tide restriction study will provide insight on the utility of this assessment approach as a tool for tracking salt marsh restoration progress and trajectory.

Study Design and Sites

The tide restricted site investigation study design was based on Before/After Control/Impact (BACI) model, where a tide restricted salt marsh is sampled before and after the restoration action and—in order to gain insight into salt marsh condition prior to restriction (impact)—a space for time substitution is employed to sample salt mashes that are not tide restricted (control).

Three tide-restricted salt marsh sites were selected as the foundation of the investigation. These sites were selected based on several criteria including:

- site has high likelihood of restoration action completed before field season 2003 (to allow for at least one year of post-restoration data for grant period),
- site has a paired reference site closely proximate,
- access is viable and obtained,
- sites cover a range of regions and tidal ranges, and
- sites are generally similar in size.

Three sites and their reference counterparts were selected: EOBP—bisected by the Cape Cod Rail Trail with marine waters from Boat Meadow Creek and Cape Cod Bay; EMC—bisected by an historic dike with marine waters from Nauset estuary and Atlantic Ocean; and MSLP—bisected by two roads with marine waters from Waquoit Bay and Nantucket Sound. All three sites had moderate (as opposed to severe) tide restrictions—that is, each of the study sites had at least half (or more) of the tidal flow of their reference counterparts, and on initial observation, all had significant presence of representative and obligate salt marsh plant species.

Over the course of the 4 years of this grant period, three different regional reference sites were also investigated in order to improve our understanding of minimally disturbed salt marshes. Regional reference sites are sites that are located in permanent conservation land; have little to no human land use or sources of disturbance; and are representative of salt marshes of the region.

Of the three sites selected, only one, EOBP, actually had its restoration action completed by the target date. EMC had its tide restriction removed in October 2003, the end of the field season; no action has yet occurred at MSLP, though efforts are still underway.

Figure 1 presents a locus view of the salt marsh sites for this investigation; Table 1 summarizes the types of sites: three pairs of reference and study sites (above and below the tide restriction) as well as four regional reference sites.

Table 2 shows the environmental variables of the salt marsh study sites. Field work for this investigation was conducted in the index period from May to October at salt marsh sites and years listed in Table 3. The biotic assemblages sampled were plants (macrophytes), aquatic macroinvertebrates, and nekton (fish and macro-decapod crustaceans). Basic water quality parameters (dissolved oxygen, salinity, temperature, and pH) were measured concurrent with the invertebrate and nekton sampling.

Table 1. Investigation sites and type.

Site	Type
EOBP–pre	Tide restricted salt marsh; before restoration action
EOBP–post	Tide restored salt marsh; after restoration action
EOBP–Ref	Paired reference salt marsh
EMC–pre	Tide restricted salt marsh; before restoration action
EMC–Ref	Paired reference salt marsh
MSLP–pre	Tide restricted salt marsh; before restoration action
MSLP–Ref	Paired reference salt marsh
ECG–Ref	Regional reference salt marsh
ECG2–Ref	Regional reference salt marsh
BGIC–Ref	Regional reference salt marsh

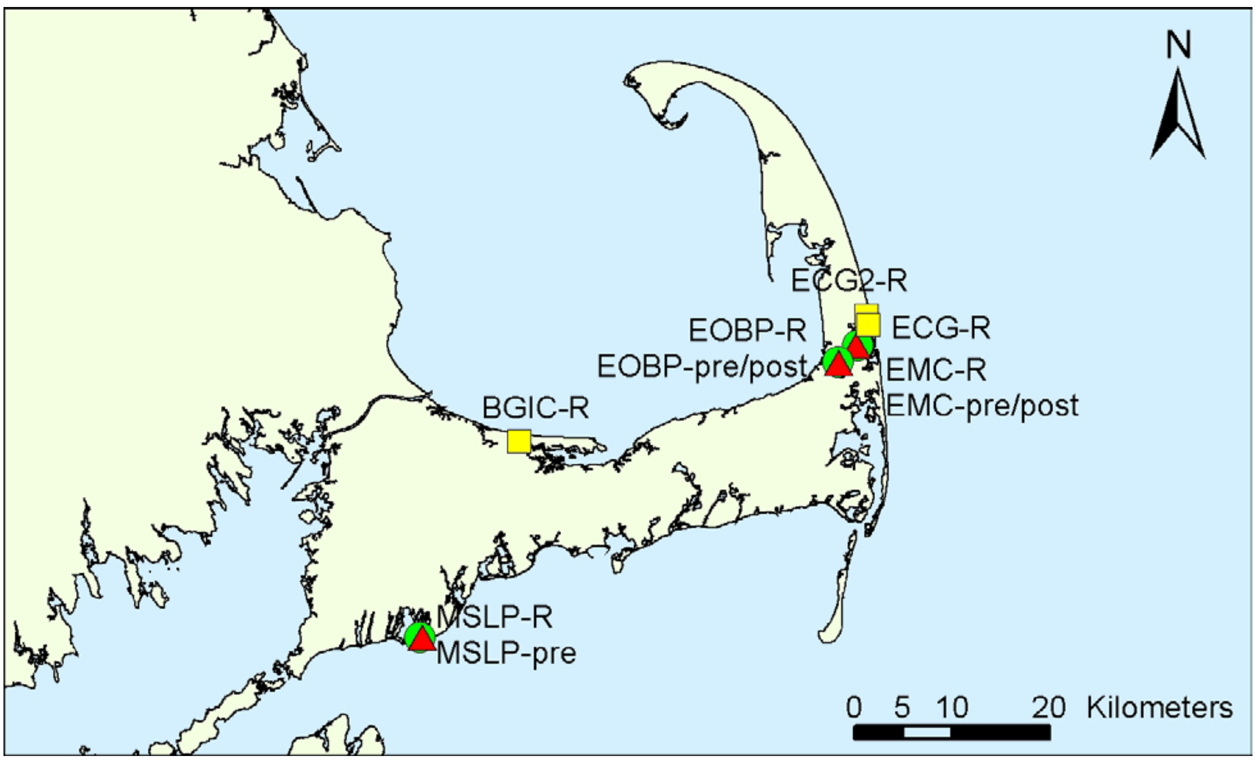

Figure 1. Locus map showing salt marsh sites for Investigation.

A short description of each site, its characteristics and landscape setting follows. Within each marsh, a distinct evaluation area was delineated according to the protocols described below in Methods.

Table 2. Environmental characteristics of study sites.

Site	Tidal Range (m)	Creek Order	Representative Creek Width (m)	Distance to Marine Water (km)	Substrate
EOBP-R	1.40	3	4.29	3.75	silts and sands w/ gravel and peat
EOPB-S	1.17 (pre) 1.35 (post)	3	2.09	3.75	silts and peat w/ sand
EMC-R (side channel)	1.5	2 (3)	15.09 (1.78)	2.85	silts and peat
EMC-S	0.65 (pre) 1.20 (post)	2	5.56	2.85	silts and sands w/ shells and gravel
MSLP-R	0.55	2	4.15	2.70	sand w/ gravel and peat
MSLP-S	0.40	2	2.02	2.70	sand and peat w/ silt
ECG-R	1.5 (est.)	2	3.18	3.12	sand w/ silt and peat
ECG2-R	1.0 (est.)	2	2.68	4.16	silts and peat
BGIC-R	1.0 (est.)	4	3.68	6.01	silts and peat

Table 3. Investigation sites, year and parameter surveyed/sampled in reporting period.

Sites	Plants	Nekton	Inverts	Avifauna	Tidal Hydrology
EOBP-pre	2001	2000-2001	2001	2000, 2001	2000
EOBP-post	2002, 2003	2002, 2003	2002, 2003	2002, 2003	2004
EOBP-Ref	2001-2003	2000-2003	2001-2003	2000-2003	2000
EMC-pre	2001-2003	2000-2003	2001-2003	2000-2003	2000
EMC-Ref	2001-2003	2000-2003	2001-2003	2000-2003	2000
EMC-post					2004
MSLP-pre	2001	2000, 2001	2001	2000, 2001	2000
MSLP-Ref	2001	2000, 2001	2001	2000, 2001	2000
ECG-Ref	2002	2002	2002	2002	
ECG2-Ref	2003	2003	2003	2003	
BGIC-Ref			2001	2000	

EOBP

Two site pairs, EOBP-Reference and EOBP-Study, are located at the top of Boat Meadow Creek, in the towns of Eastham and Orleans (Figure 2). The evaluation area for EOBP-Reference is 17,335 m^2; for EOBP-Study it is 13,188 m^2. The Cape Cod Rail Trail, or bike path, splits the tide restricted study site from its reference pair. Tidal exchange is from Cape Cod Bay via Boat Meadow Creek. The former railroad causeway fragmented the once uniform salt marsh and the installation of various forms of water control and passage structures caused the restriction of normal tidal hydrology at EOBP-Study. At the start of the investigation, there was a 36" culvert in a severe state of disrepair, partially collapsed and undermined with failing retaining wall structures (Figure 3). In April 2002, restoration of tidal flow to EOBP-Study was achieved with the installation of a new 4x6' pre-cast concrete box culvert (Figure 3). Both sites are surrounded by natural land cover (shrub and forest), residential development, and roads, including the Mid-Cape Highway (Route 6). *Phragmites australis* is found at both site pairs—at the study site it is located on both sides of the channel; at the reference site, *Phragmites* is found only on one side. The study site, EOBP-Study, also receives direct storm water discharge from an outfall that drains portions of the highway and a local access road.

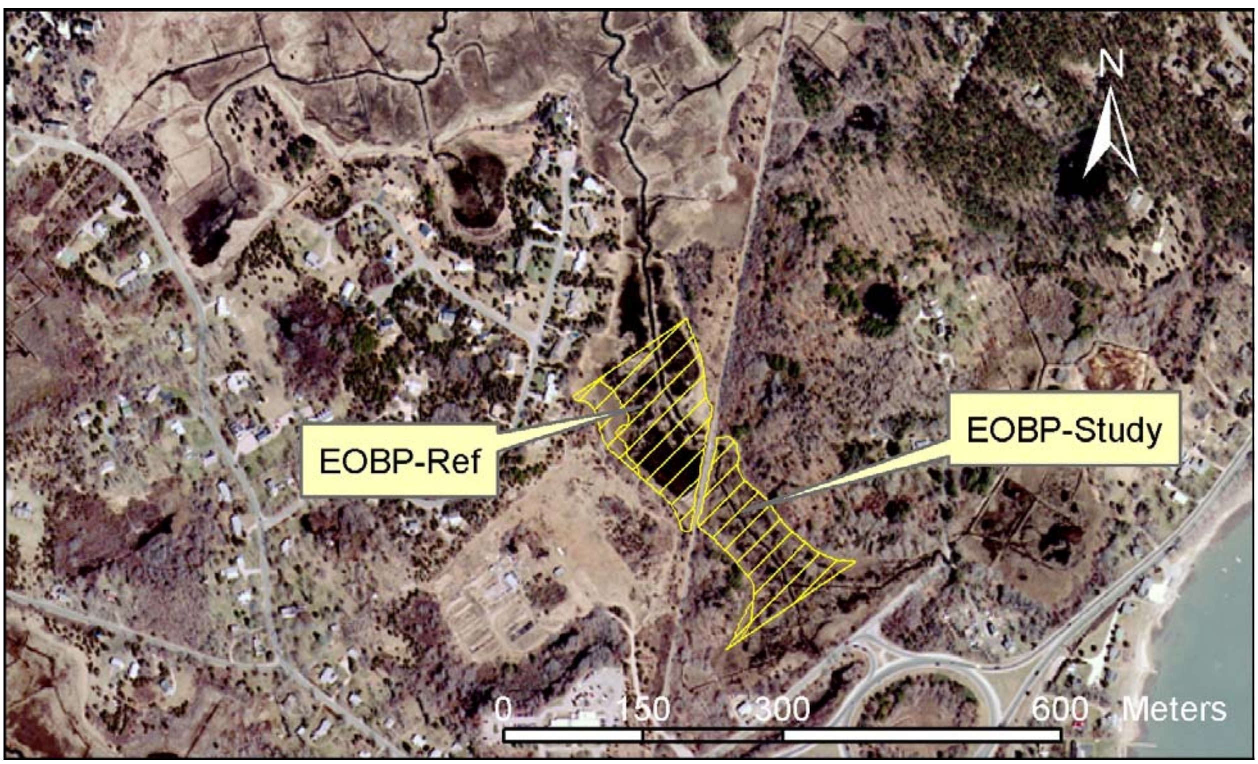

Figure 2. EOBP-Reference and EOBP-Study with evaluation areas.

Figure 3. Pre- and post-restoration of culvert at EOBP site.

Figure 4. EMC sites before and during dike work to remove sections in channel.

EMC

Two site pairs, EMC-Reference and EMC-Study, are located in the Nauset estuary at Mary Chase Marsh on the outer arm of Cape Cod in the Town of Eastham, Massachusetts (Figure 5). The evaluation area for EMC-Reference is 12,601 m^2; for EMC-Study it is 8,623 m^2. The Cape Cod National Seashore (CCNS) Fort Hill Reservation borders the site to the north. The Atlantic Ocean conveys tidal flows to the sites via Nauset Estuary and Abelino Creek. A historic stone and earthen dike bisects the marsh—the Reference site lies on the southeastern side and the restricted Study site to the northwest—and restricts tidal flow to EMC-Study (Figure 4). The sites are surrounded by natural land cover (shrub and forest), and residential development. Removal of a significant portion of the historic dike was completed in October 2003 (Figure 4) and tidal flow to EMC-Study was significantly increased. Areas of the dike were left in place so that the study site would not drain completely during ebb tide; the dike is also considered a historical structure so that complete removal was not permitted. Of note at this site is the mowing of border and marsh vegetation by a landowner on one side of the restricted study site for three continual years; also the CCNS has engaged in prescribed burns for the management of upland vegetation and has burned border and marsh plants on one side at the reference site. The reporting period for this grant (March 2000 to March 2004) did not allow for inclusion of most of the 2004 post-restoration data (collected May to September 2004) but future reports will address restoration response at this site. Hydrology and *Phragmites* height data from 2004 are included.

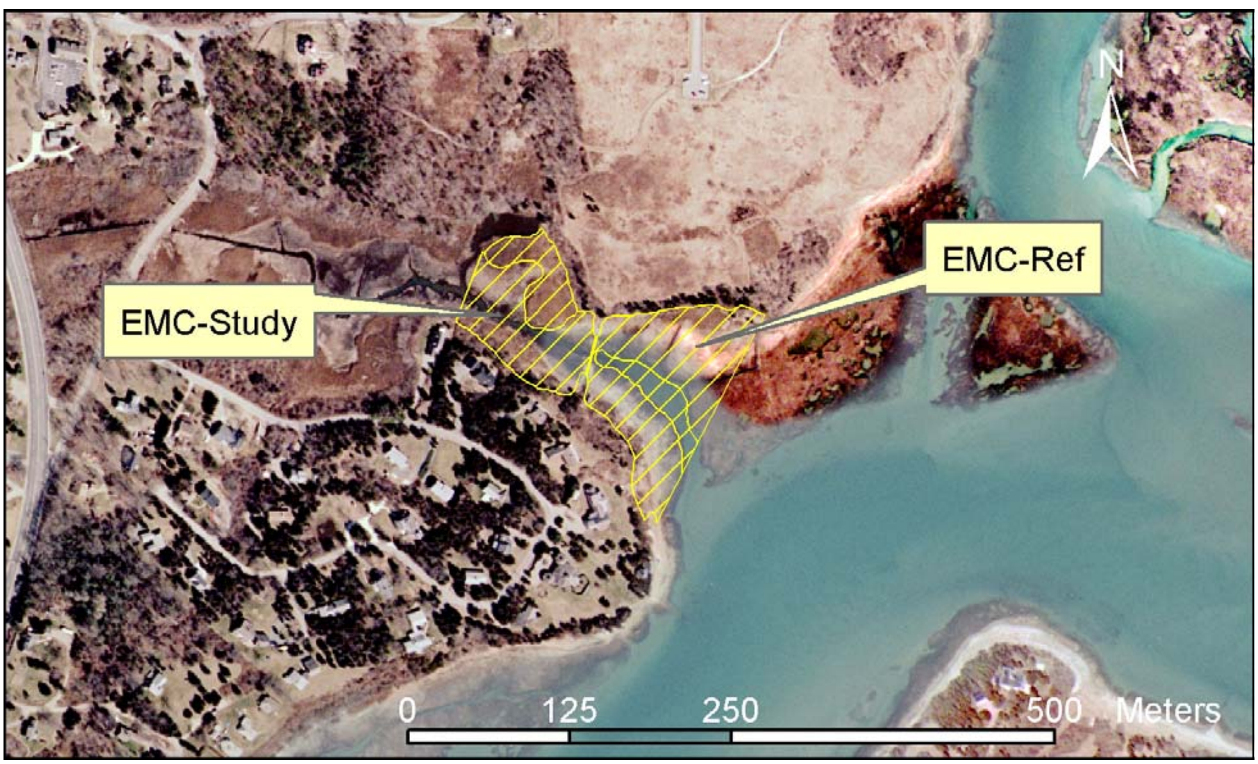

Figure 5. EMC-Reference and EMC-Study with evaluation areas.

MSLP

Two site pairs, MSLP-Reference and MSLP-Study, are located in the Waquoit Bay National Estuarine Research Reserve in land owned and managed by the Massachusetts Department of Conservation and Recreation (Figure 6). The town of Mashpee maintains an in-holding used for their local beach access. The evaluation area for MSLP-Reference is 18,038 m^2; for MSLP-Study it is 21,528 m^2. Nantucket Sound conveys tidal flow to the sites via Waquoit Bay and Sage Lot Pond. The salt marsh complex is bisected by two roadway causeways. Just east of the reference site, DCR maintains an old unimproved road for ATV access to the beach for management and emergency situations. Another road causeway further fragments the system; this road is two-lane paved and used by the town to access their in-holding beach parking lot. Contrary to original expectations, restoration of the these tide restrictions did not occur during the grant funded study period (reporting period).

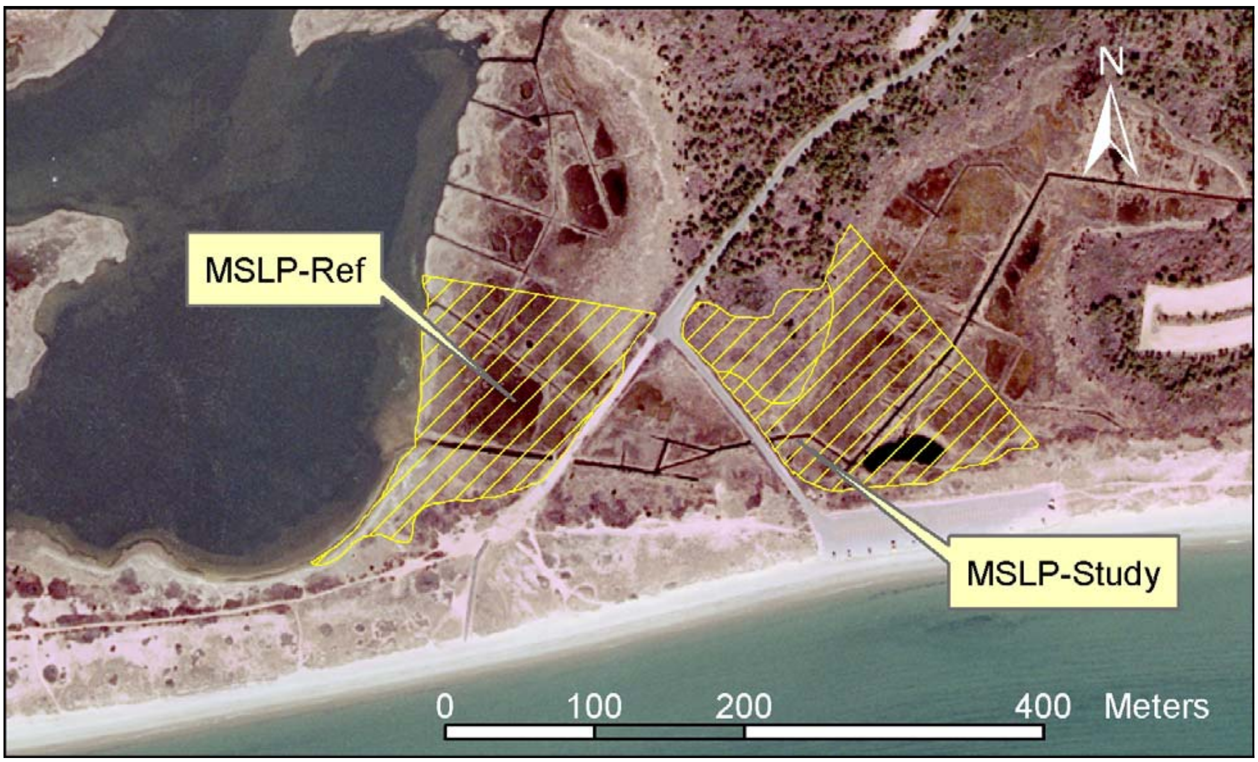

Figure 6. MSLP-Reference and MSLP-Study with evaluation areas.

ECG-Reference

Regional reference site, ECG-Reference, is located in the Cape Cod National Seashore on the outer arm of Cape Cod within the Nauset estuary and in the Town of Eastham, Massachusetts (Figure 7). The site is behind the Nauset barrier beach spit, approximately 1 km south of the former Coast Guard station. The evaluation area for ECG-Reference is 16,638 m^2. The Atlantic Ocean conveys tidal flows to the site via Nauset Estuary. The site is surrounded entirely by natural land cover (dune, beach, tidal flat, and open water).

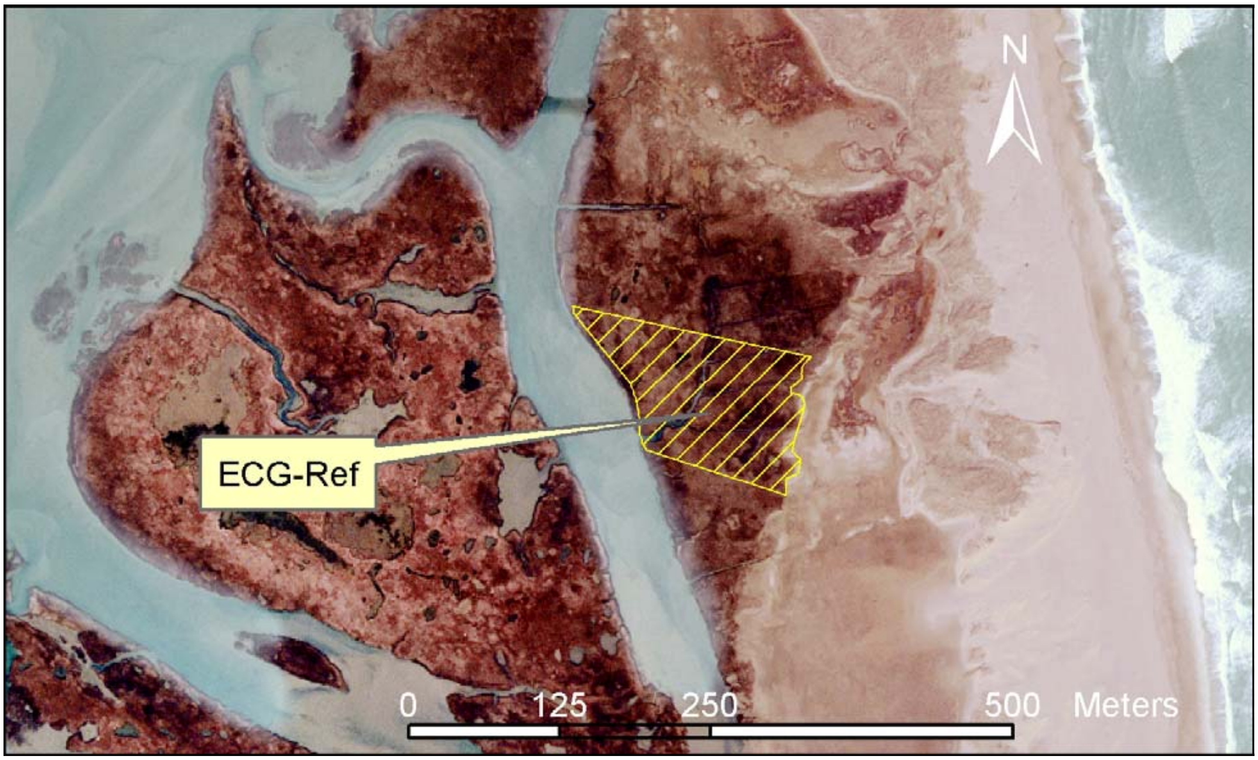

Figure 7. ECG-Reference with evaluation area.

ECG2-Reference

ECG2-Reference, a regional reference site, is located in the Cape Cod National Seashore on the outer arm of Cape Cod within the Nauset estuary and in the Town of Eastham, Massachusetts (Figure 8). The site is behind the Nauset barrier beach spit, 200m west of the former Coast Guard station. The evaluation area for ECG-Reference is 16,638 m^2. The Atlantic Ocean conveys tidal flows to the site via Nauset Estuary. The site is surrounded by natural land cover (shrub, forest, tidal flat, and open water), low-density residences, and the buildings and parking lots of the Coast Guard complex. A raised walkway crosses the marsh at its southern end for pedestrian and bicycle travel between the Coast Guard station and a remote parking lot. The walkway is elevated about 1.5m above the marsh surface allowing complete channel and marsh surface tidal flow.

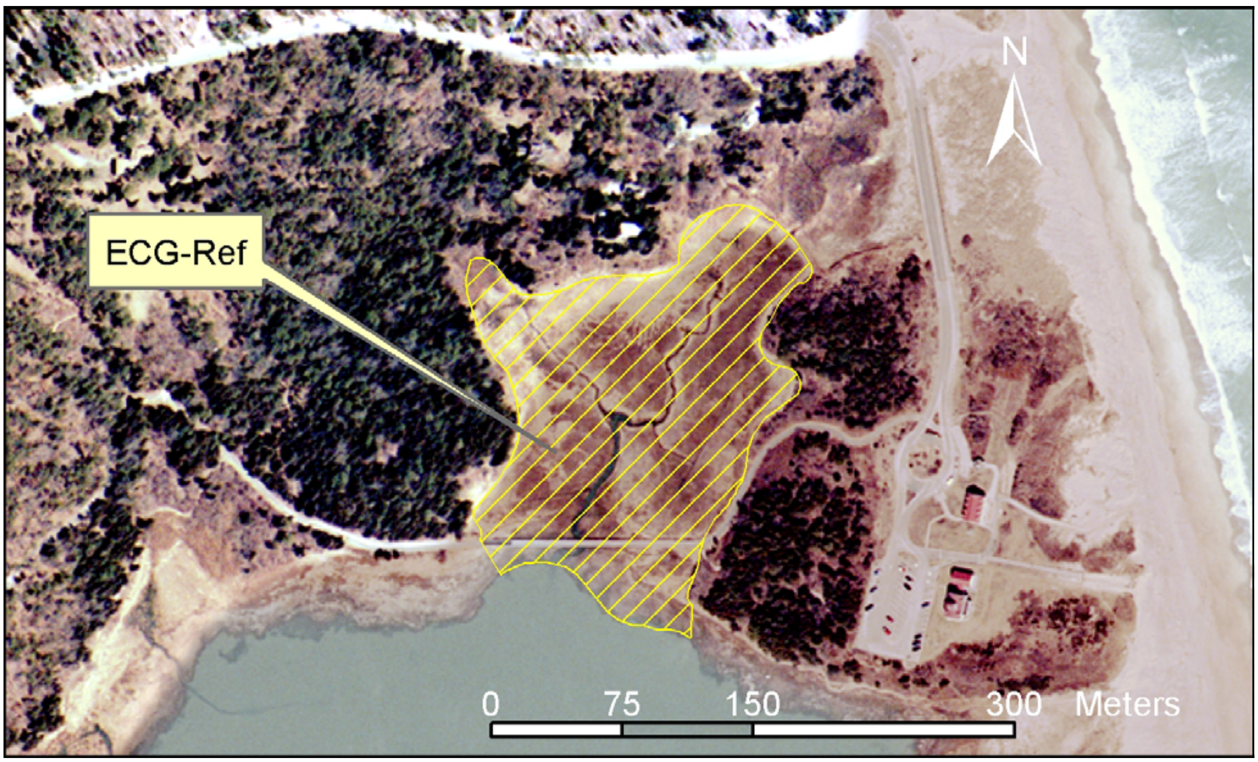

Figure 8. ECG2-Reference with evaluation area.

BGIC-Reference

BGIC-Reference is another regional reference site selected for this investigation (Figure 9). This site is located within the extensive salt marsh complex behind the Sandy Neck barrier beach in the town of Barnstable. Much of this salt marsh and barrier beach dune system is maintained as conservation land in perpetuity, owned by the Commonwealth of Massachusetts and managed by the town. The evaluation area of this site is 21,597 m^2. Cape Cod Bay conveys tidal flows to the site via Barnstable Harbor and Great Island Creek. The site is surrounded by natural land cover (dune, shrub, and open water). Recreational walking trails are present to the north of the evaluation area and there is infrequent use of a off-road trail by town resource management vehicles. In addition, this salt marsh area is the site of ongoing research by other organizations.

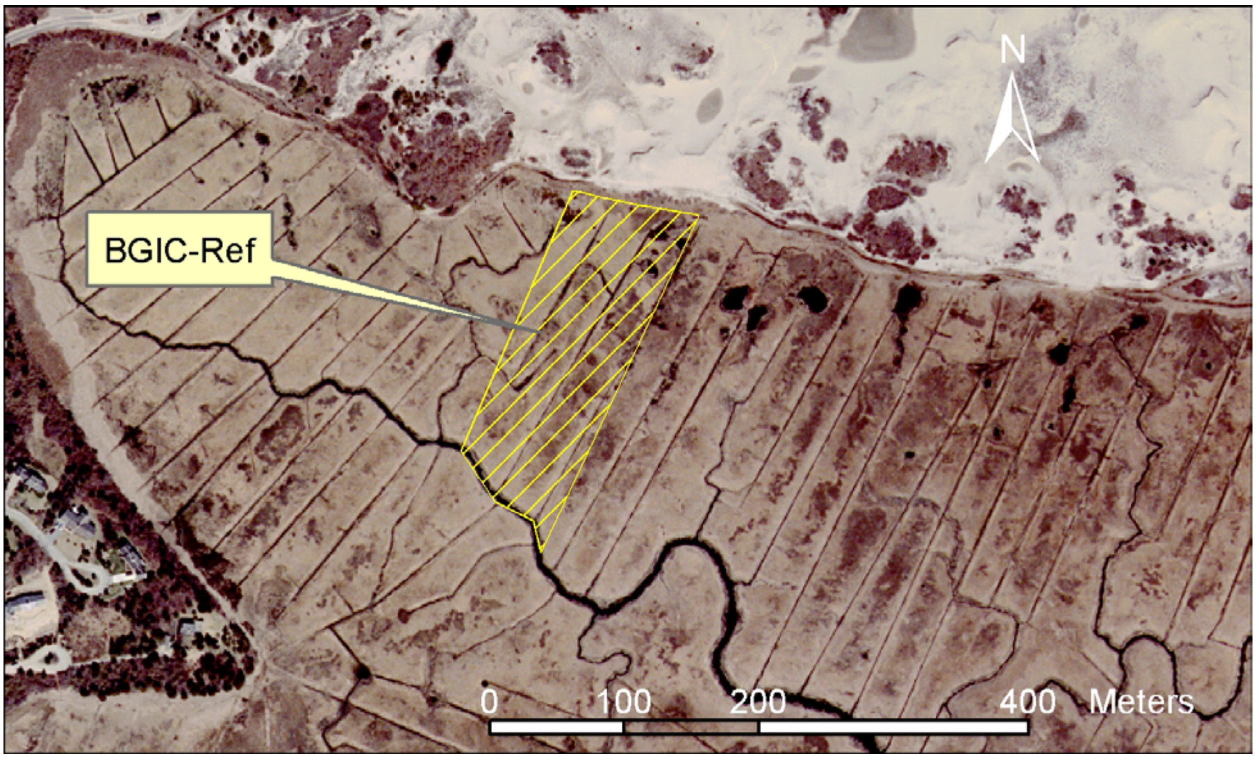

Figure 9. BGIC-Reference with evaluation area.

Methods

Evaluation Area

For this investigation, a specific evaluation area was established within the salt marsh study sites. The decision to designate an evaluation area was driven by several factors. The first was a desire to reduce natural variability caused by size, since salt marsh sizes on Cape Cod, for example, range from less than one to well over thousands of acres. Another reason was to be able to focus more specifically on the parts or areas of a site that are closer to the disturbance source—in this case the manmade dike of the road or railroad crossing and the undersized culvert. By surveying very large sites, adverse indicator response signals might be dampened or lost. Finally, to adequately survey very large marsh sites, more time and resources would be necessary.

Therefore, a subsection of the salt marsh was delineated as the evaluation area. The evaluation area for all salt marsh sites in this investigation (both reference and study sites) was established by including all of the habitat (marsh surface, sub- or intertidal creeks and channels, pools and pannes) in an area created by a bisecting transect located at a point 92 meters (300 feet) from designated start point (Figure 10).

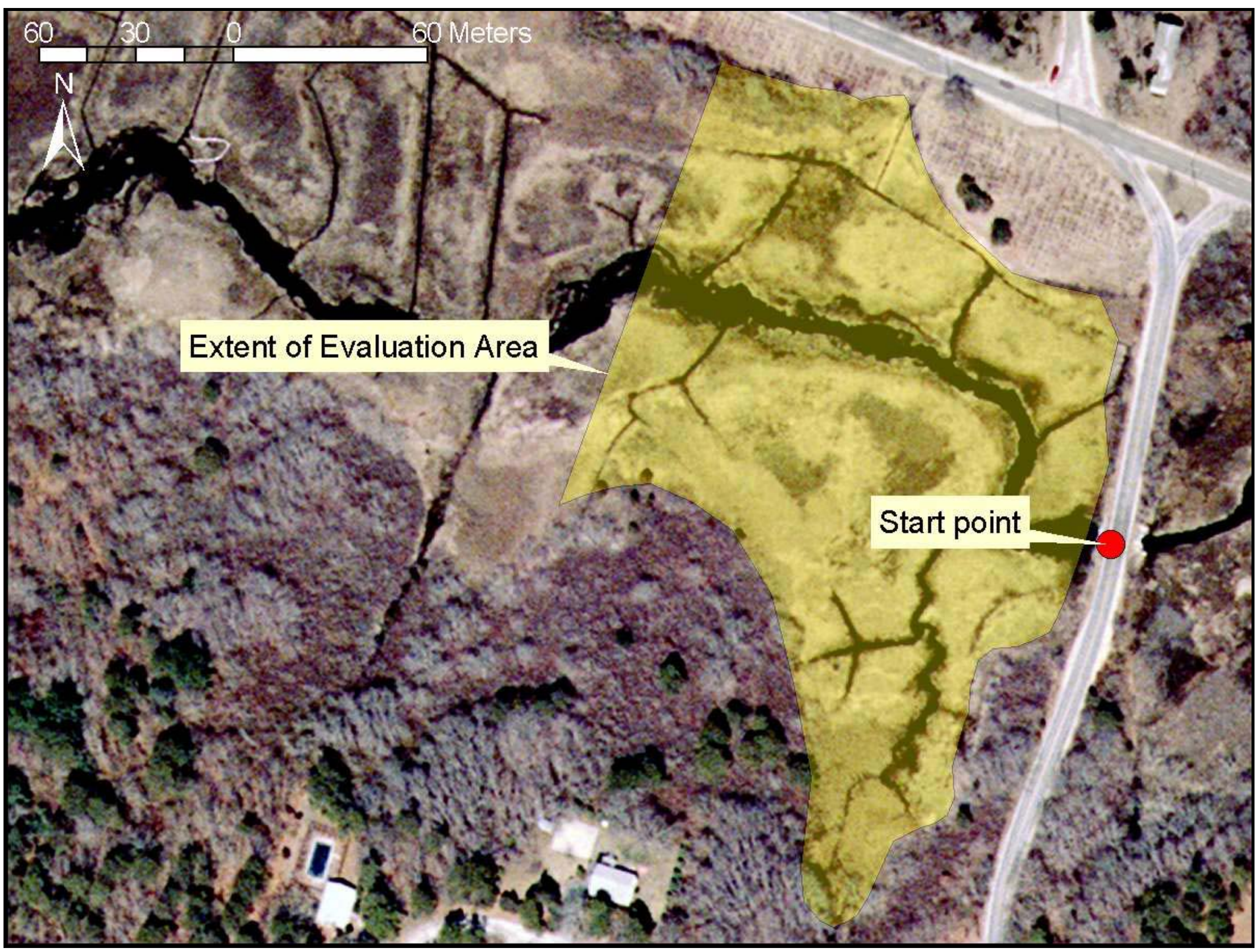

Figure 10. Salt marsh site evaluation area.

Tidal Hydrology

At each reference and study site pair (EOBP, EMC, and MSLP) the amount of tide restriction was quantified by recording the water levels above and below the restrictive feature (e.g. culvert, dike) over several above mean tide cycles. A pressure transducer (PT) and data logger set-up manufactured by Global Water (WL-14) was utilized for the measurements. Locations were selected for the siting of the PTs so that the instrument was capturing tide levels representative of the site just near the restrictive feature. A 8 foot snow fence stake was driven 3 feet into the substrate and a vertical length of perforated PVC pipe was attached to the stake. The PT was secured at the bottom of the PVC and the cable run the length of the PVC to a housing for the logger at the top of the set-up.

Figure 11. Tide height water level set-up for PTS and loggers.

The logger was configured to take readings every 10 minutes over the course of at least 4 tidal cycles. Pairs of PTs and logger were deployed simultaneously and configured to have synchronized clocks and readings. Water level height were recorded in feet (and hundredths). Tide levels at site EOBP were recorded on April 6th through 7th 2000 for the pre-restoration data and on April 6th through 7th 2004 for the post-restoration. Tide levels were taken at site EMC on September 5th and 6th 2000 for the pre-restoration and on October 28th and 29th 2003 for the post-restoration. Tide levels were recorded at site MSLP on August 30th and 31st 2000 for the pre-restoration.

Plants

At each salt marsh site, salt marsh vegetation was surveyed along twelve transects. The location of the transects were determined according to the following protocol. The evaluation area was segmented into three sections, located at 100 foot intervals along the primary transect (Figure 12).

In each of the sections, four transects were placed, two on each side of the primary channel, for a total of 12 transects The transect locations were determined by generating a random integer between 0 and 100 according to a calculator algorithm. The random integer was the distance in feet along the primary transect from the start of each section. If the location of a transect placed it on a ditch or channel or within 3 feet of another transect, that number was rejected, and a new number/location was randomly generated.

The transects were oriented to run from the bank (primary transect) to the upland edge, on a consistent compass bearing. A stake was secured in the substrate at each end of the transect and labeled with the site and transect code.

Along each transect, $1m^2$ plots were placed every 18.29 m (60 ft), starting at the creek edge 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 standard cover class categories are contained in Appendix B. This cover class was entered on the field data sheet. The community type (low marsh, high marsh, or fringe) for each plot was also recorded.

Coverage estimates also included areas within the $1m^2$ plot that were not occupied by living, rooted plants (including wrack, inorganic matter, bare ground, and open water) which were recorded as “other”.

To focus on the invasive *Phragmites australis*, three permanent plots (one per transect) were located at each paired reference and study site within a monotypic stand of *Phragmites*. During the plant survey, the tallest 10 individuals were measured. Starting in 2003, the number of live individuals were counted and recorded.

Plant surveys were conducted during peak maturity and biomass in August and September.

Avifauna

Avifauna (or bird) surveys were conducted using the point count method. Point counts were conducted from a single vantage point overlooking the marsh where all of the salt marsh evaluation area could be viewed. The same vantage point was used for all subsequent surveys at each site. All species and individuals seen or heard within a fixed time period of twenty minutes were recorded. Birds were identified by visual and/or auditory cues and using 10x42 binoculars.

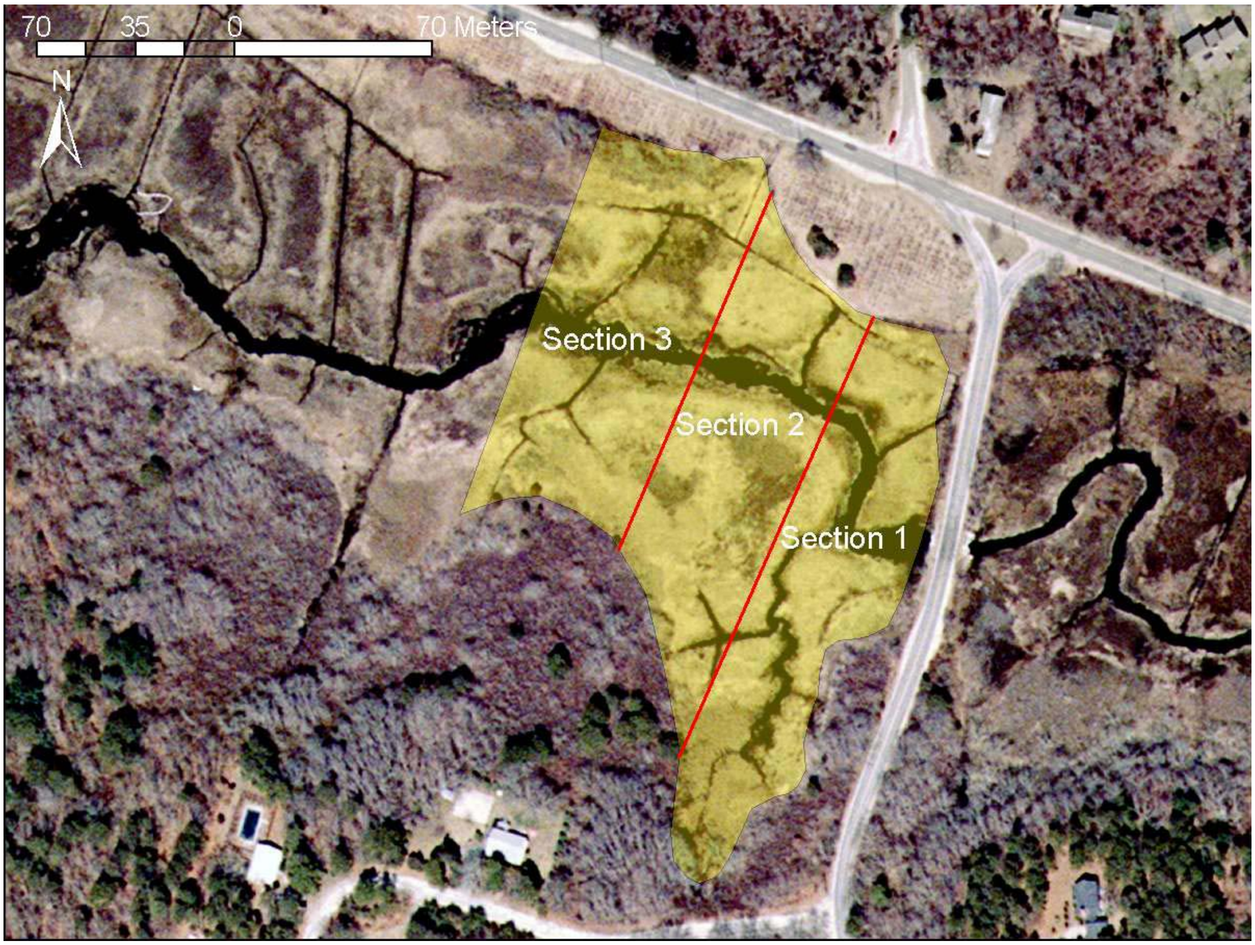

Figure 12. Sections of the evaluation area for plant survey.

Surveys were conducted in the morning, before 8:00 AM, in order to maximize detection during the time when birds are most active. Only birds within the evaluation areas or 100-foot buffer were counted during the surveys. The marsh buffer zone, or border, was included for several reasons. Many species that utilize the salt marsh as habitat do not nest directly in the salt marsh itself but in the immediate border. The border offers better protection for nesting for many species that otherwise depend on the marsh for feeding and resting activities. Buffer zones are also important for protecting marsh quality. Birds sitting or feeding directly in the salt marsh or the buffer were counted, as well as flying individuals that clearly appeared to be to feeding or otherwise searching the site. Generally, birds above 200 feet were not counted.

Surveys during a given field season were conducted at the paired sites on the same day, generally in sequence, in order to minimize impacts from weather and other variables on bird activity. Usually surveys for all sites in a given field season were conducted on the same day. Weather and tide conditions were noted on the field data forms. Where possible, surveys were conducted under different tidal conditions in order to maximize counts under variable tidal conditions when detection could be influenced by the height of the tide.

A minimum of four surveys, and as many as six, was conducted at each site over the course of the late spring and summer. Surveys generally began in late May and were conducted up through September at roughly monthly intervals. Late spring/early summer surveys were targeted to survey breeding species while late summer and early fall surveys were targeted to include migrating shorebirds in particular, but also post-breeding activities by herons and the fall land bird migration.

Data sheets were used to record the data. On the data sheet, investigators logged each species seen or heard and the number of individuals of each species seen or heard. In instances when an individual of a species would fly back and forth across a survey site during a survey, best professional judgment was used to determine whether it was likely to be the same individual or a different one in order to avoid duplicate counting. Date, time, weather, and tidal conditions were also recorded. To further minimize data variability from variable detection skills, a single investigator conducted all of the surveys. Notations were made as to whether the individuals were active within the salt marsh, flying-over, or in the buffer-zone. Data sheets were photocopied with the original set archived in a data folder while the observer kept the copy for data entry and analysis.

Nekton

The sampling strategy was designed to survey the channel habitat (sub and inter-tidal creeks). The evaluation area was divided into three sub-units along the 300' linear length of creek channel. Stations were established along the primary transect or spine at the following three intervals from the starting point: 0 to 20 feet, 140 to 160 feet, and 280 to 300 feet (Figure 13).

Seines were utilized to sample creek channels. For each sampling survey, at three stations in the site, a seine haul was conducted. At each station, a stop net was placed across the channel from one bank to the opposite. At a point 10m downstream (or with the tide) from the stop net, the seine was dragged through the water column, against the tidal flow along the creek bank and substrate for the 10m length to the stop net. The bag seines were carefully withdrawn from the creek and pulled onto the marsh surface. The collected nekton were carefully extracted from the seine and placed into processing buckets. The nekton were then removed by dip nets, sorted into species, and then the individuals for each species set were identified and measured. Species, abundance, and total biomass were enumerated (i.e. number of fish and decapods per haul, length, for each individual: standard length, carapace length). All data was recorded on a standardized field sheet.

In the case that an unidentifiable species was encountered, it was placed in a vial with preserve (10% formaldehyde solution; transfer to 70% ethyl alcohol), clearly labeled with date, site, sample number, station, and subunit #, and returned to the lab for identification.

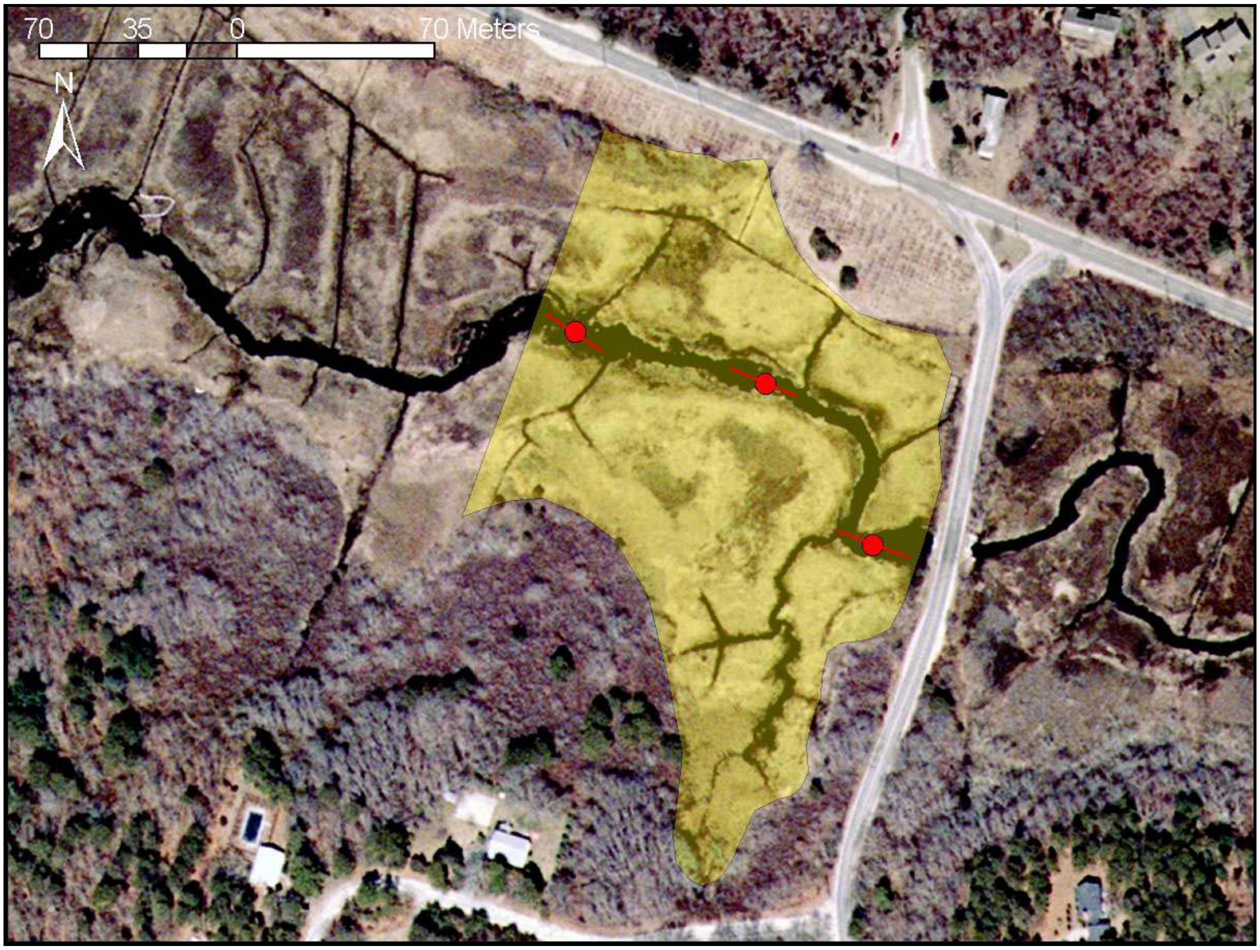

Figure 13. Stations in Evaluation Area for Invertebrate and Nekton samples.

At all sites, the tidal creeks sampled were the primary creeks, except at EMC-R and regional reference ECG-R. Two secondary tidal creeks (150’ and 300’) were sampled at EMC-R because the main creek below the tidal restriction was too wide for the seine to effectively limit escapes; therefore, EMC-R stations included a combination of primary (0’ station) and secondary tidal creeks (150’ and 300’ stations). Secondary creeks (approximately at 200’ and 300’) were also sampled at ECG.

Temperature, salinity, dissolved oxygen and pH were measured at each station prior to each haul with a YSI 600 probe attached to a YSI 650 hand-held data logger. Water depth was shallow, so stratification was not an issue in most cases and bottom measurement were collected. In instances when wide variability between surface and bottom measures were observed, both surface and bottom measures were recorded.

Surveys were generally run each month from April to October.

Aquatic Macro-Invertebrates

The sampling protocol was designed to survey representative populations of macro-invertebrates 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 are located along the primary transect or spine at the following three intervals from the starting point: 0 to 20 feet, 140 to 160 feet, and 280 to 300 feet (Figure 13).

At each of the three invertebrate stations, the following discrete samples were collected at low tide (within 90 minutes on either side of the actual time of low tide):

- Sub- or inter-tidal open water zone:
  - ✓ one D-Net sweep along the bottom substrate, edge of bank toe, and next to any large debris (logs, rocks, tires),
  - ✓ one auger sample from top of substrate to a depth of approximately 6 inches (15-16 cm), and
  - ✓ one 18” x 18” survey plot on the surface of the benthic substrate.
- Inter-tidal bank zone:
  - ✓ one 18” x 18” survey plot on bank surface.

Each sample was placed in a sealed plastic bag, and labeled with the following: site number, site name, date of sampling, sample number, sampling method, name of sampler. After sorting the discrete samples for each station are combined to form a composite sample of the various habitats sampled.

The site field data sheets recorded the relevant sample numbers. All samples were bagged, preserved in 90% ethyl alcohol, placed in a cooler and returned to the laboratory for sorting, identification and enumeration.

At each site, a habitat characterization is completed that summarizes the salt marsh conditions at the sampling site. The information collected includes the characterization of hydrology, vegetation, substrate, available food sources for invertebrates, and visible evidence of human disturbance for the site.

Temperature, salinity, dissolved oxygen and pH were also measured at each station prior to sampling with a YSI 600 probe attached to a YSI 650 hand-held data logger. Water depth was shallow, so stratification was not an issue in most cases and bottom measurement were collected. In instances when wide variability between surface and bottom measures were observed, both surface and bottom measures were recorded.

In the laboratory samples were sorted, separating organisms from debris. Invertebrates were then placed in glass vials in 90% ethyl alcohol and sealed with screw tops. Invertebrates were later counted and identified without sub-sampling to Family Level (Fauchald, 1977; Gosner, 1978; Meinkoth, 1988; Pollock, 1998, Weiss, 1995). Processed samples were returned to their labeled vials with 90% ethyl alcohol for archival storage. A sample custody sheet recorded full details of all samples, and the stage of their progress from marsh to archival action.

The invertebrate surveys were conducted in late May and again in late August or early September.

Results and Discussion

Due to the structure and obligations of the grant, the reporting period (ending March 31, 2004) did not allow for inclusion of most of the 2004 data (collected May to September 2004). The results presented here focus primarily on the effects of tide restriction, and to a lesser extent, initial responses of tide restricted sites to restored tidal hydrology. Two years of post-restoration data are presented for study site EOBP, and hydrology and *Phragmites* height data for EMC from 2004 are included. Future reports or publications will address long-term restoration response.

For this section, the following naming convention is used: Reference sites of the reference/study pair (as well as the regional reference sites) are identified as "SITE NAME–R". Study sites of the reference/study pair are referenced by their restoration status, so that study sites before the restoration of tidal hydrology are identified as "SITE NAME–pre" and after restoration of tidal hydrology are identified as "SITE NAME–post".

Abundance values refer to numbers of individuals (e.g. number / unit of effort). In some cases, the abundance numbers have been converted to a percent abundance to allow for a comparison of relative contribution of taxa; in these cases abundance is specifically expressed as percent abundance. When biomass is utilized it is specific with applicable weight (e.g. grams / unit of effort).

Variability is expressed as standard error (standard deviation/square root of units of effort). Data sets were first evaluated for normal distribution in order to use parametric tests with a Shapiro-Wilk W test. For non-normal distributions, data were transformed (log [x+1]). Statistical significance was calculated with a two-tailed T-Test assuming unequal variance. The critical probability values (p) used were 0.05 (1 in 20) and 0.01 (1 in 100).

Tidal Hydrology

Results from the tidal hydrology measurements confirmed that restrictions were present at study sites EOBP, EMC, and MSLP. For sites EOBP and EMC, the removal (or partial removal at EMC) of the restrictive feature resulted in increased tidal flow to the study site. The difference in water height from the reference site to the study site and the percent of the tidal range restricted are presented in Table 4.

Figures 14 through 16 show the tidal amplitude curves from the observed tide periods at EOBP, EMC, and MSLP. The pre-restoration graphs demonstrate representative symptoms of restricted tidal flow: curtailed high tide levels, higher low tide levels (water backed-up in the system), and time lags between the cycles.

As indicated by the observed tides, the removal of the collapsed 36’ culvert and its replacement with a 4’ x 6’ new culvert at EOBP allowed for nearly complete restoration of flow to the study site (Figure 14). At EMC however, the tide height survey after the partial dike removal shows that the study site sees 80% of the range of the reference which is a significant increase from pre-restoration (Figure 15). This partial flow obstruction is due to a shelf at the invert of the channel that was purposefully left in place to ensure that water did not completely drain at ebb tide. While tide range is an excellent indicator, the elevation of the height of flood tides can and should be quantified. At MSLP with a tidal range of just over 0.5 meter, the tide restriction is evident at both the flood and ebb tides, with only 70% of the tidal range making it to the study site (Figure 16). Because of its unique importance, the use of tidal hydrology as an indicator to track restoration is highly recommended.

Table 4. Difference in height between reference and study, and percent of tide range restricted.

Site	Unrestricted range observed (cm)	Difference in water height (cm)	Percent of tide restricted
EOBP-pre	141.37	24.35	17.22 %
EOBP-post	140.39	5.00	3.57 %
EMC-pre	128.26	63.09	49.20 %
EMC-post	149.35	32.00	21.43 %
MSLP-pre	55.17	16.46	29.79 %
MSLP-post	n/a	n/a	n/a

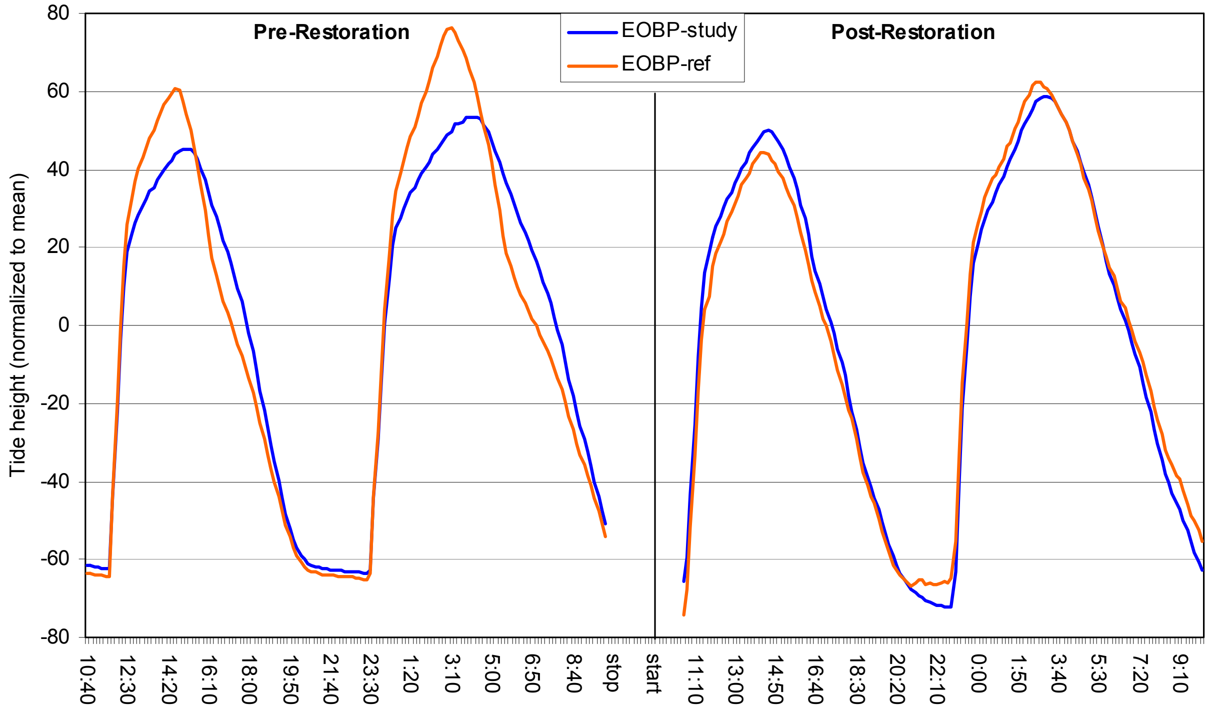

Figure 14. Tidal amplitude curves for EOBP pre- and post-restoration.

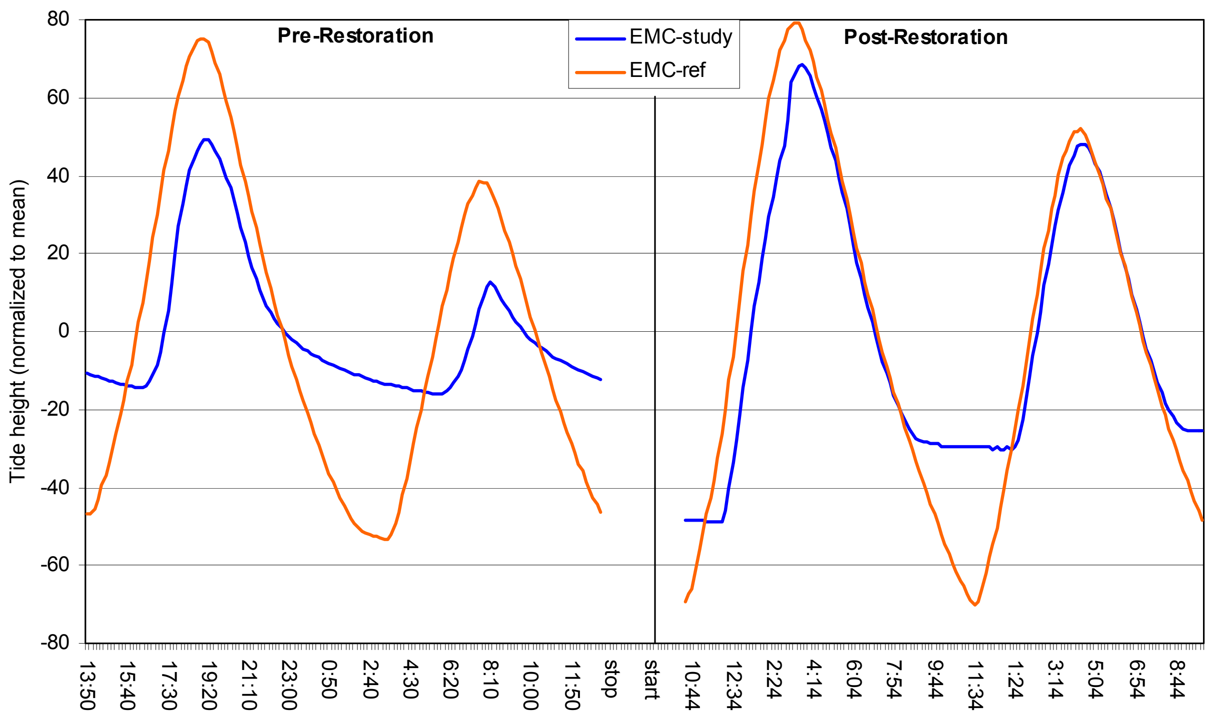

Figure 15. Tidal amplitude before and after restoration at EMC.

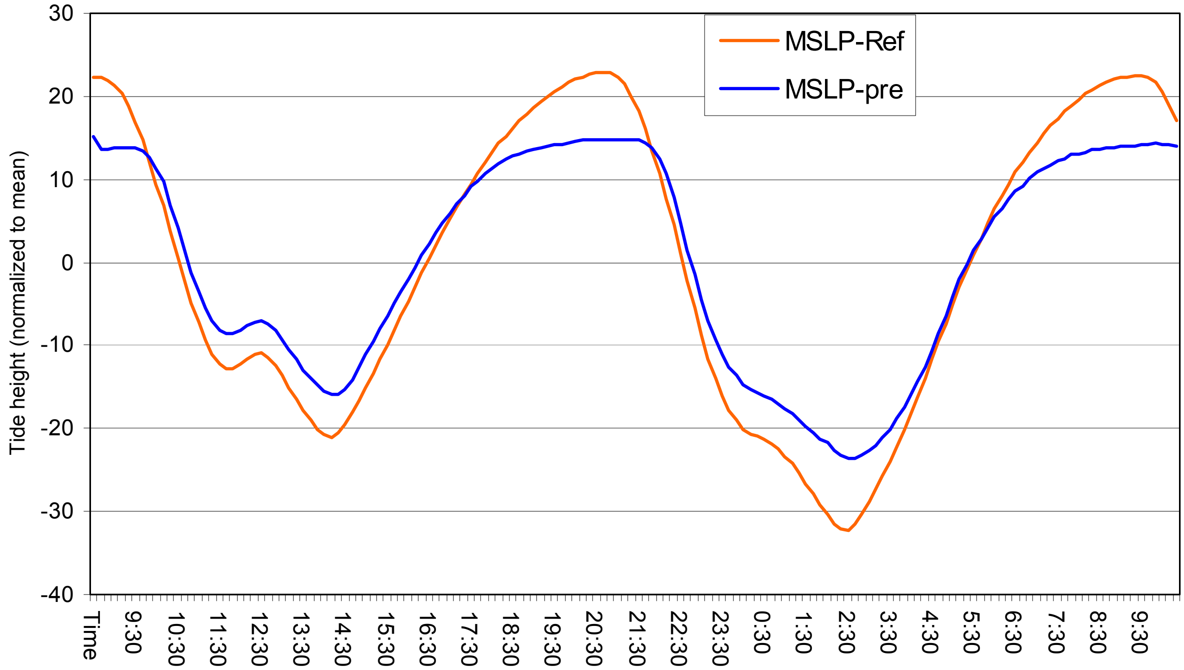

Figure 16. Tidal amplitude before restoration at MSLP.

Water Quality

Water quality measurements were taken in connection with the nekton and invertebrate surveys; summarized results are displayed in Table 5. For each site, water depth was shallow, so stratification was not an issue in most cases and bottom measurement were collected. In instances when differences between surface and bottom measurements were observed, both surface and bottom measures were recorded.

Table 5. Water quality results by site and year for reporting period (standard error).

Site	Year	Water Temperature (ºC)	Salinity (ppt)	Dissolved Oxygen (mg/l)	pH
EOBP-pre	2000	21.2 (2.2)	24.3 (1.6)	na	na
	2001	18.2 (1.3)	15.8 (1.2)	3.0 (0.3)	7.0 (0.04)
EOBP-post	2002	18.7 (1.2)	15.5 (1.8)	2.7 (0.2)	6.8 (0.03)
	2003	17.4 (0.9)	13.6 (1.8)	3.1 (0.3)	6.4 (0.04)
EOBP-R	2000	19.1 (2.0)	25.3 (1.5)	na	na
	2001	18.5 (1.3)	13.9 (1.2)	3.5 (0.5)	6.9 (0.02)
	2002	19.5 (1.2)	17.0 (2.1)	2.4 (0.2)	6.7 (0.02)
	2003	17.3 (0.8)	13.8 (1.5)	3.2 (0.2)	6.3 (0.07)
EMC-pre	2000	17.6 (1.9)	26.3 (1.2)	4.6 (0.3)	7.0 (0.03)
	2001	19.4 (0.3)	21.6 (2.1)	5.0 (0.5)	7.2 (0.1)
	2002	15.7 (0.9)	23.8 (1.2)	5.3 (0.9)	6.9 (0.1)
	2003	19.2 (1.4)	21.4 (1.7)	7.1 (0.6)	6.7 (0.1)
EMC-R	2000	20.6 (1.7)	27.0 (2.2)	6.8 (0.8)	7.3 (0.2)
	2001	19.5 (0.6)	26.4 (1.7)	6.1 (0.5)	7.3 (0.1)
	2002	16.5 (0.7)	22.2 (2.0)	7.7 (0.9)	7.0 (0.1)
	2003	17.2 (1.0)	27.0 (1.1)	8.7 (0.4)	6.5 (0.1)
MSLP-pre	2000	18.7 (1.3)	19.6 (1.9)	8.3 (0.4)	7.8 (0.3)
	2001	20.7 (1.6)	21.6 (0.9)	7.2 (0.6)	7.6 (0.1)
MSLP-R	2000	19.9 (1.4)	27.3 (1.4)	8.1 (0.4)	7.5 (0.1)
	2001	20.2 (1.5)	24.4 (1.2)	7.0 (0.4)	7.4 (0.1)
ECG	2002	15.4 (3.2)	30.3 (6.3)	6.5 (1.3)	6.7 (1.4)
ECG2-R	2003	20.3 (6.1)	25.6 (7.7)	6.4 (2.3)	6.8 (2.4)

Water quality parameters showed typical seasonal variability, with the warmest temperatures and lowest dissolved oxygen seen in late summer. Salinity appeared to be influenced by rain events. Generally, data suggest that study sites had lower salinity than their reference pairs, but statistical tests for difference have not yet been conducted. Water chemistry values also look to be strongly influenced by a site's proximity to marine waters.

For the EOBP sites, comparison of annual means of the water quality parameters did not appreciably differ between the Reference of Study (pre- or post- restoration) sites.

For the EMC sites, water temperature and pH did not appear different between EMC-R and EMC-S, but lower dissolved oxygen was evident each year at EMC-S compared to EMC-R and higher salinity was measured at EMC-R compared to EMC-S each year except 2002. The tidal restriction obviously influenced water quality in EMC-S, particularly during and after substantial rain events.

Salinity tended to be higher at MSLP-R compared to MSLP-pre. Other parameters (water temperature, dissolved oxygen and pH) showed little difference. Water temperature increased from May through September and decreased September to October.

ECG-R had the highest mean salinity, due to its proximity to marine waters. Temperature and dissolved oxygen varied throughout 2002; dissolved oxygen levels were notably low in August and September but rebounded in October. ECG2-R had more freshwater influence than ECG, primarily suspected from local groundwater tables. Water quality measurements varied throughout 2003.

Plants

A total of forty-four species were surveyed at the salt marsh study sites. Table 6 shows the total number of taxa surveyed at each site, the mean taxa (per transect) with the standard error, and the mean abundance (cover) with the standard error. The complete species list with abundance values is listed in Appendix B. The indicators that were examined for use to assess condition and to track and report on restoration response for the plants biotic assemblage were:

- ✓ plant abundance (% cover),
- ✓ plant taxa richness,
- ✓ abundance (% cover) of invasive species,
- ✓ abundance (% cover) of low marsh grass,
- ✓ abundance (% cover) of high marsh grasses,
- ✓ habitat affinity values,
- ✓ *Phragmites* height, and
- ✓ plant community composition.

Table 6. Plant data summary: Total taxa, mean taxa, abundance.

SiteCode	Year	Total # Taxa	Mean # Taxa	Standard Error	Abundance per m^2	Standard Error
EOBP-pre	2001	10.00	2.92	0.45	72.34	10.18
EOBP-post	2002	7.00	2.75	0.51	66.65	11.52
EOBP-post	2003	12.00	3.08	0.51	74.97	11.67
EOBP-R	2001	10.00	4.33	0.47	60.53	8.86
EOBP-R	2002	10.00	3.75	0.49	53.07	9.18
EOBP-R	2003	14.00	5.42	0.54	77.77	11.93
EMC-pre	2001	13.00	4.58	0.73	78.63	6.64
EMC-pre	2002	15.00	4.00	0.73	55.57	5.22
EMC-pre	2003	15.00	5.58	0.94	74.32	6.79
EMC-R	2001	16.00	4.67	0.45	84.53	8.79
EMC-R	2002	14.00	4.58	0.57	65.80	6.29
EMC-R	2003	13.00	4.67	0.64	74.94	8.27
MSLP-pre	2001	20.00	10.17	0.73	84.55	6.21
MSLP-R	2001	28.00	11.50	0.71	69.79	6.45
ECG-R	2002	8.00	4.58	0.58	61.65	14.69
ECG2-R	2003	11.00	6.83	0.39	87.78	9.49

In general terms, the study sites (tide-restricted) have less taxa and lower abundances than their reference (or unrestricted pairs). Variability both in taxa numbers and in abundance values can be seen at sites across years, and although it is relatively minor, it can be attributed to both natural changes and to survey precision. Seasonal or annual factors such as rainfall, temperatures, and severity of winter can affect plant community composition. The survey transect is fixed but its location each year is influenced by such factors as recovery of start and end markers (approximately 10% of the physical markers were lost to icing and vandalism but the point is replaced by GPS) and the actual physical placement and alignment of the transect tape.

The examination of overall species diversity shows that the site with the maximum number of species was MSLP-R in 2001 (n=28); the lowest number was EOBP-post in 2002 (n=7). The species with the highest frequency of occurrence were *Spartina alterniflora* and *Spartina patens*, occurring at each site (n=9) and in every year. *Distichlis spicata*, *Phragmites australis*, and *Salicornia europaea* were found at eight of the sites. Thirteen of the plant species occurred only once.

Taxa richness can be utilized as a condition or restoration indicator and was computed and averaged by transect (as unit of effort) with variability expressed as standard error. Figure 17 displays the taxa richness results. Sites MSLP-R and MSLP-pre have approximately twice the species than the other sites. The pattern that emerges for the taxa richness indicator is that the reference sites have greater numbers of taxa than the study (pre) site of the paired sites, except for EMC, where the reference site had 0.03 fewer mean species. All paired means were within standard error variability, except for EOBP, where the reference site mean number of taxa was significantly higher (at 99%) than both the -pre and -post study means. For EOBP, taxa richness is a good indicator of restoration success and could be deemed to have been met when the means of the study -post and reference site are no longer significantly different.

The abundance of invasive species was examined as a condition or restoration indicator and was computed as the mean abundance of plant species with a positive invasive attribute on a transect basis (with variability expressed as standard error). The species attribute list is in Appendix C. *Phragmites australis* is the dominant invasive for salt marsh systems. Figure 18 displays the abundance of invasive species results. The pattern for this indicator is that the study sites (–pre and –post) have greater mean abundances of invasive species than the reference sites of the paired sites. EOBP-pre, EOBP-post, and EMC-pre means were significantly higher than their reference counterparts' means. Abundance of invasives appears to be an excellent indicator of restoration success.

The abundance of the low marsh grass, *Spartina alterniflora*, was computed as the mean abundance of *S. alterniflora* on a transect basis (with variability expressed as standard error). *S. alterniflora* is the dominant low marsh grass and, for some systems, may be the dominant species. *S. alterniflora* is an obligate salt marsh species, and because it occupies the inter-tidal zone where it is generally flooded twice a day, it is found in most all salt marsh systems. Tide restricted sites that are rebounding after restored tidal hydrology are expected to see an initial increase in the extent of *S. alterniflora* and then over time a return to a more complex zonation of low marsh and high marsh communities. Confounding this concept is the fact that sea-level is rising and the marsh plain may not be keeping pace, so that current areas of high marsh may be in conversion to low marsh. Additionally, human eutrophication may be shifting the natural competition on the marsh plain so that *S. alterniflora* may be advantageously expanding. Figure 19 displays the results of *Spartina alterniflora* abundance at each site. The reference site pair has greater abundance of this low marsh grass than its study (restricted) counterpart, but only at EOBP is this difference significant. Note how

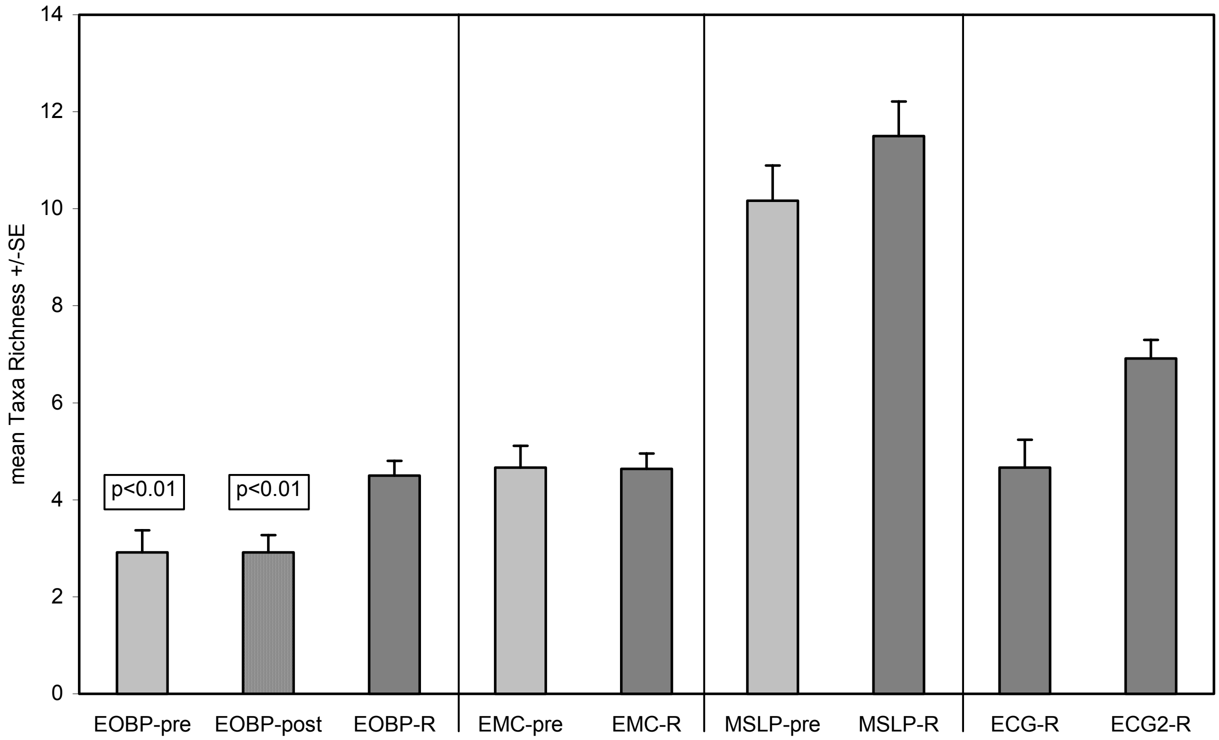

Figure 17. Mean plant taxa richness per transect (+/- SE) for reporting period.

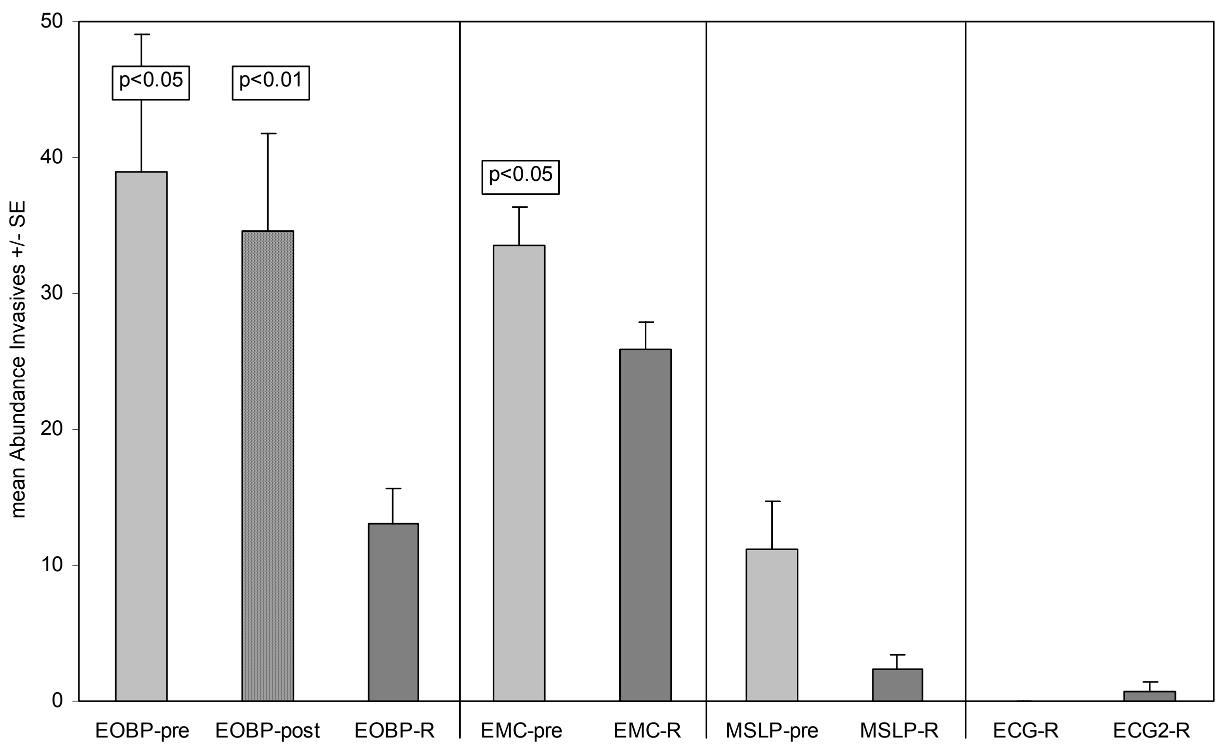

Figure 18. Mean abundance of invasive plants (% cover) per transect (+/- SE) for reporting period.

different the mean abundance values are for the regional reference sites. This appears to be a reasonably good indicator to use to track condition and restoration response.

The abundance of high marsh grasses, *Spartina patens, Distichlis spicata* and *Juncus gerardii*, was examined as indicators and computed as the mean abundance of high marsh grasses on a transect basis (with variability expressed as standard error). High marsh grasses generally occupy the portion of the marsh plain that is flooded only on mean or greater tides. These turf grasses are not as adept as *S. alterniflora* at dealing with salt stress. For many extensive (and older) salt marsh systems, high marsh is the dominant community, expanding both landward and seaward as the marsh plain accretes and builds over the upland fringe and the low marsh. As previously mentioned for the *S. alterniflora* indicator, this long-standing model may be at risk as marsh plains may not be accreting adequate sediments to keep pace with accelerated sea-level rise and human eutrophication may be shifting the natural competition to the favor of *S. alterniflora*. The results for the high marsh grasses indicator are shown in Figure 20. No distinct pattern emerges here—in some cases the study site pair has more high marsh than its counterparts and in no cases are the mean abundance values significantly different. Note again how different the mean abundance values are for the regional reference sites. As an indicator, its utility may be limited to tracking long term shifts in marsh plant communities.

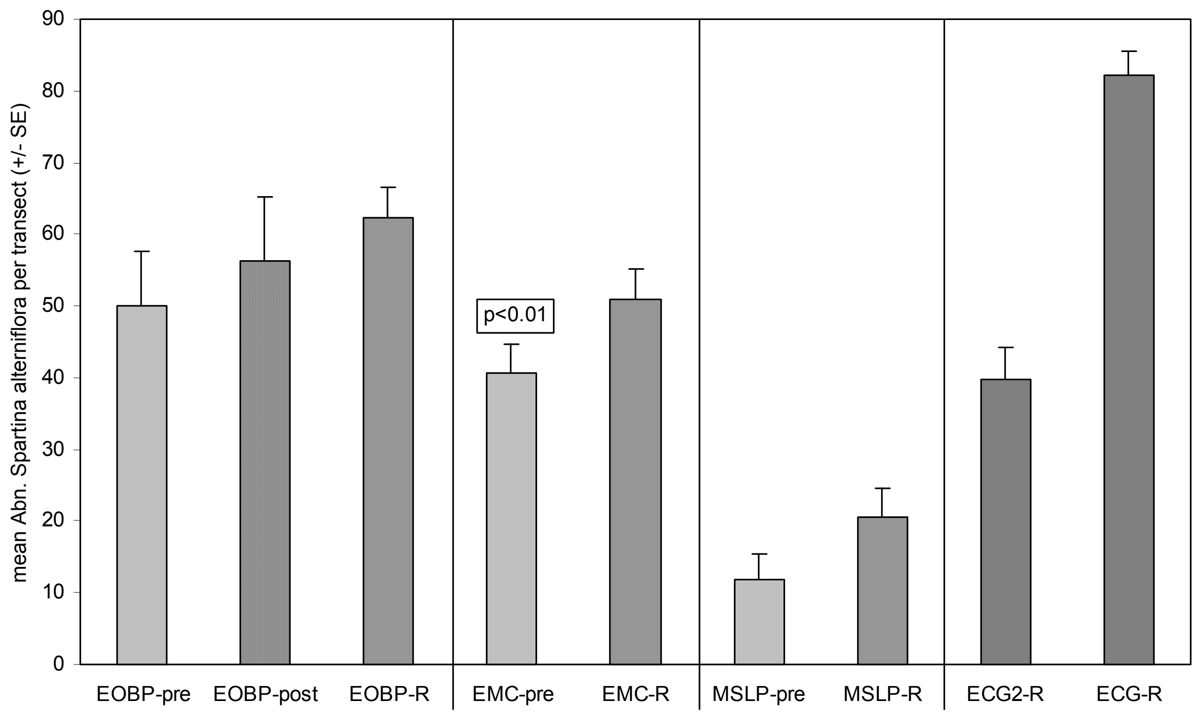

Figure 19. Mean abundance of S. alterniflora (% cover) per transect (+/- SE) for reporting period.

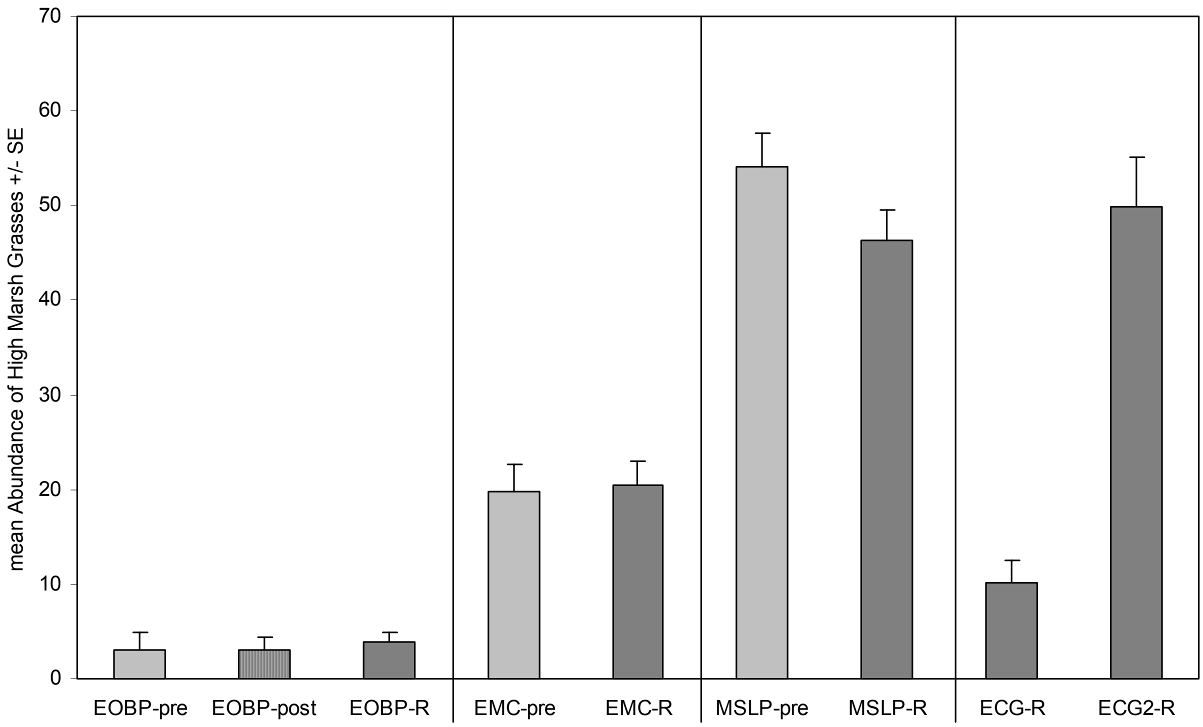

Figure 20. Mean abundance of high marsh grasses (% cover) per transect (+/- SE) for reporting period.

To examine habitat affinity, the mean abundance of the species surveyed at each marsh was weighted according to set of habitat affinity scores. These scores were assigned to a species to account for its occurrence in salt marshes as the preferred habitat type or niches. For example, *Spartina alterniflora*, *Spartina patens* and *Salicornia europaea* are almost always found in coastal salt marshes and have a habitat affinity score of 1.0. Other species, such as *Typha angustifolia* and *Teucrium canadense*, can be found in salt marshes along the upland border, but they can also be found in brackish and even fresh water marshes; their score is 0.5. *Ambrosia artemisiifolia* and *Phragmites australis* are opportunistic generalists and can be found in a wide variety of habitats, including non-wetland and highly disturbed areas; they have been assigned habitat affinity scores of 0.2. The habitat affinity value for each site was computed by taking the total abundance of each species on a transect and then weighting this abundance by the habitat affinity score (abundance * HA score). The values for each transect were averaged to derive the mean habitat affinity value (with variability expressed as standard error). The habitat affinity scores list is in Appendix B. As a rule, the habitat affinity values will decline with disturbance and degradation and will increase following restoration action. The results, shown in Figure 21, support this rule, and significant difference can be seen between all of the three reference and study (restricted) pairs. For EOBP-pre and –post, an increase in the habitat affinity value is observed, a good sign of restoration response.

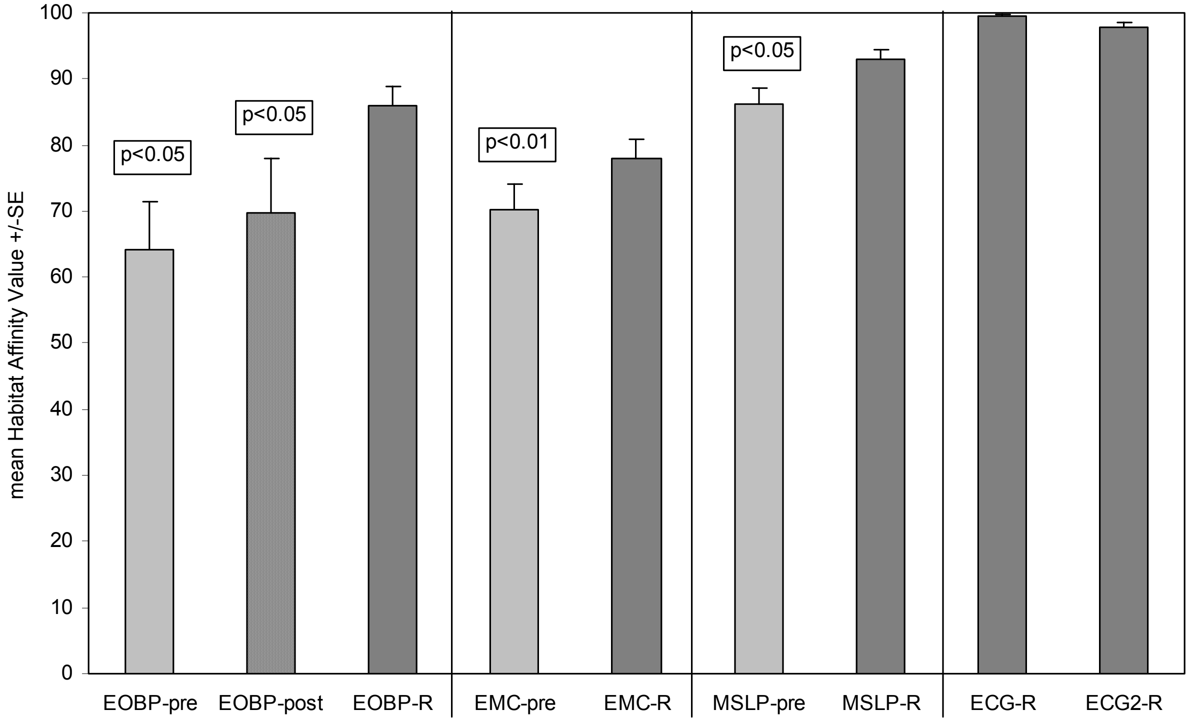

Figure 21. Mean plant habitat affinity value per transect (+/- SE) for reporting period.

In the examination of *Phragmites australis* height, 2004 data was included—last minute processing of August 2004 as this document was being finalized—to enable a first look at post-restoration response for EMC. As stated in the methods, the ten tallest Phragmites individuals were measured in three plots each year. The trends for both post-restoration sites (EOBP-post and EMC-post) look good, with decreasing height of plants, but these mean heights are not statistically different from the pre-restoration heights. For EOBP and MSLP, the mean heights at the study site are significantly different from their reference site counterparts. Most of the permanent *Phragmites* plots at site EMC were affected by land management practices that occurred without notice to the investigators in the Spring prior to each survey date. The Cape Cod National Seashore uses prescribed burning to manage upland habitat at Fort Hill and—either deliberately or accidentally—part of the *Phragmites* community was burned in 2002. The height of *Phragmites* appears to be an excellent indicator to track for future restoration response.

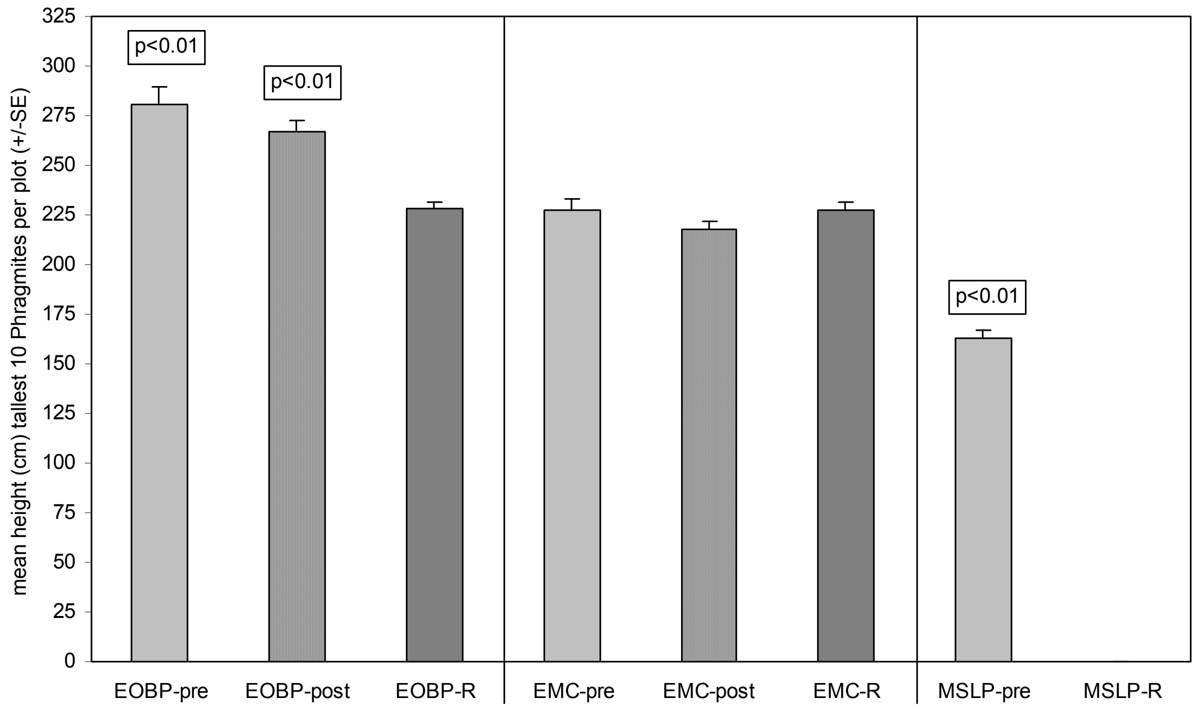

Figure 22. Mean height tallest 10 Phragmites (cm) per plot (+/- SE) for reporting period.

The plant community composition for each site is strongly influenced by a small number of species as shown in Table 7, which lists the three most abundant taxa for each site by year with the corresponding abundance value. In most cases, only two taxa represent over 75% of the total plant cover of the site. Of note here is the *Phragmites australis* abundance values for EMC-pre and EMC-R which were affected by the land management practices described above and by continual mowing through the spring and summer of the salt marsh border at the study site by a private landowner, apparently without local Conservation Commission consent.

Another method of examining community composition is generate similarity matrices and then to display the relationships between sites using such tools as multi-dimensional scaling (MDS). With Primer 5 software (2002, Primer-E, LTD), Bray-Curtis similarity values are created (Table 8). The higher the value, the more similar two site's communities are. So, for example, in Table 6, EOBP-pre is more similar to EOBP-post than to EOBP-ref and is the least similar to MSLP-pre.

Using Primer's MDS function, a plot can be produced to graphically represent the similarity matrix. For all of the MDS analyses for this report, the regional reference sites (BGIC, ECG and ECG2) were not used—their inclusion tends to overshadow or conceal the similarities (and differences) between the reference and study pairs which are the primary focus of the investigation. In the MDS plots, the distance between the site labels is the measure of similarity: the closer the labels the more similar the sites. Using MDS, it is possible to group similar sites and to establish restoration trajectories, tracking the community composition similarity over time. Figure 23 shows the relative similarity of each site's plant community, with the reference/study pairs can be closely grouped. One might note movement (though very small) of the EOBP-pre and post on the trajectory towards the reference standard.

Table 7. Plants: Three most abundant taxa and values.

Site	Genus Species	Total % Abundance
EOBP-pre	Spartina alterniflora	49.98
	Phragmites australis	38.89
	Distichlis spicata	2.54
EOBP-post	Spartina alterniflora	56.31
	Phragmites australis	34.55
	Scirpus robustus	4.14
EOBP-R	Spartina alterniflora	62.39
	Phragmites australis	13.07
	Agropyron pungens	8.00
EMC-pre	Spartina alterniflora	40.55
	Phragmites australis	33.59
	Spartina patens	17.43
EMC-R	Spartina alterniflora	50.91
	Phragmites australis	25.86
	Spartina patens	15.54
MSLP-pre	Distichlis spicata	23.88
	Juncus gerardii	18.98
	Spartina alterniflora	11.75
MSLP-R	Spartina alterniflora	20.53
	Distichlis spicata	18.97
	Juncus gerardii	17.27
ECG-R	Spartina alterniflora	82.21
	Spartina patens	10.22
	Salicornia virginica	4.03
ECG2-R	Spartina alterniflora	39.73
	Spartina patens	29.62
	Juncus gerardii	13.94

Table 8. Bray-Curtis similarity matrix for plant communities.

	EOBP-pre	EOBP-post	EOBP-R	EMC-pre	EMC-R	MSLP-pre	MSLP-R
EOBP-pre	1.00						
EOBP-post	91.58	1.00					
EOBP-R	74.29	78.11	1.00				
EMC-pre	74.36	74.93	60.04	1.00			
EMC-R	75.22	75.74	67.53	88.84	1.00		
MSLP-pre	27.94	26.70	34.90	37.78	38.95	1.00	
MSLP-R	30.27	29.26	38.33	39.74	41.78	74.38	1.00

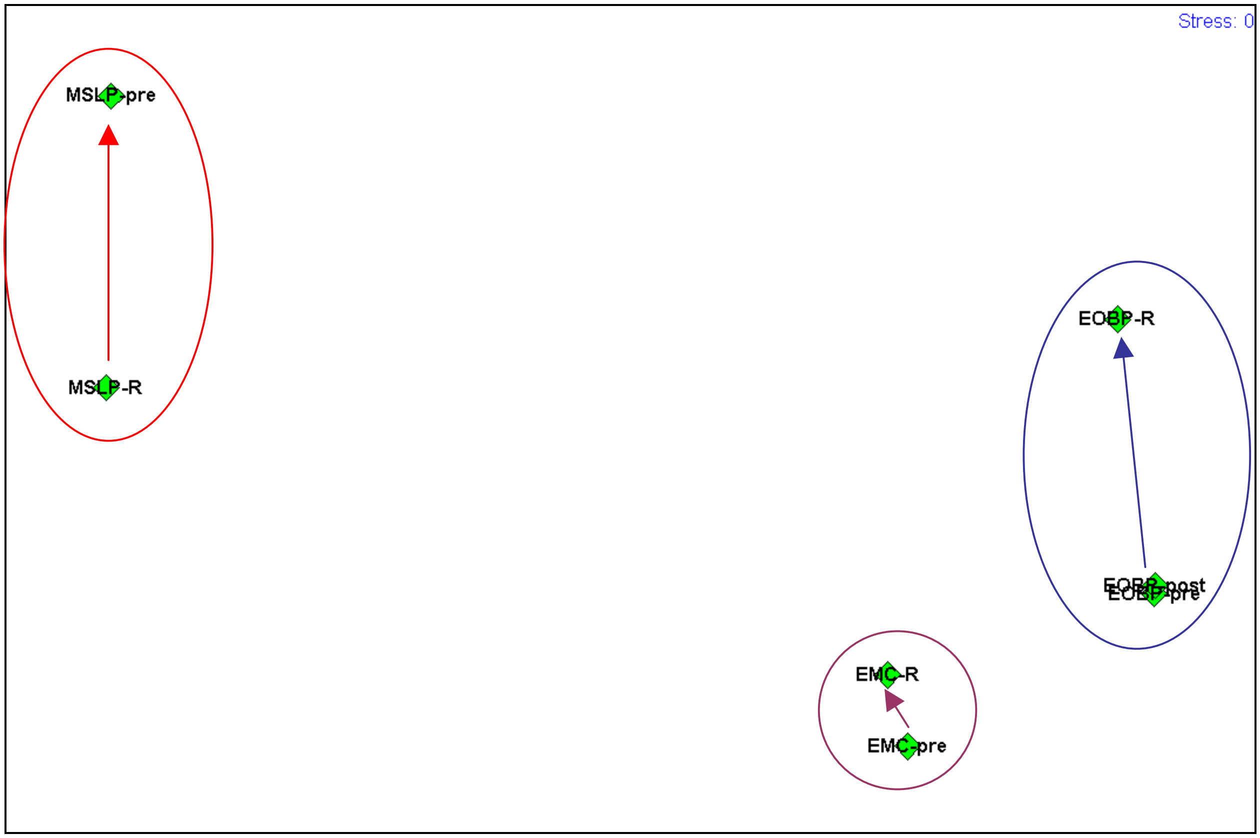

Figure 23. MDS plot of plant community similarity with proposed restoration trajectories.

Avifauna

A total of ninety-three species were surveyed at the salt marsh study sites during the reporting period. Table 9 shows the total number of taxa surveyed at each site, the mean taxa (per observation) with the standard error, and the mean abundance (per observation) with the standard error. The complete species list with total percent abundance values is listed in Appendix C The indicators that were examined for use to assess condition and to track and report on restoration response for the avifauna component of the investigation were:

- ✓ avifauna abundance (# per observation),
- ✓ avifauna taxa richness,
- ✓ number of wetland dependent species,
- ✓ number of neotropical migrants,
- ✓ abundance of aerial foraging species (# per observation),
- ✓ number of resident species, and
- ✓ avifauna community composition.

Table 9. Avifauna data summary: Total taxa, mean taxa, abundance

Site	Year	Total Taxa	Mean # Taxa per Observation	Standard Error	Mean Abundance per Observation	Standard Error
EOBP-pre	2000	20	13.00	1.53	41.00	3.61
EOBP-pre	2001	23	11.25	0.48	19.25	0.95
EOBP-post	2002	22	11.00	0.71	29.60	3.78
EOBP-post	2003	28	13.40	0.68	28.20	2.62
EOBP-R	2000	28	15.67	1.20	42.00	2.00
EOBP-R	2001	35	17.50	2.33	46.50	7.31
EOBP-R	2002	29	15.00	1.52	34.60	3.23
EOBP-R	2003	32	17.00	0.95	75.20	30.66
EMC-pre	2000	30	17.33	1.20	40.00	3.00
EMC-pre	2001	24	13.00	1.47	34.50	5.69
EMC-pre	2002	32	18.80	1.07	57.60	6.90
EMC-pre	2003	25	17.80	1.02	52.40	4.34
EMC-R	2000	35	15.33	1.20	41.00	8.50
EMC-R	2001	33	15.00	2.42	35.50	2.90
EMC-R	2002	40	20.00	1.10	60.60	7.25
EMC-R	2003	37	16.00	0.84	47.20	6.56
MSLP-pre	2000	27	14.33	2.73	43.00	4.73
MSLP-pre	2001	31	11.60	1.50	30.20	5.18
MSLP-R	2000	30	18.00	1.00	61.33	11.67
MSLP-R	2001	34	13.60	1.54	36.20	6.65
BGIC-R	2000	33	16.33	1.76	104.67	36.22
ECG-R	2002	42	18.60	1.60	484.80	295.51
ECG2-R	2003	38	17.40	0.75	55.00	4.34

In general terms, the study sites (tide-restricted) have less taxa and lower abundances than their reference (or unrestricted pairs). Variability both in taxa numbers and in abundance values can be seen at sites across years. Examples of the factors that may affect bird abundances and community composition in any given year include variations in food supply, habitat structure, and over-winter survival, all of which are a function of many physical and biological interactions.

Taxa richness is expected to be higher in sites where habitat quality and food supply are most optimal, so that, with increasing disturbance, the number of species is expected to decline. The number of species present is examined rather than the number of individuals as a measure of niche availability. Figure 24 displays the results of the taxa richness indicator for avifauna species. Significant differences were observed in the EOBP and EMC sites between the study and reference marshes. The regional reference site data suggest that overall variability in taxa richness can be high, most likely due to differences in habitat structure. With two years of post-restoration data, there was no observed change at the EOBP site. Taxa richness appears to be a good indicator to follow.

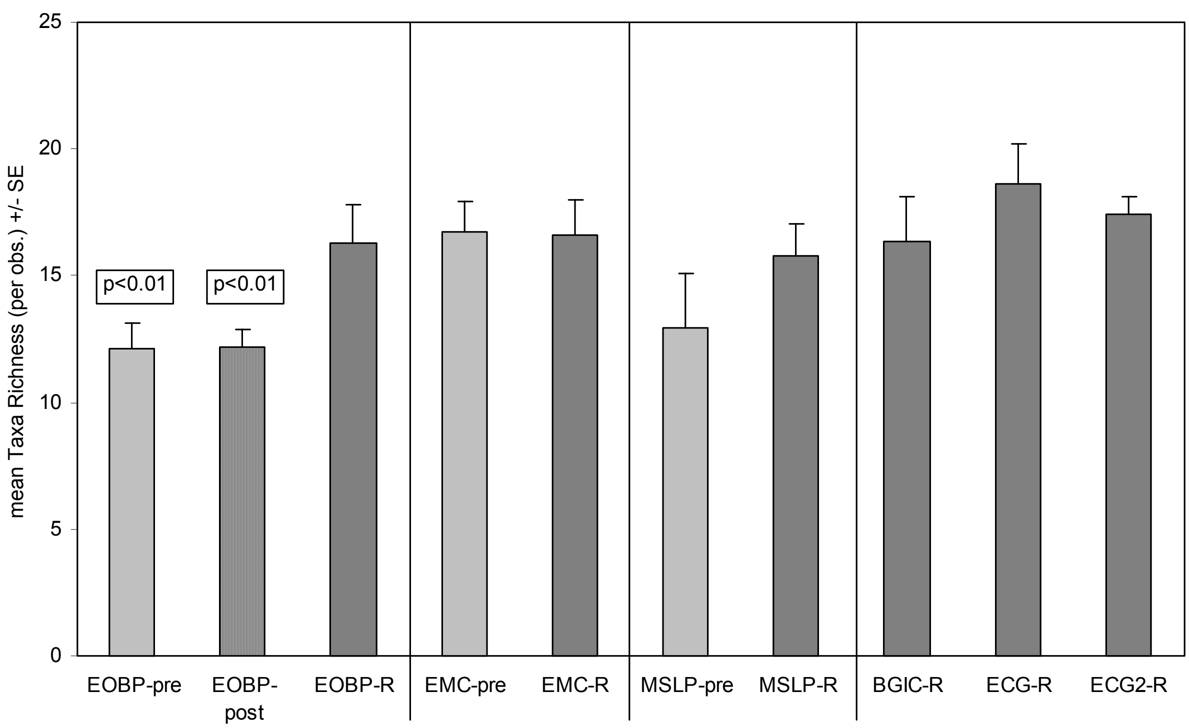

Figure 24. Mean avifauna taxa richness per observation (+/- SE) for reporting period.

Species with a wetland dependency attribute was examined as an indicator of condition or restoration response. Wetland dependency is defined as a species utilization of wetland habitats for important feeding, breeding, or resting functions, or any other life stage critical to improving survival. The bird species attribute table is listed in Appendix D. The number of wetland dependent species is expected to decline with increasing disturbance since these species are expected to require habitat that ties them directly to healthy, aquatic sites. The number of individuals of wetland dependent species is expected to follow the same trend and was calculated for comparison. Optimal wetland habitat may have larger numbers of the same species, depending on the territory size they require. Figure 25 displays the results of the number of wetland dependent species indicator for avifauna species. Data suggest that the reference sites have greater mean numbers of wetland dependant taxa, with fairly high variability between sites. Large groups of shorebirds strongly influencing the regional reference sites. Significant differences were found between the reference and study pairs at EOBP and EMC. This indicator also appears to be a good candidate to track condition and restoration response.

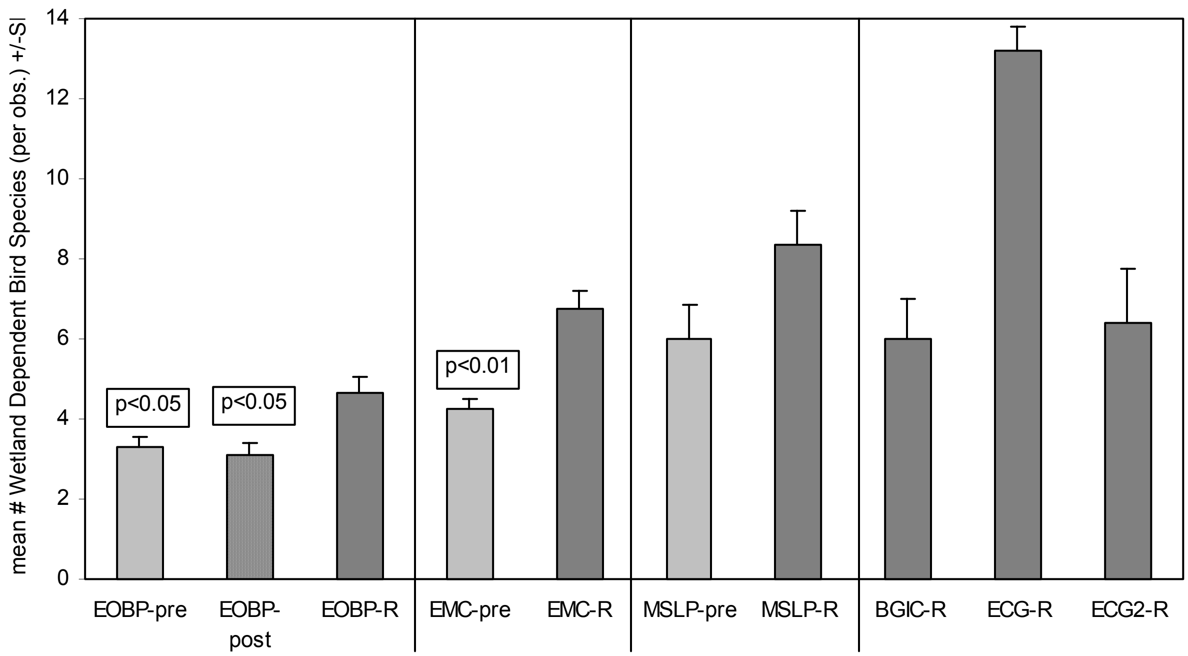

Figure 25. Mean # of wetland dependent bird species per observation (+/- SE) for reporting period.

The number of neo-tropical migrant species is another potential indicator examined for this project. Neo-tropical migrants are defined as species which migrant long distances to spend the winter months in Central or South America or the Caribbean. The bird species attribute table is in Appendix D. The number of species that are neo-tropical migrant is expected to decline with increasing disturbance since these species are almost all habitat specialists that are sensitive to habitat quality. The number of individuals of neo-tropical migrants was also been calculated for comparison and showed similar trends. Neo-tropical migrants often move in flocks so numbers of individuals may be an important indicator. Figure 26 displays the results of the number

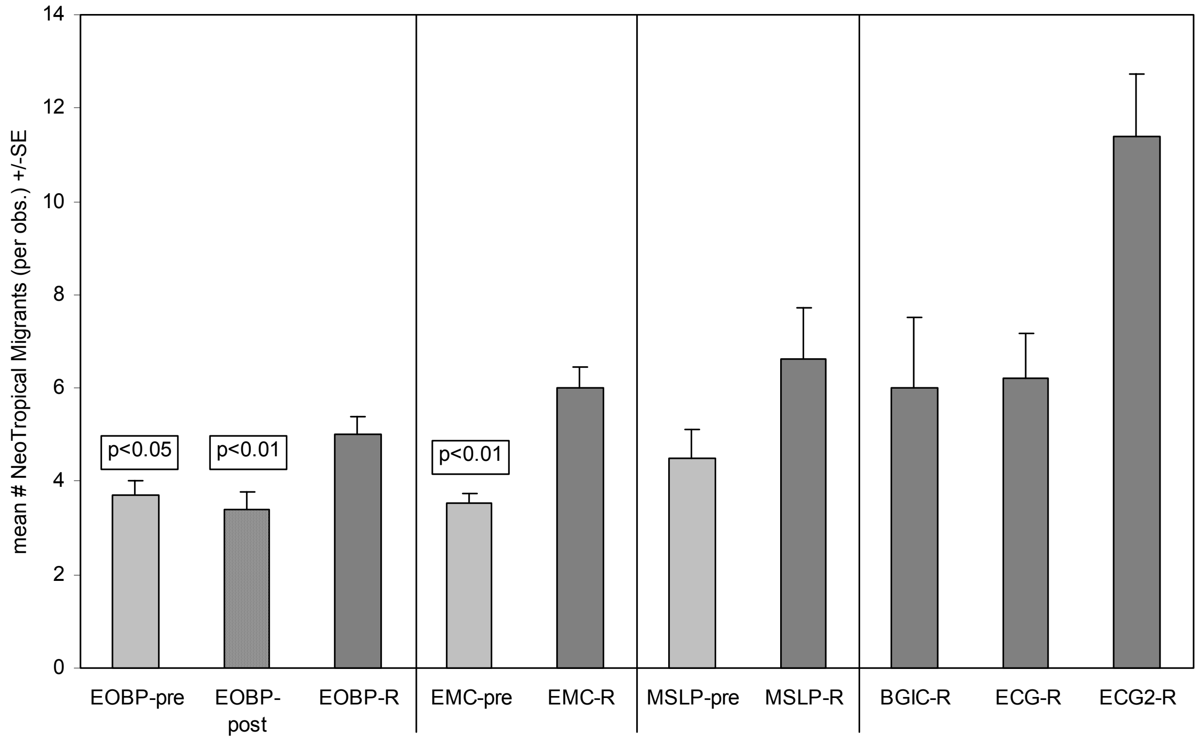

Figure 26. Mean # of neo-tropical migrants per observation (+/- SE) for reporting period.

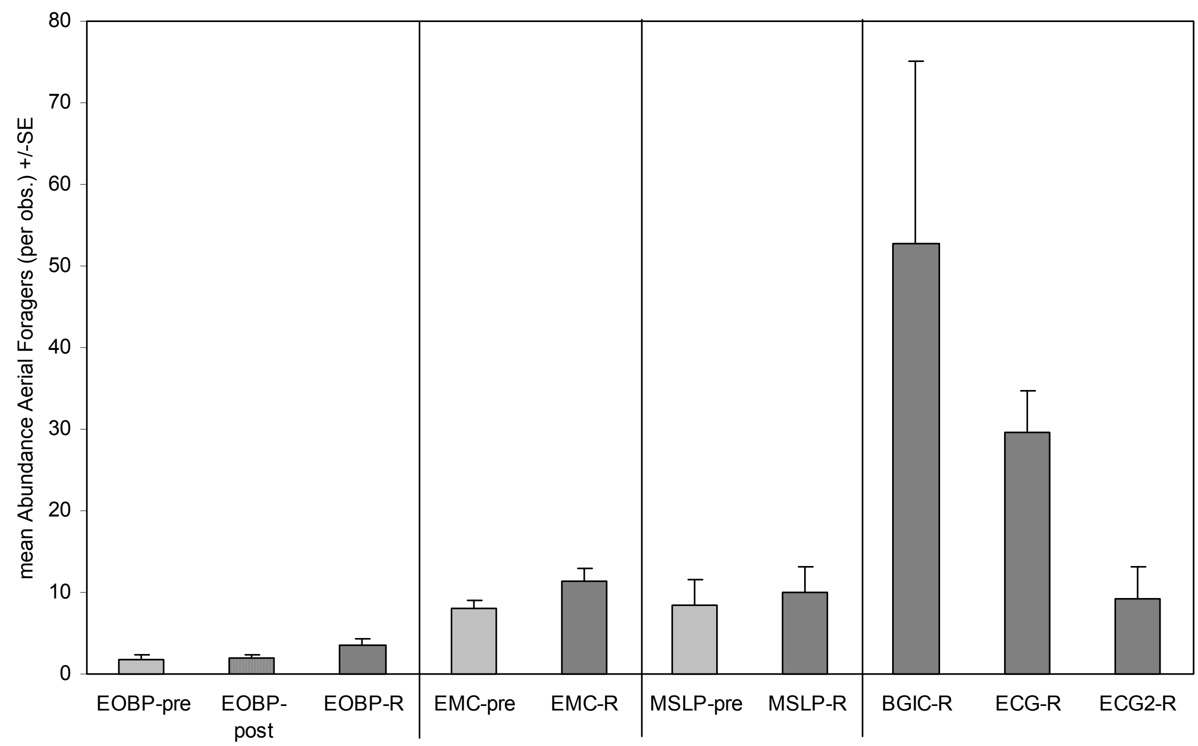

Figure 27. Mean abundance of aerial foragers (#) per observation (+/- SE) for reporting period.

of neo-tropical migrant species indicator for avifauna species. The results are very consistent with the results reported for wetland dependency, again with reference sites having higher mean number of neo-tropical taxa and also with occasional large groups affecting variability. This is a promising indicator.

Insectivorous aerial foragers feed on insects while flying and depend on a healthy insect population for food. They are expected to decline with increasing impacts to invertebrate populations that are expected with increasing wetland impacts. Figure 27 displays the results of the mean abundance of aerial foragers indicator for avifauna species. No statistically significant differences between reference and study site pairs were found for the data on aerial foragers. The trend suggests that the data follow a similar pattern to the previous three metrics but more sampling may be needed.

Another attribute assessed was the abundance of resident species. Residents are those species that are expected to be present all year at the location and do not migrate (except perhaps for short distances). The species with a positive resident attribute can be found in Appendix D. Resident species tend to be habitat generalists and are less sensitive to habitat quality, and, therefore, are predicted to increase with increasing disturbance. Figure 28 displays the results of the number of resident species indicator for avifauna species. The data do not demonstrate any strong patterns or relationships, except at the EMC site. More data are needed.

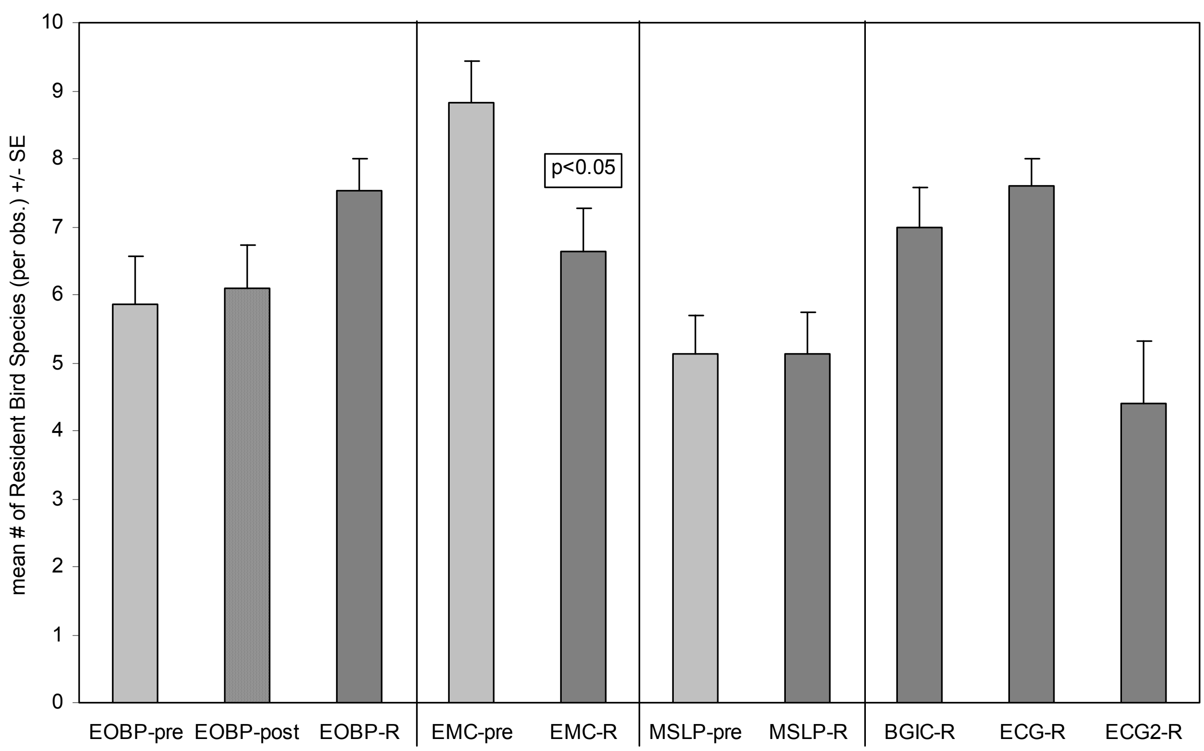

Figure 28. Mean # of resident bird species per observation (+/- SE) for reporting period.

The avifauna community composition for each site is generally very diverse. As shown in Table 10, which lists the three most abundant taxa for each site by year with the corresponding abundance value, in most cases, the top three taxa do not even total 50% of the total abundance for the sites.

Another method of examining community composition is generate similarity matrices and then to display the relationships between sites using such tools as multi-dimensional scaling (MDS). With Primer 5 software (2002, Primer-E, LTD), Bray-Curtis similarity values are created (Table 11). The higher the value, the more similar two site's communities are.

Table 10. Avifauna: Three most abundant taxa and values.

Site	Common Name	Total % Abundance
EOBP-pre	Red-Winged Blackbird	28.45
	Gray Catbird	8.93
	American Goldfinch	8.49
EOBP-post	Red-Winged Blackbird	26.21
	American Goldfinch	8.10
	Gray Catbird	7.54
EOBP-R	Red-Winged Blackbird	26.54
	Common Grackle	7.61
	Mourning Dove	7.21
EMC-pre	Common Grackle	14.36
	Red-Winged Blackbird	13.79
	Barn Swallow	9.55
EMC-R	Red-Winged Blackbird	14.97
	Barn Swallow	11.61
	Common Grackle	9.83
MSLP-pre	Red-Winged Blackbird	15.23
	Tree Swallow	12.52
	American Goldfinch	11.02
MSLP-R	Red-Winged Blackbird	11.45
	American Goldfinch	8.97
	Mute Swan	8.80
BGIC-R	Tree Swallow	29.06
	Salt-Marsh Sharp-Tailed Sparrow	13.67
	Barn Swallow	10.12
ECG-R	Short-Billed Dowitcher	30.34
	Semipalmated Sandpiper	12.58
	Common Tern	7.44
ECG2-R	Common Grackle	13.50
	American Goldfinch	8.53
	Red-Winged Blackbird	8.06

Table 11. Bray-Curtis similarity matrix for avifauna communities.

	EOBP-pre	EOBP-post	EOBP-R	EMC-pre	EMC-R	MSLP-pre	MSLP-R
EOBP-pre	1.00						
EOBP-post	79.11	1.00					
EOBP-R	69.33	71.88	1.00				
EMC-pre	69.51	68.16	70.60	1.00			
EMC-R	59.73	58.73	63.34	74.98	1.00		
MSLP-pre	55.74	53.30	58.67	59.40	62.43	1.00	
MSLP-R	49.26	48.08	51.57	51.44	61.56	70.85	1.00

Using Primer's MDS function, a plot can be produced to graphically represent the similarity matrix. For all of the MDS analyses for this report, the regional reference sites (BGIC, ECG and ECG2) were not used—their inclusion tends to overshadow or conceal the similarities (and differences) between the reference and study pairs which are the primary focus of the investigation. In the MDS plots, the distance between the site labels is the measure of similarity: the closer the labels the more similar the sites. Using MDS, it is possible to group similar sites and to establish restoration trajectories, tracking the community composition similarity over time. In Figure 29, it is clear that each of the site's communities are distinct, with the reference/study pairs grouping closely. One might note movement (though very small) of the EOBP-pre and post on the trajectory towards the reference standard.

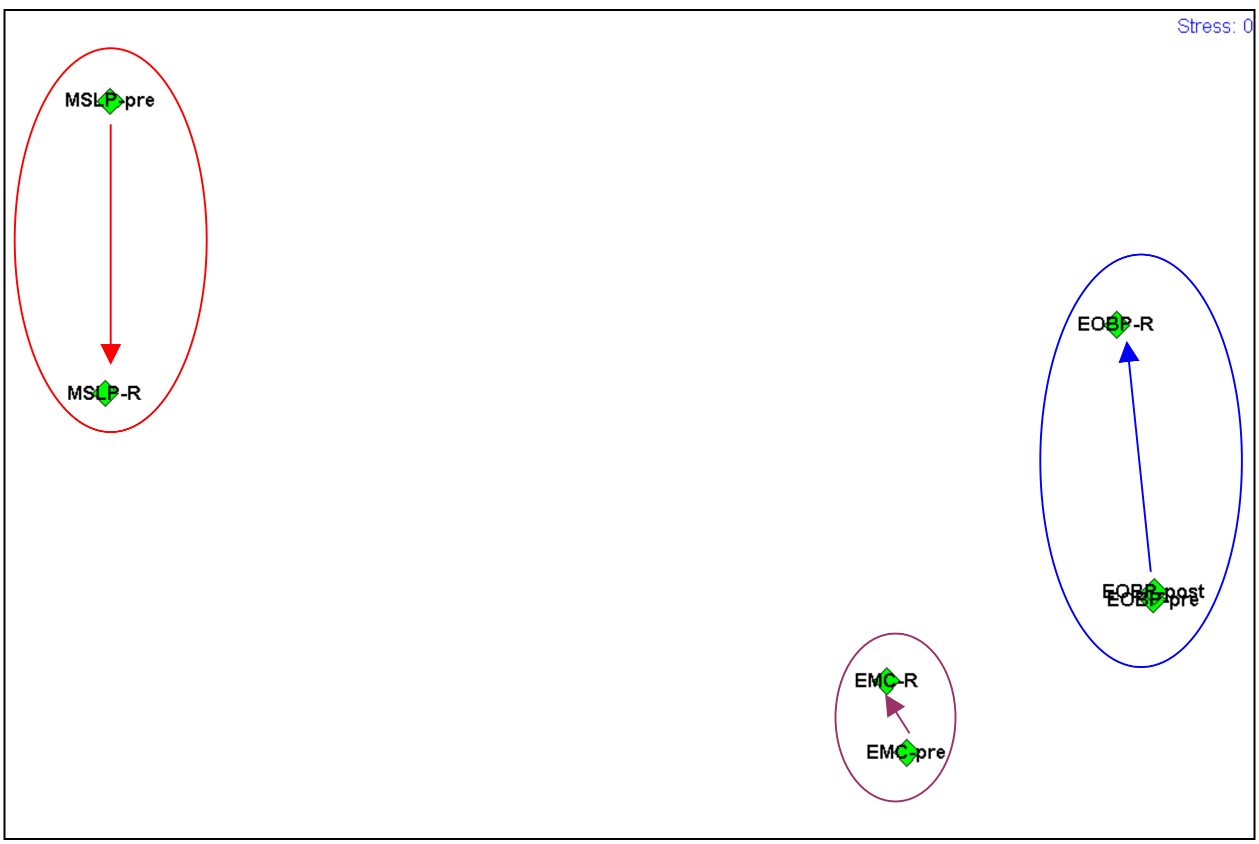

Figure 29. MDS plot of avifauna community similarity with proposed restoration trajectories.

Nekton

A total of 29 species and 53,101 total fish were collected at the salt marsh study sites during the reporting period. Table 12 shows the total number of taxa surveyed at each site, the mean taxa (per haul) with the standard error, the mean abundance (per haul) with the standard error, and the mean weight (per haul) with the standard error. The complete species list with abundance and weight is listed in Appendix E. The indicators that were examined for use to assess condition and to track and report on restoration response for the nekton component of the investigation were:

- ✓ nekton abundance (# per haul),
- ✓ nekton taxa richness,
- ✓ mummichog abundance (# per haul),
- ✓ non-mummichog abundance (# per haul),
- ✓ green crab relative biomass (grams per haul)
- ✓ mummichog length,
- ✓ number of transient species, and
- ✓ nekton community composition.

Table 12. Nekton data summary: Total taxa, mean taxa, abundance, and weight.

Site	Year	Total Taxa	Mean # Taxa per Haul	Standard Error	Mean Abundance per Haul (n)	Standard Error	Mean Weight per Haul (g)	Standard Error
EOBP-pre	2000	8	3.67	0.29	62.33	31.15	199.46	99.13
EOBP-pre	2001	7	3.27	0.21	131.07	35.61	291.91	79.37
EOBP-post	2002	7	3.53	0.24	61.47	30.13	187.64	114.74
EOBP-post	2003	5	1.87	0.22	8.40	1.45	20.47	4.28
EOBP-R	2000	9	3.89	0.42	39.67	15.34	64.13	15.29
EOBP-R	2001	8	3.80	0.43	63.67	16.39	90.66	13.33
EOBP-R	2002	7	3.13	0.27	14.27	2.39	33.41	6.69
EOBP-R	2003	7	2.20	0.33	15.33	4.55	28.93	8.41
EMC-pre	2000	9	4.22	0.22	106.67	34.40	161.16	68.66
EMC-pre	2001	7	4.00	0.39	56.00	15.69	101.77	24.36
EMC-pre	2002	11	3.06	0.35	34.11	7.78	108.69	39.27
EMC-pre	2003	7	2.67	0.48	48.42	19.40	36.83	10.60
EMC-R	2000	10	5.00	0.53	249.38	65.41	262.49	104.20
EMC-R	2001	8	3.58	0.34	161.00	41.14	262.77	86.78
EMC-R	2002	11	3.17	0.33	126.56	47.47	128.98	35.68
EMC-R	2003	12	3.00	0.66	133.92	76.94	139.42	84.71
MSLP-pre	2000	12	4.00	0.39	41.33	16.15	73.98	31.99
MSLP-pre	2001	14	5.53	0.79	153.87	43.29	211.11	70.52
MSLP-R	2000	17	4.75	0.68	236.92	72.17	213.28	85.85
MSLP-R	2001	14	4.80	0.66	210.20	52.35	189.71	48.53
ECG-R	2002	8	1.81	0.20	270.46	97.64	274.55	104.66
ECG2-R	2003	9	3.93	0.30	1521.36	634.67	1589.93	715.65

As displayed in Table 12, for nekton abundance (combining all fish and crab species), the Reference and Study pairs showed different patterns, depending on the site and year (inter- and intra-annual variability). The 2003 collections were notably smaller than 2000, 2001, and 2002.

For EOBP, abundance was highest at EOBP-pre and virtually the same for EOBP-post and EOBP-R for the reporting period. The study site (EOBP-pre and EOBP-post) generally showed higher variability, as evidenced by the standard error, than EOBP-R. The relative abundance was notably higher at EMC-R compared to EMC-pre. EMC-R consistently demonstrated higher catches for each study year. The seasonal abundance of nekton generally increased through the summer and declined near the end of a sample season.

MSLP-R demonstrated higher relative abundance in 2000 and 2001 compared to MSLP-S in 2000 and 2001. The relative abundance of nekton was higher each sample period at MSLP-R, except for the August 2001 survey.

Extremely large catches of mummichog, Atlantic silverside and striped killifish during 2003 at ECG2-R influenced the annual mean and standard error. Relatively large catches also occurred at ECG-R, but this estimate of relative abundance was much lower than ECG2-R. The high relative abundance at ECG2-R was largely influenced by big catches in July 2003.

The total number of species ranged from 5 at EOBP-post in 2003 to 17 at MSLP-R in 2000. Data suggested a decreasing trend in species richness from 2000 to 2003, except for MSLP. Atlantic silverside, green crab, mummichog, sheepshead minnow, and striped killifish were found at all of the sites. Eight of the nekton species occurred only at one site. As a potential condition or restoration indicator, taxa richness was computed and averaged by seine haul (as unit of effort) with variability expressed as standard error. Figure 30 displays the taxa richness results. Sites MSLP-R and MSLP-pre have more species than the other sites. There is no statistical difference between the paired sites (reference and study), and the utility of taxa richness as an indicator to track restoration is questionable.

Looking at the abundance of mummichogs as an indicator shows that for sites EOBP and MSLP, the study pairs actually have higher abundances than their reference counterparts; conversely, the reference site of EMC has the higher numbers (Figure 31). The regional reference mummichog abundance values are an order of magnitude higher than the other sites. There are significant differences in mummichog abundances between EOBP-pre and EOBP-R, EMC-pre and EMC-R, and MSLP-pre and MSLP-R. These differences imply that this indicator may be very useful in tracking restoration progress, but because the higher abundance pattern varies between reference and study across sites, the indicator may be best utilized as a site-specific one, with goals driven explicitly by the reference /study pair. Also negative connotations of setting a potential restoration goal for fewer mummichogs should be addressed.

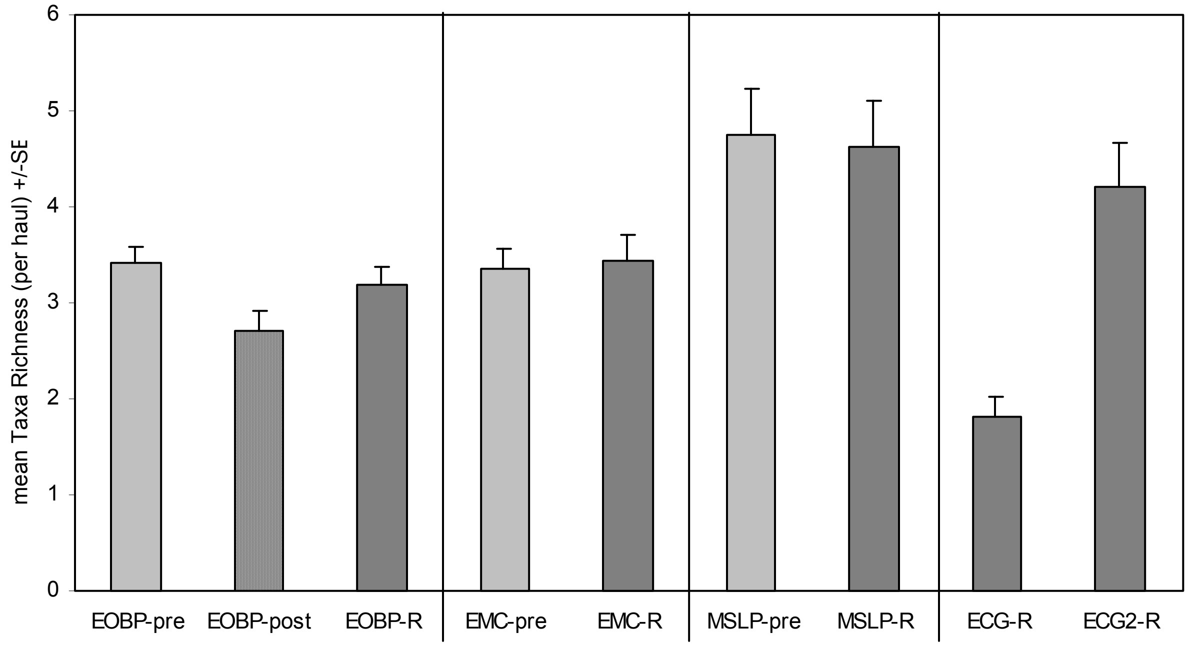

Figure 30. Mean nekton taxa richness per haul (+/- SE) for reporting period.

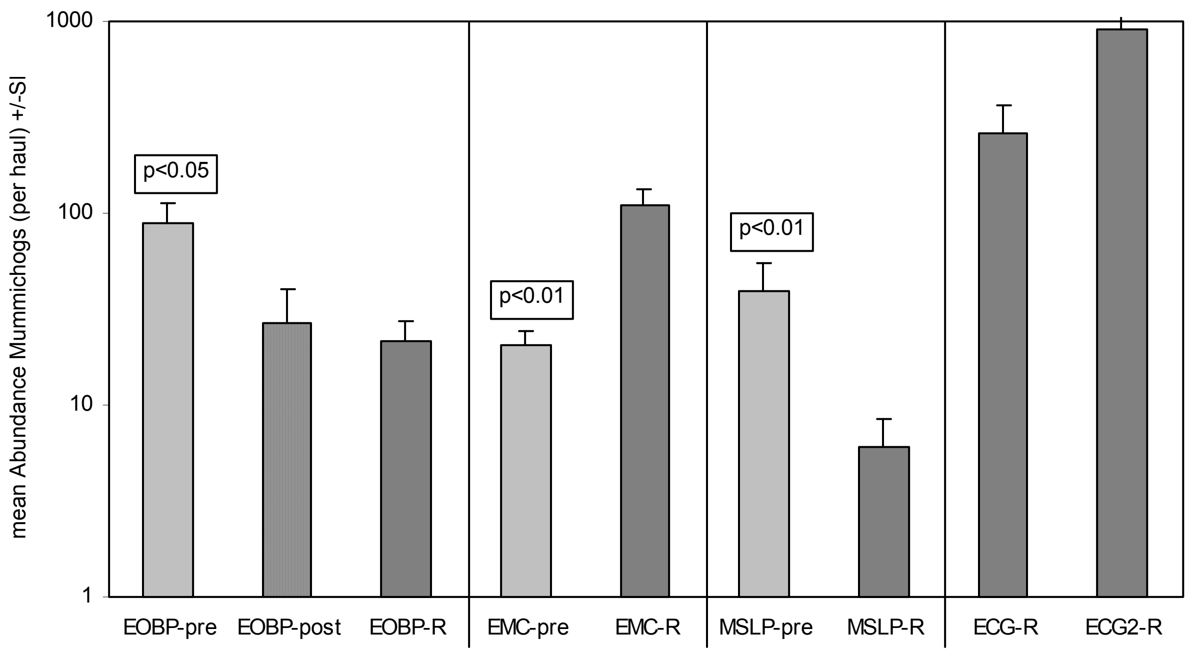

Figure 31. Mean abundance of mummichogs (#) per haul (+/- SE) for reporting period.

Using the abundance of non-mummichog species as an indicator again shows no clear-cut pattern—for some of the reference/study pairs, the reference will have a greater abundance and for other it is the study site. For EMC and MSLP, the reference site has greater numbers of non-mummichog species, with the difference between EOBP-pre and EOBP-R as well as MSLP-pre and MSLP-R being statistically significant (Figure 32).

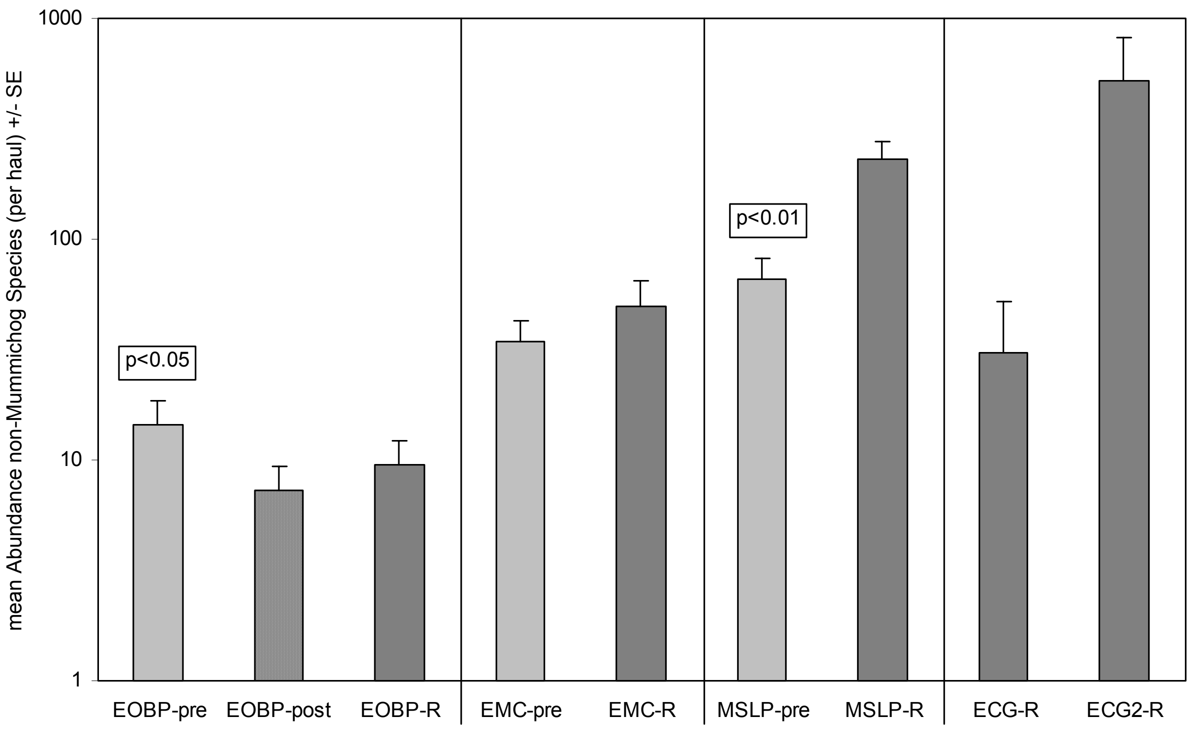

Figure 32. Mean abundance of non-mummichog species (#) per haul (+/- SE) for reporting period.

Similarly, for mean mummichog length, the reference sites for EOBP and EMC have longer mean lengths, but for MSLP the mummichogs are bigger at the study site (Figure 33). Significant differences are seen at EMC and MSLP.

The mean biomass of green crabs was considered as a potential indicator. The invasive green crab is an opportunistic species that may exploit the tide-restricted site because of its apparent lack of nekton predators. The results as shown in Figure 34 indicate that generally the study site does maintain a higher biomass of green crabs than its reference pair (excepting MSLP). As an indicator it may be helpful to use to track the hypothetical decline of this species, but as with others, it seems to be very site specific.

In looking at groups or guilds, two based on life cycle habitat can be examined: residents and transients. Residents are those fish that are thought to spend most if not all of their life cycle in the marsh environment, while transients use the salt marsh for only some part of their life cycle. The list of transient species is found in the nekton attribute list in Appendix F. For the transient indicator, the relationship is very strong—

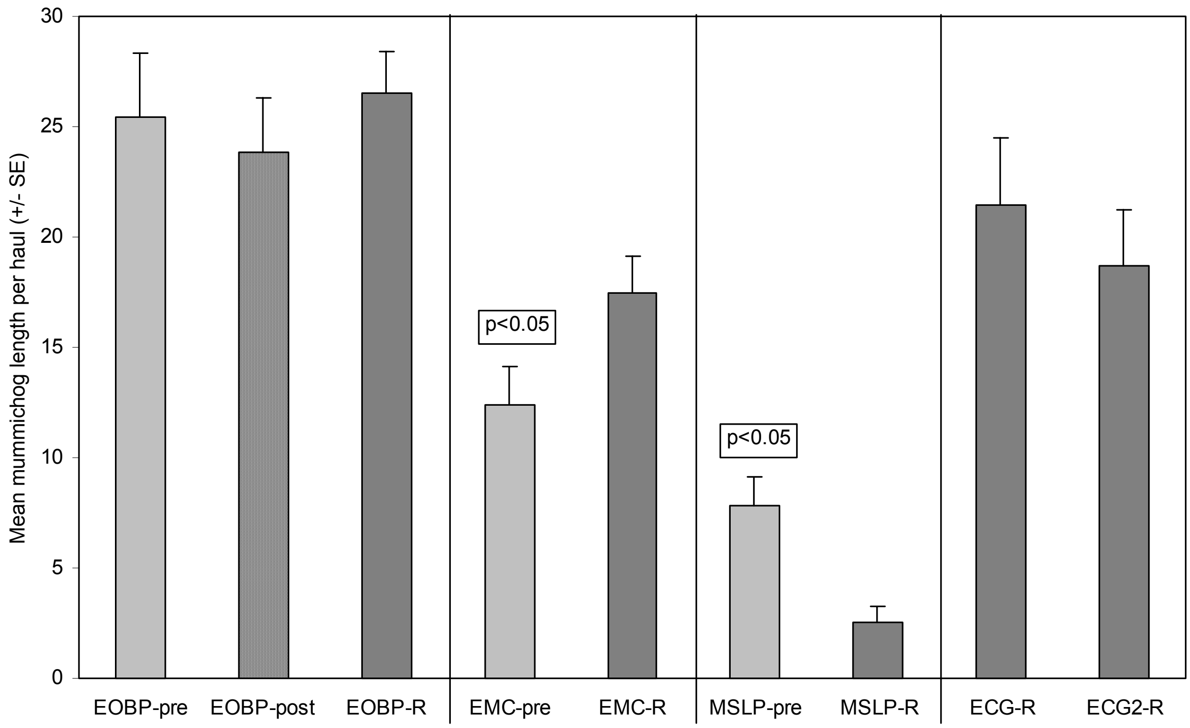

Figure 33. Mean standard length of mummichogs (mm) per haul (+/- SE) for reporting period.

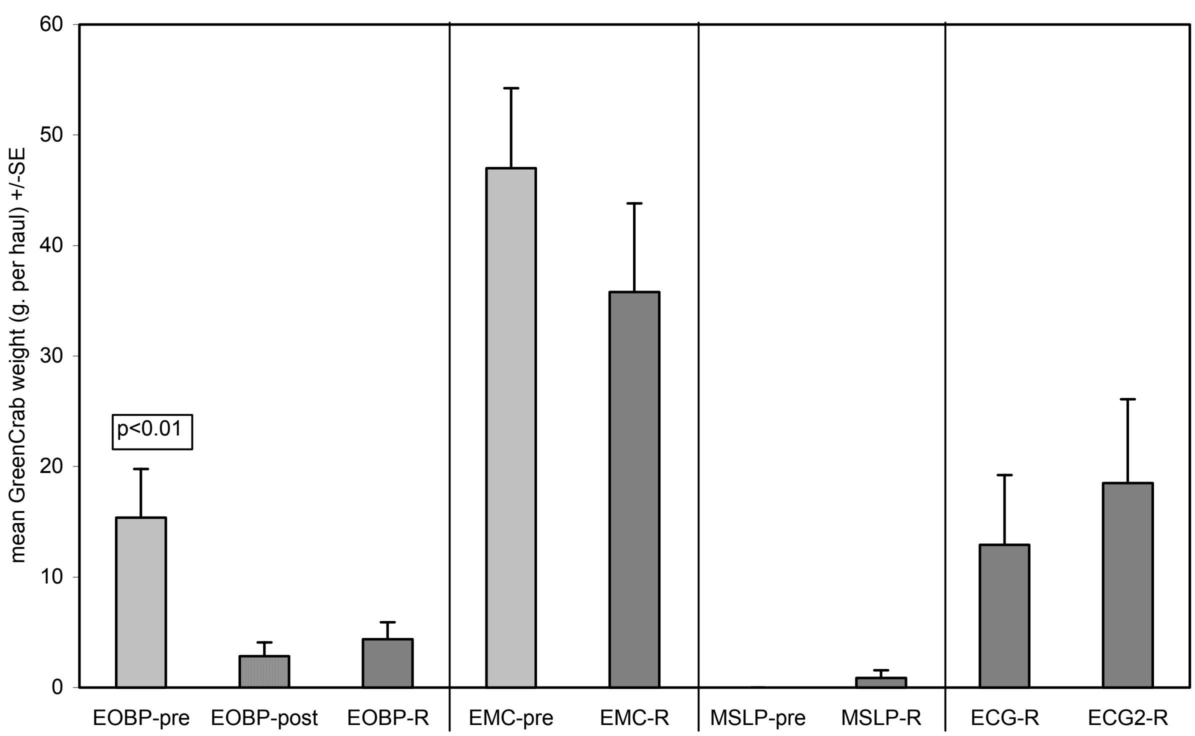

Figure 34. Mean green crab weight (g) per haul (+/- SE) for reporting period.

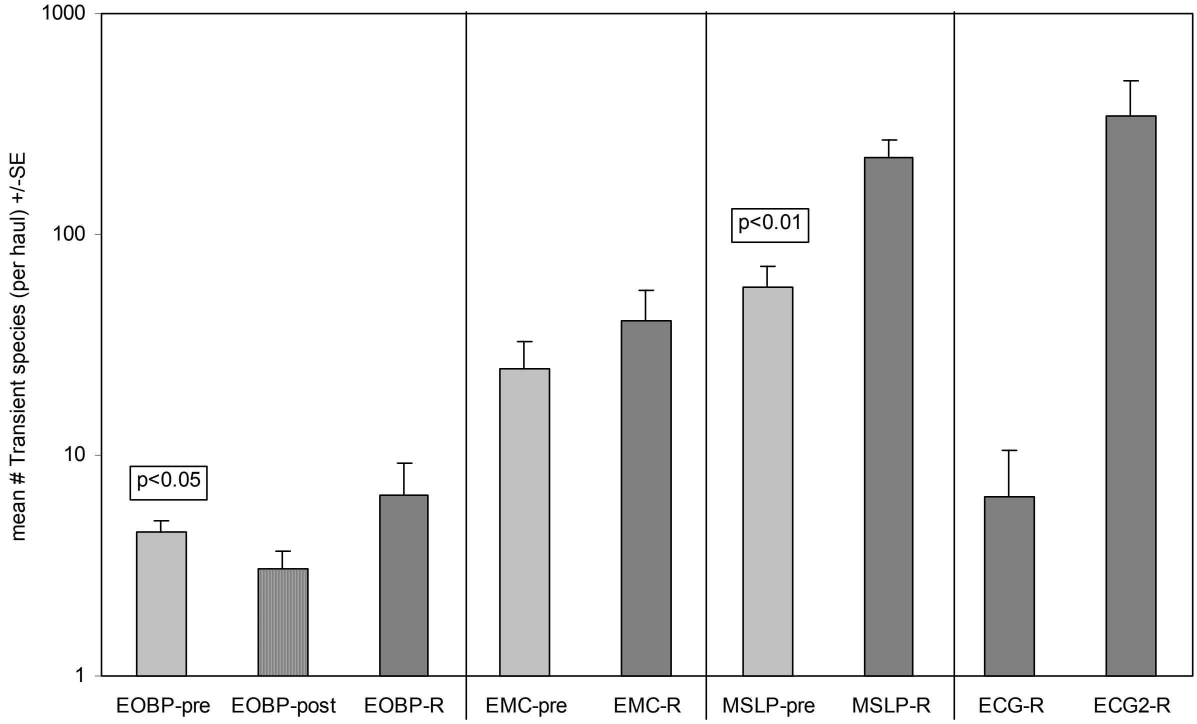

Figure 35. Mean abundance of transient species (#) per haul (+/- SE) for reporting period.

the reference sites support more numbers of transient species than their study site counterparts, as shown is Figure 35. Though we do not see significant differences between the reference and study pairs for all sites, it does appear to be a promising indicator.

The nekton community composition for each site is strongly dominated by two species, the mummichog and the Atlantic silverside. Table 13 lists the three most abundant taxa for each site by year with the corresponding abundance value. In most cases, the top three taxa total over 85% of the total abundance for the sites.

Using MDS again, we can further examine similarities between sites by generating similarity matrices and then displaying the relationships on graphs. For the nekton communities, the Bray-Curtis similarity values are shown in Table 14. As a reminder, the higher the value, the more similar two site's communities are. In looking at the MDS plot in Figure 36, it is clear that each site's nekton communities are distinct, but that reference/study pairs can be grouped by shared similarity of certain species and abundances. The movement of the EOBP-pre and -post does not fall on the trajectory towards the reference standard and that the EOBP-post community is more akin to EOBP-pre than to EOBP-R .

Table 13. Nekton: Three most abundant taxa and values.

Site	Common Name	Total % Abundance
EOBP-pre	Mummichog Sheepshead minnow American eel	84.65 4.25 3.20
EOBP-post	Mummichog Sheepshead minnow American eel	68.50 12.80 20.55
EOBP-R	Mummichog Atlantic silverside Striped killifish	66.91 15.32 5.87
EMC-pre	Atlantic silverside Mummichog fourspine stickleback	41.42 34.81 13.51
EMC-R	Mummichog Atlantic silverside fourspine stickleback	65.71 21.59 3.93
MSLP-pre	Atlantic silverside Mummichog fourspine stickleback	48.13 36.49 3.50
MSLP-R	Atlantic silverside Mummichog sheepshead minnow	90.59 2.50 2.09
ECG-R	Mummichog striped killifish sheepshead minnow	88.88 6.73 1.79
ECG2-R	Mummichog Atlantic silverside striped killifish	59.68 22.13 17.70

Table 14. Bray-Curtis similarity matrix for avifauna communities.

	EOBP-pre	EOBP-post	EOBP-R	EMC-pre	EMC-R	MSLP-pre	MSLP-R
EOBP-pre	1.00						
EOBP-post	90.20	1.00					
EOBP-R	87.67	83.42	1.00				
EMC-pre	65.52	62.66	73.93	1.00			
EMC-R	70.62	66.83	78.63	81.31	1.00		
MSLP-pre	65.25	62.51	72.35	78.68	72.84	1.00	
MSLP-R	56.63	53.34	63.32	66.67	60.35	78.32	1.00

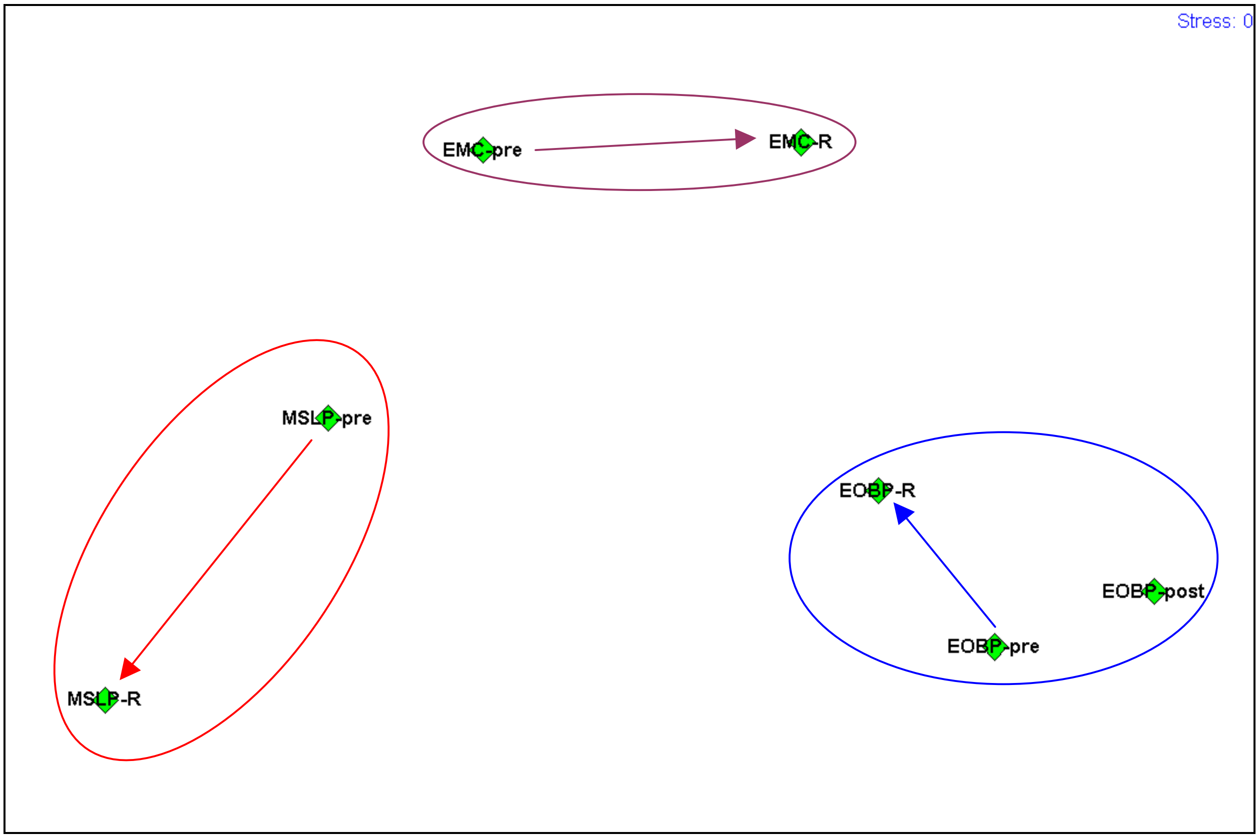

Figure 36. MDS plot of nekton community similarity with proposed restoration trajectories.

Aquatic Macro-Invertebrates

A total of 109 taxa and 22,739 total invertebrates were collected at the salt marsh study sites during the reporting period. Table 15 shows the total number of taxa surveyed at each site, the mean taxa (per composited sample) with the standard error, the mean abundance (per haul) with the standard error. The complete taxa list with abundance is listed in Appendix G. The indicators that were examined for use to assess condition and to track and report on restoration response for the invertebrate component of the investigation were:

- ✓ abundance,
- ✓ taxa richness,
- ✓ marine taxa abundance,
- ✓ number of crabs,
- ✓ shrimp abundance,
- ✓ number of amphipods and isopods, and
- ✓ community composition.

Table 15. Invertebrate data summary: Total taxa, mean taxa, and mean abundance.

Site	Year	Total Taxa	Mean # Taxa per sample	Standard Error	Mean Abundance per sample	Standard Error
EOBP-pre	2001	32	14.83	1.28	251.33	53.44
EOBP-post	2002	25	12.33	0.84	172.17	63.86
EOBP-post	2003	26	12.50	1.02	167.67	40.05
EOBP-R	2001	35	14.67	0.80	259.50	62.85
EOBP-R	2002	28	11.83	1.30	118.00	35.47
EOBP-R	2003	31	13.67	1.58	158.50	35.36
EMC-pre	2001	34	14.67	2.44	162.83	35.58
EMC-pre	2002	44	18.67	2.36	215.50	63.07
EMC-pre	2003	39	17.83	2.01	331.67	66.52
EMC-R	2001	37	16.33	1.73	314.83	19.63
EMC-R	2002	46	21.00	2.05	233.00	51.44
EMC-R	2003	37	18.67	1.09	520.17	135.07
MSLP-pre	2001	42	16.50	2.57	176.67	39.33
MSLP-R	2001	49	21.00	2.53	214.83	64.62
BGIC-R	2001	29	12.00	1.59	203.00	41.18
ECG2-R	2003	27	12.00	1.48	222.50	63.97
ECG-R	2002	30	10.67	2.04	67.67	23.46

As displayed in Table 15, invertebrate abundance shows different patterns, depending on the site and year (inter- and intra-annual variability). While the total taxa at each site and the mean number of taxa per sample are relatively consistent, the mean abundance (number of individuals) varies considerably both on a sample basis and on a site basis.

Abundance per sample was highest at EMC-R and lowest at ECR-R (Table 15, Figure 37). As seen in Figure 37, the use of abundance as an indicator will be site-specific, as there is no discernable pattern between reference or study sites—for EMC and MSLP,

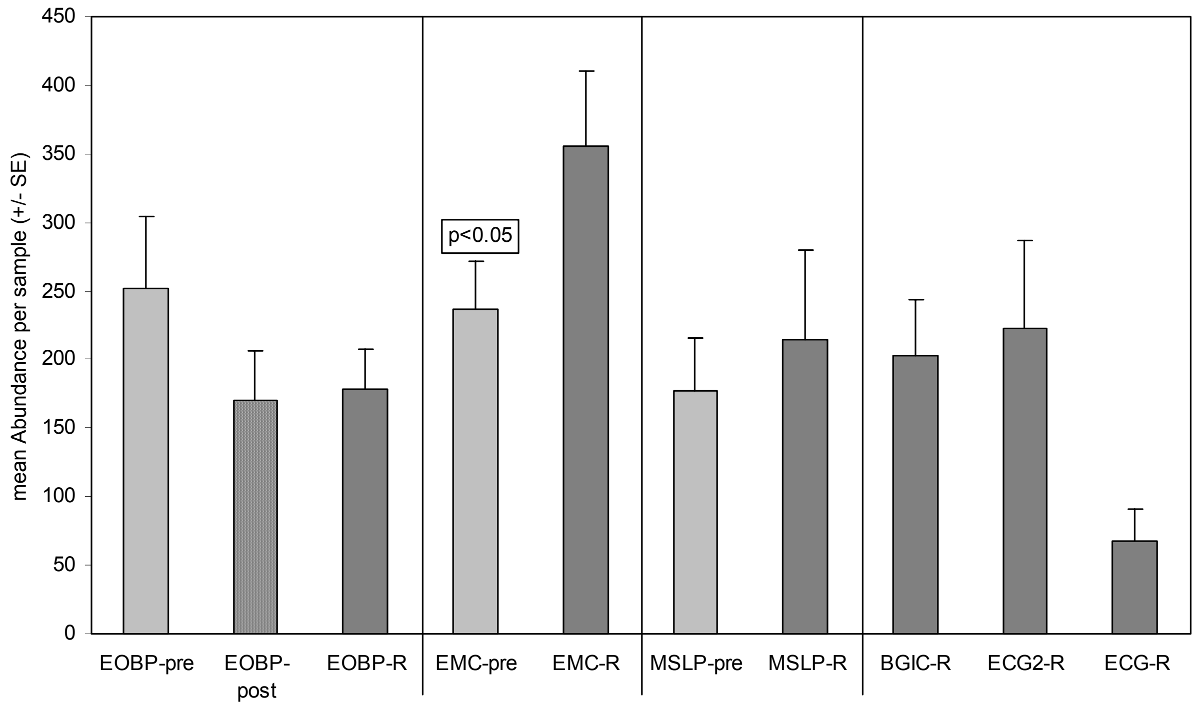

Figure 37. Mean invertebrate abundance (#) per sample (+/- SE) for reporting period.

greater mean abundances per composited sample are see at the reference site, but for EOBP, the greater values are found at the study site, EOBP-pre.

Using taxa richness as an indicator, Figure 38 shows that diversity is highest at the MSLP and EMC sites. Again, there is not a consistent pattern here, but the data suggest that the use of taxa richness could be a good indicator for site-specific comparison (reference/study pairs). Significant difference in mean abundance values was found between EMC-pre and EMC-R. Variability is high due to the overall patchiness of this assemblage.

The invertebrates as an assemblage require the greatest amount of resources, from time to equipment and resources. Specialized experience in identification is also a pre-requisite. The lowest specific taxonomic level to which collected specimens can be identified to influences the selection and application of indicators. Because species level identification can be extremely difficult and also perhaps unachievable given limited resources, general patterns have to be examined among groups, families, and guilds of invertebrates.

One of several indicators that emerged in the examination of these groups and guilds is the marine taxa—that is taxa that are known to be marine aquatic organisms, as opposed to those that are either terrestrial or freshwater. Figure 39 shows that like the taxa richness and abundance indicators, a consistent pattern is not evident, but the data

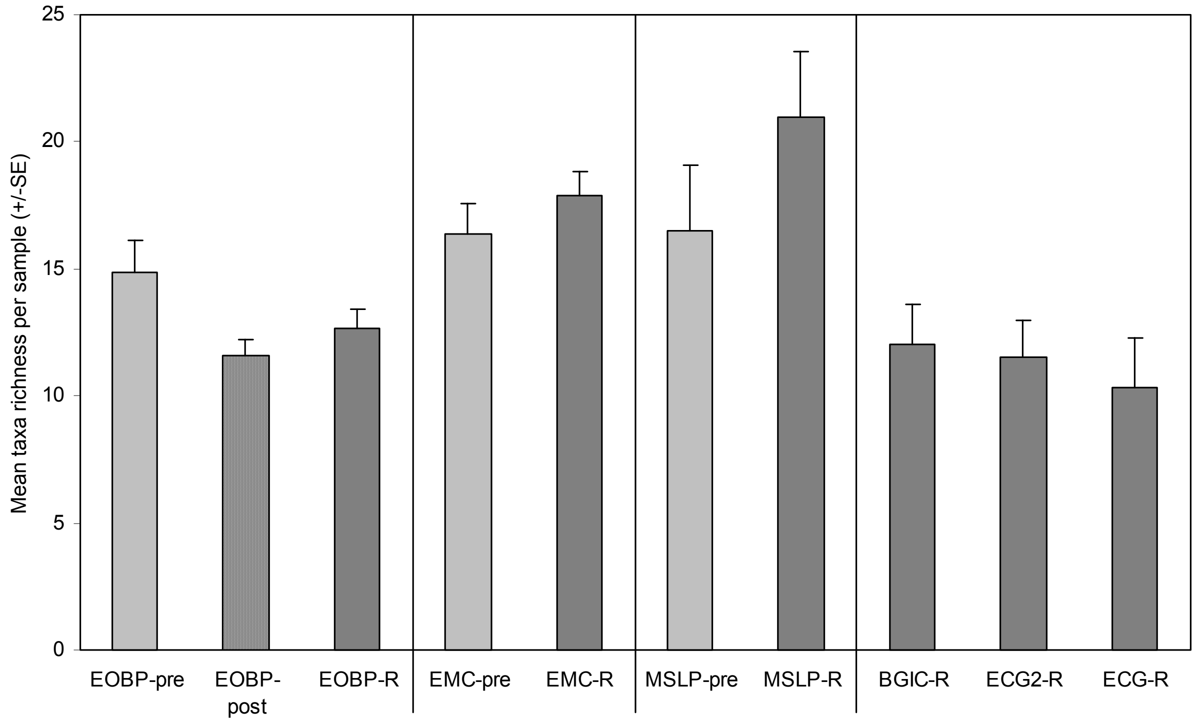

Figure 38. Mean invertebrate taxa richness per sample (+/- SE) for reporting period.

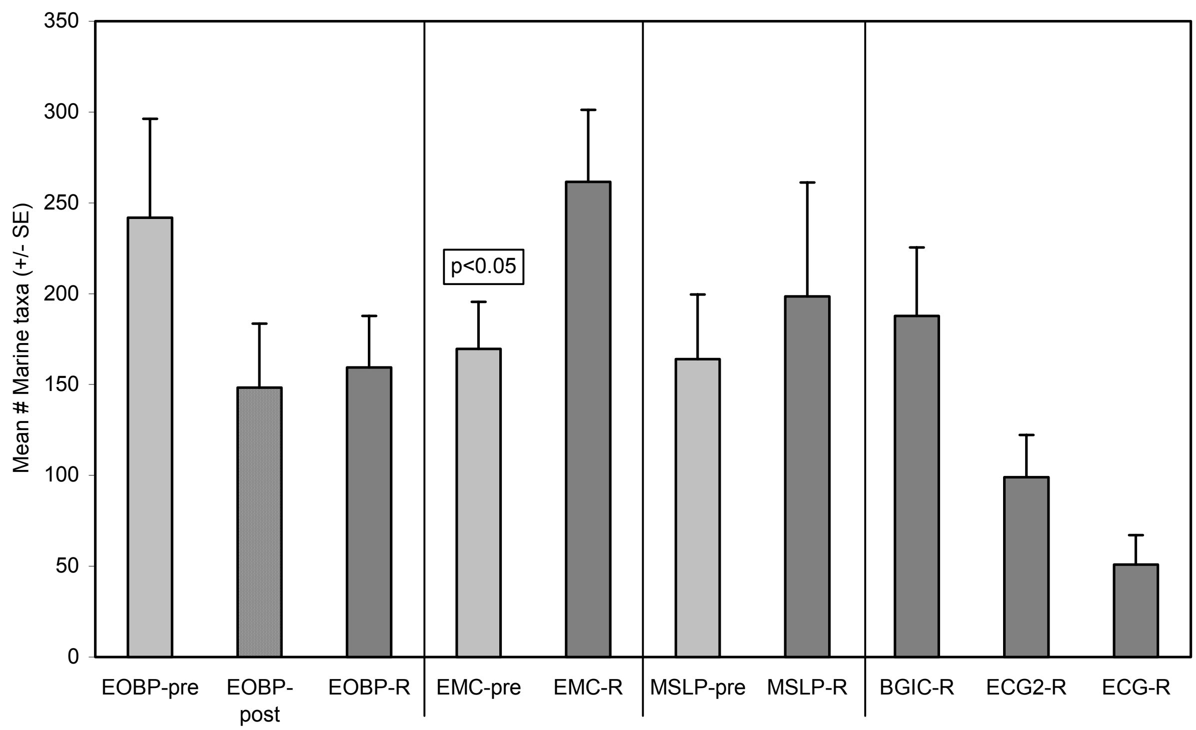

Figure 39. Mean number of marine taxa per sample (+/- SE) for reporting period.

suggest that the use of marine taxa could be a good indicator for site-specific comparison (reference/study pairs). Again, a significant difference in mean abundance values was found between EMC-pre and EMC-R and, again, variability is high due to the overall patchiness of this assemblage.

A fairly consistent pattern does materialize in the examination of mean number of crabs per sample (Figure 40). Here, for each reference/study pair the reference site has higher abundances, and again a significant difference was identified between EMC-pre and EMC-R. More samples or greater sampling frequency might help to reduce variability, though it is thought that much of this scatter is the natural patchiness and elusiveness of the crabs.

Looking at the mean percent abundance of shrimp reveals high variability between sites but close similarity for the reference/study pairs (Figure 41). A notable increase can be seen from EOBP-pre to EOBP-post but this is not statistically significant. More data may improve the utility of this indicator.

Combining the mean numbers of amphipods and isopods does not indicate a consistent pattern, but the data suggest it could be a good indicator for site-specific comparison between reference/study pairs (Figure 42). A significant difference in mean abundance values was found between EOBP-pre and EOBP-R, with the post-restoration values very close to the reference site. Again, variability is high and might be reduced with increased sample size and frequency.

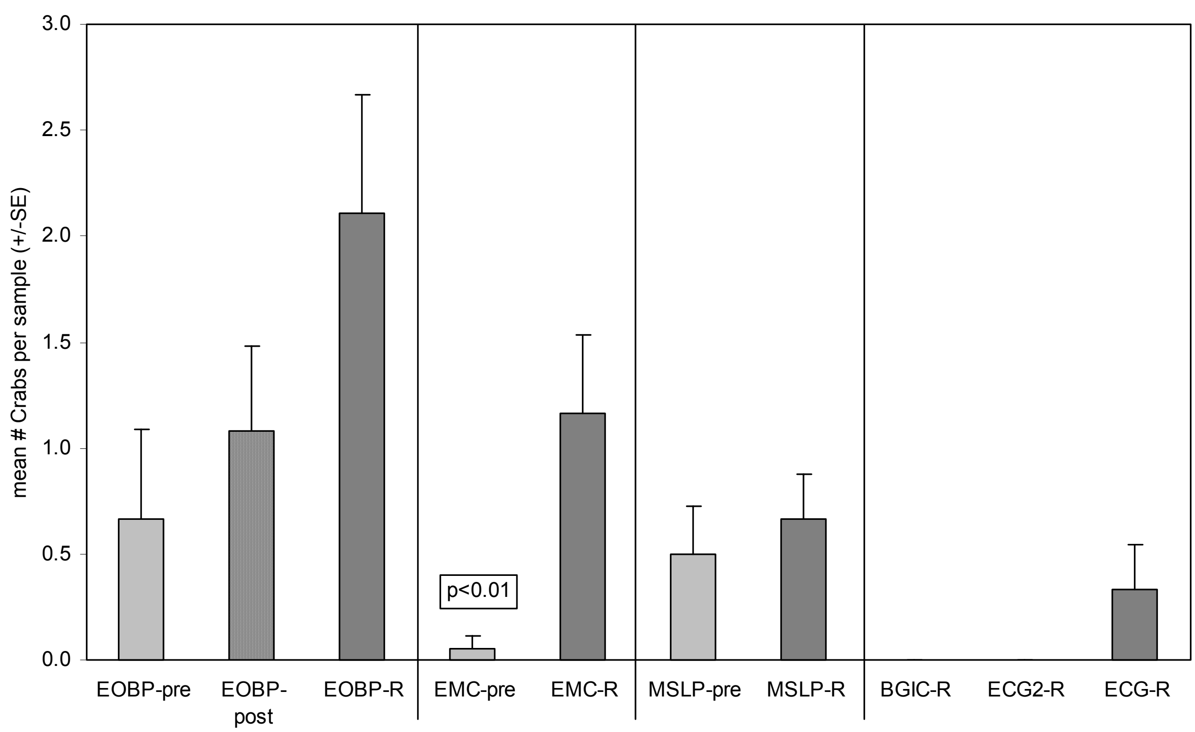

Figure 40. Mean number of crabs per sample (+/- SE) for reporting period.

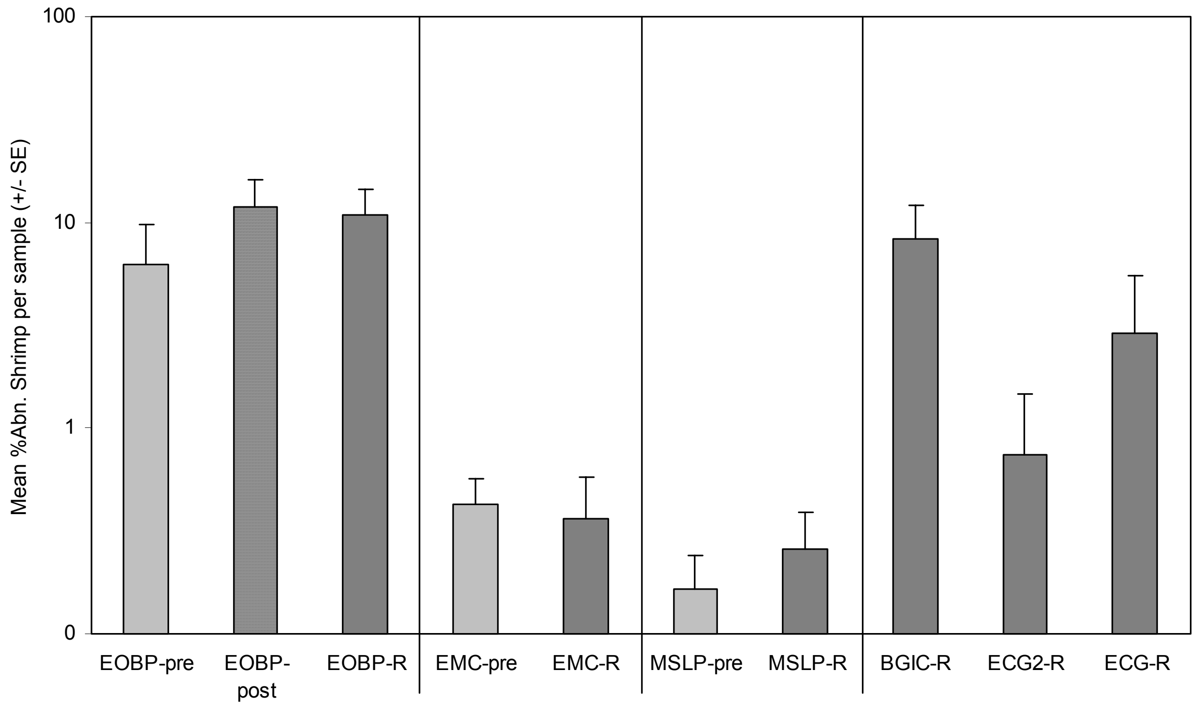

Figure 41. Mean percent abundance shrimp per sample (+/- SE) for reporting period.

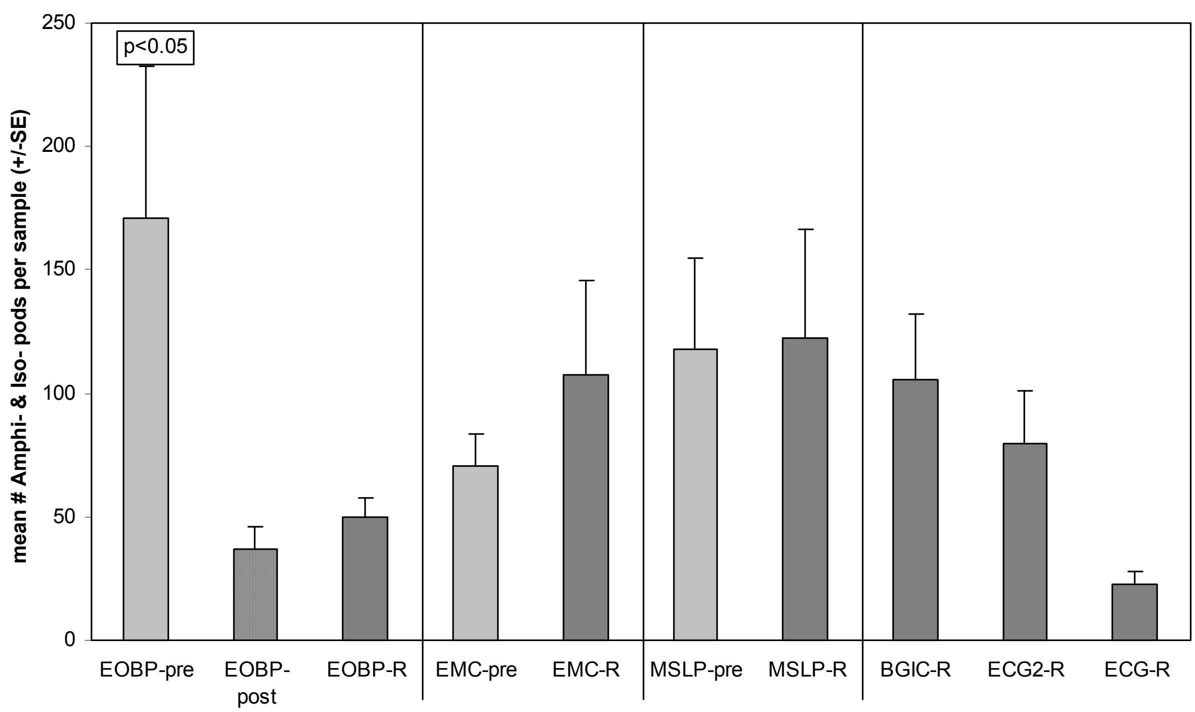

Figure 42. Mean number of amphipods & isopods per sample (+/- SE) for reporting period.

The invertebrate community composition by site is dominated by *Gammarid* and *Tailtridae* amphipods, *Palaemonid* shrimp, and *Oligochaete* worms. Table 16 lists the three most abundant taxa for each site by year with the corresponding abundance value. The invertebrate communities at these sites are relatively diverse, with the top three taxa averaging about 60% of the total abundance for the sites, less than the dominant taxa of the plant and nekton communities, but more than the highly diverse avifauna.

Table 16. Invertebrates: Three most abundant taxa and values.

Site	Taxa	Total % Abundance
EOBP-pre	Gammaridae	42.51
	Palaemonidae	15.19
	Talitridae	11.27
EOBP-post	Palaemonidae	55.37
	Gammaridae	10.89
	Talitridae	5.74
EOBP-R	Palaemonidae	44.78
	Gammaridae	14.15
	Talitridae	8.71
EMC-pre	Talitridae	21.22
	Oligochaeta	18.73
	Spionidae	16.29
EMC-R	Oligochaeta	19.19
	Talitridae	14.78
	CapItellidae	11.58
MSLP-pre	Oniscidae	38.58
	Talitridae	12.45
	Gammaridae	5.66
MSLP-R	Talitridae	22.58
	Ischyroceridae	17.77
	Nereidae	7.99
BGIC-R	Palaemonidae	26.44
	Gammaridae	18.31
	Caprellidae	13.38
ECG2-R	Oligochaeta	45.54
	Gammaridae	22.10
	Talitridae	13.18
ECG-R	Talitridae	21.92
	Oligochaeta	15.27
	Sabellidae	15.02

Using MDS again, we can further examine similarities between sites by generating similarity matrices and then displaying the relationships on graphs. For the invertebrate communities, the Bray-Curtis similarity values are shown in Table 17. As a reminder, the higher the value, the more similar two site's communities are. Figure 43 shows the MDS plot, confirming that the invertebrate communities of these sites are very distinct. The reference/study pairs group tightly indicating that these paired sites are more similar to one another than to any other site. The movement of the EOBP study site from -pre to -post shows that it's similarity really shifted after restoration action so that EOBP-post is more similar to the reference site than to EOBP-pre.

Table 17. Bray-Curtis similarity matrix for invertebrate communities.

	EOBP-pre	EOBP-post	EOBP-R	EMC-pre	EMC-R	MSLP-pre	MSLP-R
EOBP-pre	1.00						
EOBP-post	43.66	1.00					
EOBP-R	55.39	77.77	1.00				
EMC-pre	33.50	24.52	34.87	1.00			
EMC-R	37.92	23.42	30.80	70.20	1.00		
MSLP-pre	35.18	27.40	35.35	34.57	31.59	1.00	
MSLP-R	31.84	26.40	32.09	40.79	33.26	52.09	1.00

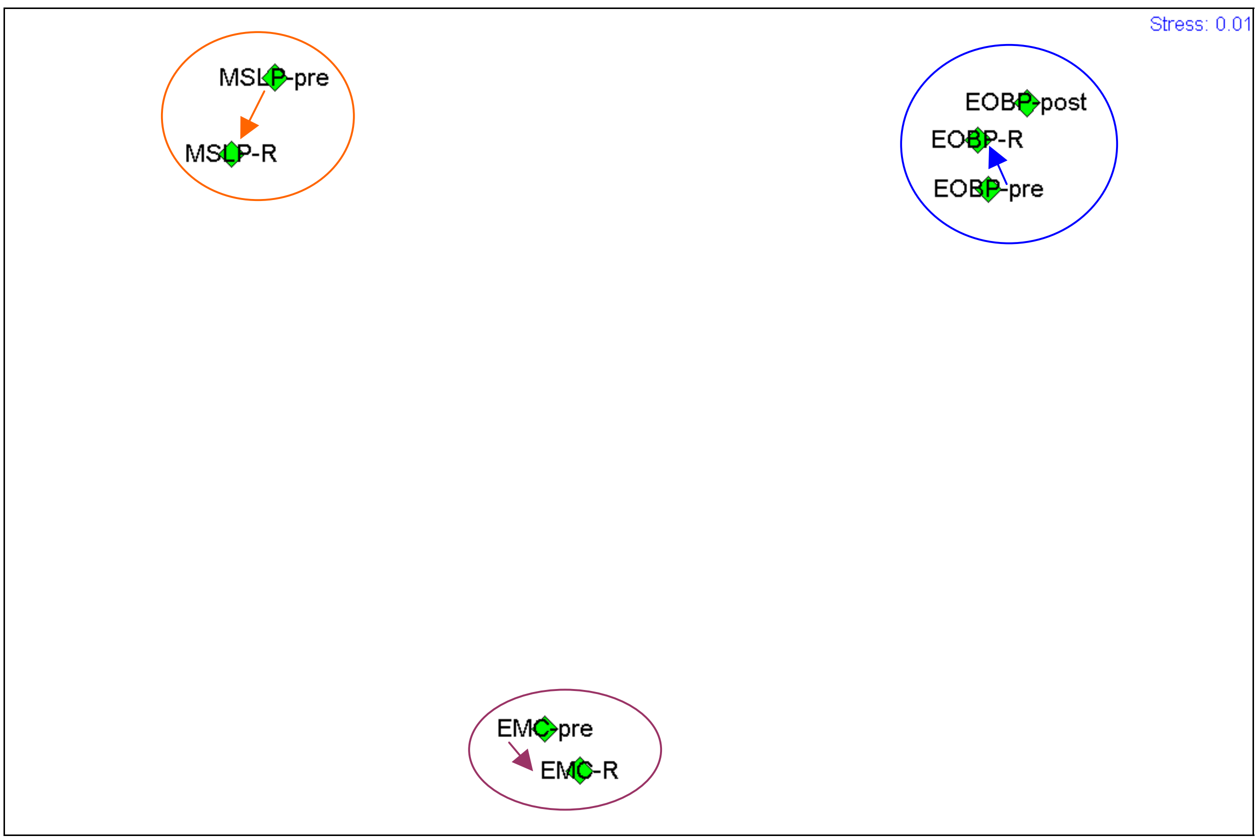

Figure 43. MDS plot of invertebrate community similarity with proposed restoration trajectories.

Conclusions and Recommendations

The primary goal of the Cape Cod Salt Marsh Assessment Project was to advance and improve the salt marsh assessment approach and indicators developed by CZM in previous projects through its application to two separate investigations. This volume of the Grant Report dedicated to the second investigation—a long-term comparison of indicators from selected tide restricted and reference salt marshes. The intent of this work was to document differences in indicators between two groups of salt marshes (tide-restricted study sites and their reference pairs) and to examine response to tidal restoration actions.

The working hypothesis was that there will be differences in certain indicators between the reference (normal tide regimes) and study site (tide restricted) pairs and sites but that other factors, such as site-specific habitat availability or trophic interactions, will affect indicator status and response.

Three tide-restricted salt marsh sites were selected as the foundation of the investigation. These sites were selected based on several criteria including: site has high likelihood of restoration action completed before field season 2003 (to allow for at least one year of post-restoration data for grant period), site has a paired reference site closely proximate, access is viable and obtained, sites cover a range of regions and tidal ranges, and sites are generally similar in size. Three sites and their reference counterparts were selected: EOBP—bisected by the Cape Cod Rail Trail with marine waters from Boat Meadow Creek and Cape Cod Bay; EMC—bisected by an historic dike with marine waters from Nauset estuary and Atlantic Ocean; and MSLP—bisected by two roads with marine waters from Waquoit Bay and Nantucket Sound. None of these three sites had severe tide restrictions—that is, each of the study sites had at least half (or more) of the tidal flow of their reference counterparts and on initial observation, all had significant presence of representative and obligate salt marsh plant species.

Of the three sites selected, only one, EOBP, actually had its restoration action completed by the target date. EMC had its tide restriction removed in October 2003, the end of the field season; no action has yet occurred at MSLP, though efforts are still underway. Over the course of the 4 years of this grant period, three different regional reference sites were also investigated.

Due to the structure and obligations of the grant, the reporting period (ending March 31, 2004) did not allow for inclusion of most of the 2004 data (collected May to September 2004). The results presented in this report focus primarily on the effects of tide restriction, and to a lesser extent, initial responses of tide restricted sites to restored tidal hydrology. Two years of post-restoration data are presented for study site EOBP, and hydrology and *Phragmites* height data for EMC from 2004 are included. Future reports or publications will address long-term restoration response.

A very large data set has been developed for this investigation, with multiple years and survey/sample runs worth of measurement and information for hydrology, plants, avifauna, nekton, and invertebrates. Using this data, numerous indicators were proposed and examined; selected indicators were included in this report. From this body of work, a number of observations and conclusions have been become evident and are listed here. In addition, the authors also make recommendations for future work .

In general, it is apparent that there are both similarities and differences between the study and reference site pairs, as well as between other sites. There are a suite of biotic and abiotic indicators that are able to clearly (and in some cases statistically) show the effects of tide restriction and the restoration (or partial-restoration) of normal tide levels. The fact that there are as many similarities as differences may be largely due to the nature of the study sites—that they are still tidal, in a degraded state or declining in condition perhaps, but still would be considered salt marshes by any wetland professional. Other sites where tide restrictions are more severe (so that there is very little to no tidal flow) would exhibit very different characteristics than the ones investigated here.

One of the most important conclusions from this work is that indicators are very much site-specific, and setting realistic and valid restoration criteria will require particular and detailed understanding of the system under investigation. This means that for every restoration site for which restoration professionals and managers wish to confirm a degraded state and to establish restoration performance criteria (regulatory or otherwise), there needs to be pre- and post-restoration data collected, as well as reference site monitoring.

Long-term studies are also necessary. One year pre- and one year post-restoration will do little to capture the very long term changes that have occurred in the marsh over time and that will occur with restored tidal hydrology.

This work is very resource intensive. For just one year of this investigation, four biotic assemblages and two abiotic parameters were conducted at 5 sites, times the number of stations, times the number of surveys, so that it becomes clear that field effort and resource needs quickly add up. While, it is true that some assemblages and parameters require less resources than others, there are still very few funding sources for this type of work. Even through a restoration grant, the funding agency will sponsor 1-5% of the total project budget for monitoring, but the time limitations of the grant often precludes any long-term post-restoration monitoring, and certainly not to the scale and level of effort conducted for this investigation.

Another generalized conclusion is that an indicator that works at one site does not necessarily work at another. Sites are naturally unique—factors like tidal range, landscape setting, underlying geology, localized hydrology, natural influences such as episodic storms or continual sea-level rise, past and current human disturbances, and an array of others all combine to give a site individual characteristics. Even with our ability to discern abiotic site characteristic differences, these factors may or may not matter to the biota. Why nekton so clearly prefer one site over another (see the sheer biomass of site ECG2) is an example of a question that needs more specific data than that obtained by this investigation.

We recommend that instead of trying to do less work at more sites, more intensive and high-quality work is done on fewer sites. This is not to say that less resource-intensive parameters should not be monitored at as many sites as possible, but rather that because of the resources and time required to meaningfully examine a variety of biotic responses, that select restoration sites be designated as sites of special monitoring, where long-term investigations are established and all effort is taken to secure funding for the required effort. Our recommendation is to monitor two to three years of pre-restoration (both study and reference), the first two years post-restoration, and then every other year for six years, and finally, returning year 10 and 15.

The indicators that were evaluated in this investigation are listed in Table 18. This table also shows if the indicator revealed a consistent pattern (i.e. that the study site values were all either lower or higher than their reference pairs) or if the values varied among sites, denotes sites that had statistical differences between the study (pre- or post-restoration) and the reference pairs, and finally makes a general recommendation on usage as an indicator. A "▲" mark means the indicator showed a strong pattern or consistent relationship, had explicable results for most or all of the sites, and shows strong promise—therefore recommended for further use. A "▬ " mark means the indicator had mixed patterns overall, but might be utilized for site-specific work, and that it needs more work and evaluation before use.

The plant survey methodology and frequency appears to be adequate; one recommendation would be fix more permanent transect markers due the loss of roughly ten percent of the 1m length/1" diameter PVC markers due to ice scour or vandalism. These lost positions were located again through GPS and field tape measurements, but with more permanent markers this replication would not be necessary.

Because the resources and time commitment to monitor vegetation is low, plants are highly recommended as biotic indicators for salt marsh condition and restoration assessment efforts. One additional recommendation for future work would be to establish more permanent *Phragmites* plots (for measuring height and density) to increase the data robustness and reduce variability. Also, the *Phragmites* management efforts at EMC should only proceed with corresponding monitoring. The data do not show any strong trend but observations indicate that the stands burned in the Spring 04 grow back nearly as tall as those not burned and perhaps at a greater density.

To address some of the inter- and intra-annual variability of avifauna, surveys may need to be conducted at a greater frequency for better statistical evaluation, especially during spring and later summer migration periods. Also, there is need to examine the effect that episodic observations of large flocks have on the data and the indicators. These

Table 18. Indicator summary and usage recommendation.

Indicator	Pattern	Significant differences from Reference pair	Usage?
Tidal hydrology (tide height amplitude)	Consistent	n/a	▲
Plants: Taxa richness	Consistent	EOBP-pre	▲
Plants: Abundance of invasive species	Consistent	EOBP-pre, EOBP-post, EMC-pre, MSLP-pre	▲
Plants: Abundance of S. alterniflora	Consistent	EMC-pre	▲
Plants: Abundance of high marsh grasses	Varied	none	—
Plants: Habitat affinity values	Consistent	EOBP-pre, EOBP-post, EMC-pre, MSLP-pre	▲
Plants: Phragmites height	Varied	EOBP-pre, EOBP-post, MSLP-pre	▲
Plants: MDS community assessment	Consistent	n/a	▲
Avifauna: Taxa richness	Varied	EOBP-pre, EOBP-post	▲
Avifauna: Wetland dependent species	Consistent	EOBP-pre, EOBP-post, EMC-pre	▲
Avifauna: Neo-tropical migrants	Consistent	EOBP-pre, EOBP-post, EMC-pre	▲
Avifauna: Aerial foragers	Consistent	none	▲
Avifauna: resident species	Varied	EMC-pre	—
Avifauna: MDS community assessment	Varied	n/a	▲
Nekton: Taxa richness	Varied	none	▲
Nekton: Abundance of mummichogs	Varied	EOBP-pre, EMC-pre, MSLP-pre	▲
Nekton: Abundance of non-mummichogs	Varied	EOBP-pre, MSLP-pre	▲
Nekton: Mummichog length	Varied	EMC-pre, MSLP-pre	—
Nekton: Green crab biomass	Consistent	EOBP-pre	▲
Nekton: Transient species	Consistent	EOBP-pre, MSLP-pre	▲
Nekton: MDS community assessment	Varied	n/a	▲
Invertebrates: Abundance	Varied	EMC-pre	—
Invertebrates: Taxa richness	Varied	none	▲
Invertebrates: Marine taxa	Varied	EMC-pre	▲
Invertebrates: Crabs	Consistent	EMC-pre	▲
Invertebrates: Shrimp	Varied	none	—
Invertebrates: Amphipods and isopods	Varied	EOBP-pre	—
Invertebrates: MDS community assessment	Varied	n/a	▲

periodic counts with hundreds or low thousands of individuals act to add variability and to skew data patterns. Data transformations dampen this effect, but additional thought and discussion on this topic is needed. With greater survey frequency, these events may in fact turn out to be not be so episodic.

As a higher trophic assemblage, avifauna abundance and density patterns vary from year to year for many reasons, so that avifauna surveys should be conducted over long time period, particularly if birds are responding to changes in vegetation and macroinvertebrates.

The study of nekton focused on sampling tidal creeks with bag seines during the day. While tidal creeks are important habitats within salt marsh systems, they represent only one of many microhabitats found within the salt marsh. Nekton, including fishes and decapod crustaceans, use of salt marsh systems varies in time and space. Environmental conditions that influence community characteristics of nekton and behavior of nekton species that influence catches are not completely understood. Tidal cycle, time of day, and season affect the distribution and composition of the nekton community. Additionally, large-scale influences such as weather patterns, climate change and human disturbance (e.g., eutrophication and over-fishing) affect the distribution and composition of the nekton community.

To initiate the development of indicators of marsh condition based on nekton, it is reasonable to focus on a particular habitat, but results need to be viewed cautiously because sampling does not encompass all habitats within the marsh. Future efforts to sample nekton may want to consider multiple sampling techniques in different habitats and different times of day (e.g., day / night sampling) to examine the variability in characteristics of the nekton community and identify potential indicators of marsh condition.

This investigation found inter-annual and intra-annual variability in nekton catches. The variability observed demonstrates the value of long-term (multi-year) monitoring of nekton. The abundance and distribution of nekton is patchy and periodic samples can not guarantee catches that completely represent the nekton community and condition of the marsh. Systematic, long-term monitoring is required to begin to understand the forces (natural and human-induced) that affect the nekton community and to identify appropriate indicators of marsh condition.

Particular nekton species were consistently collected during the study (e.g., mummichog and Atlantic silverside). These species, or species that have a (somewhat) predictable pattern of abundance (potentially sheepshead minnow, striped killifish, American eel), may warrant targeted study to examine environmental factors which influence their abundance and distribution.

The presence of specific life history stages of nekton may indicate the condition of a marsh. Particularly, finding newly recruited nekton (e.g., young-of-the-year fishes) in the marsh demonstrates the importance of the salt marsh as a nursery habitat; salt marshes are known to function as nursery habitat, but it is not understood of how environmental conditions or anthropogenic disturbances affect this important habitat function. Investigating the recruitment and growth of resident and/or transient fishes to salt marsh may prove a useful indicator of marsh condition.

The salt marsh is a known feeding ground and refuge for nekton. Further investigation on the trophic dynamics within study and reference salt marsh may prove a valuable indicator of salt marsh condition. Gut fullness may be a specific indicator that demonstrates the value of foraging habitat within the salt marsh.

The use of invertebrates as a biotic assemblage for salt marsh condition and restoration assessment efforts needs to be evaluated on a case-by-case basis in light of the resource and time requirements and the information generated. Invertebrates are critical components of the food chain, offer direct and indirect links to commercial fisheries, and when dealt with by experienced and qualified taxonomists may be able to tell valuable stories of marsh condition and response to restoration. The assemblage is probably the most resource intensive, so that a decision to pursue invertebrate work should be made with adequate resources, especially for the identification component.

The invertebrate assemblage, like nekton and avifauna, is highly variable over both space and time; perhaps the most variable as it's position low on the trophic scale makes it extremely vulnerable to effects of prey on abundance and distribution patterns. One recommendation might be to concentrate sampling when nekton abundance is lowest (e.g. May and June).

The use multi-variate analyses and techniques like multi-dimensional scaling have great promise for their ability to integrate complex data sets with wide numbers of taxa and varied abundance patterns. In addition to handling these complicated data sets, these techniques are able to factor in other variables such as degree of tide restriction, soil/substrate types, water quality characteristics (salinity, dissolved oxygen), and distance from marine waters.

Finally, even though the EPA sponsored portion of this investigation has been completed, MA-CZM plans to continue to monitor these sites as necessary in order to obtain a long-term perspective on condition and response to the restoration of tidal hydrology. In 2004, plant, avifauna and nekton monitoring was conducted at the EOBP (year 3 post-restoration) and EMC (year 1 post-restoration) sites, and with the Waquoit Bay National Estuarine Research Reserve at the MSLP sites (still pre-restoration). Resources were not available in 2004 to support invertebrate monitoring and funding sources need to be identified and secured in order to continue with this work. Although plans have not been finalized, we are proposing the schedule in Table 19 for additional monitoring for this long-term investigation. We plan to synthesize and compile various elements of this investigation for further reports and for submission to peer-reviewed journals.

Table 19. Proposed monitoring schedule and sites for continued investigation.

Site	2005	2006	2007	2008	2009	2010
EOBP		Year 5 Post		Year 7 Post		Year 9 Post
EMC	Year 2 Post		Year 4 Post		Year 6 Post	
MSLP		Year 1 Post?	Year 2 Post?		Year 4 Post?	
Regional Reference	Yes			Yes		Yes

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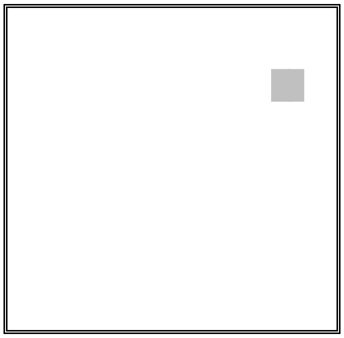
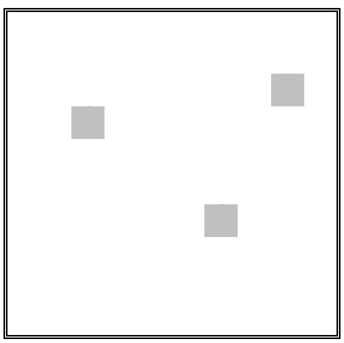
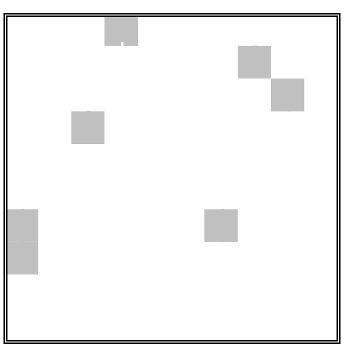
Appendix A: Plant cover classes and midpoints



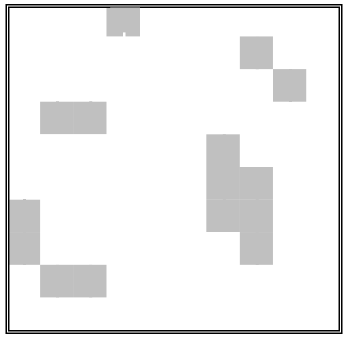
(Trace to 1%)
Use 1%



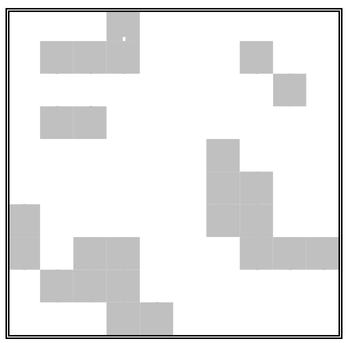
(2% to 4%)
Use midpoint 3%



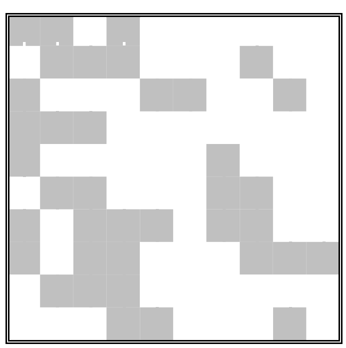
(5% to 10%)
Use midpoint 7%



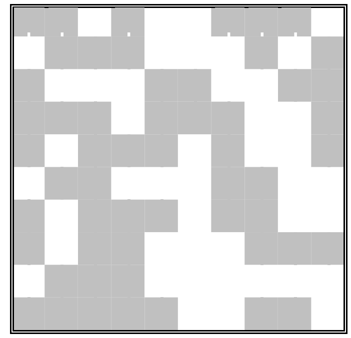
(11% to 19%)
Use midpoint 15%



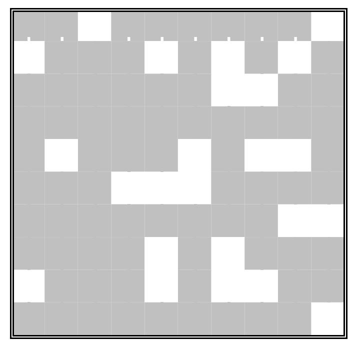
(20% to 30%)
Use midpoint 25%



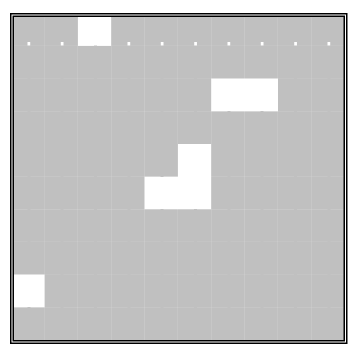
(31% to 45%)
Use midpoint 38%



(46% to 64%)
Use midpoint 55%



(65% to 87%)
Use midpoint 76%



(88% to 100%)
Use midpoint 94%

Appendix B: Plant species list and abundance (#) values

GenusSpecies	EOBP-pre 2001	EOBP-post 2002	EOBP-post 2003	EOBP-R 2001	EOBP-R 2002	EOBP-R 2003	EMC-pre 2001	EMC-pre 2002	EMC-pre 2003	EMC-R 2001	EMC-R 2002	EMC-R 2003	MSLP-pre 2001	MSLP-R 2001	ECG-R 2002	ECG2-R 2003
Agalinis maritime													6	2		
Agropyron pungens				163	225	1	3	15	1	3	31			1		220
Agrostis stolonifera			38			7		7			1	10				3
Ambrosia artemisiifolia										1						
Ammophila breviligulata					1									7		
Aster tenuifolius						1					1	1	26	89		
Atriplex patula			3			4			14	1	1					1
Baccharis halimifolia													155	30		
Calystegia sepium					1			3			7					
Chamaecyparis thyiodes														55		
Cyperus filicinus									2					7		
Distichlis spicata	57	47	38	62	30	122	32	38	3	10	72	57	905	959		339
Euthamia graminifolia													6			
Festuca rubra													3	35		
Glaux maritima										1						
Iva frutescens	25	7	3	224	87	202					1		275	518		
Juncus gerardii				3		7	8	40	41	123	146	25	780	698		648
Limonium nashii						1	2		8	3		7	26	108	25	
Myrica cerifera													3	15		
Myurica cerifera														3		
Panicum virgatum										1			25	91	1	
Phragmites australis	806	630	827	547	338	393	800	424	637	852	420	621	392	54		58
Plantago maritima													26	30		
Polygonum arifolium														3		
Polygonum sagittatum										7						
Prunus virginiana	25															
Ptilimnium capillaceum									28							

GenusSpecies	EOBP-pre 2001	EOBP-post 2002	EOBP-post 2003	EOBP-R 2001	EOBP-R 2002	EOBP-R 2003	EMC-pre 2001	EMC-pre 2002	EMC-pre 2003	EMC-R 2001	EMC-R 2002	EMC-R 2003	MSLP-pre 2001	MSLP-R 2001	ECG-R 2002	ECG2-R 2003
Rosa rugosa													1	4		
Salicornia europaea			3	9	20	106	11	3	27	1	5	12	36	73	36	87
Salicornia virginica												1		10	184	
Scirpus americanus								1			4					
Scirpus pungens	3						2	1	3	7		16		1		
Scirpus robustus	36	55	143	67	83	31	1									
Solidago sempirvirens			1				38	53	61	61	44	4	259	71		89
Spartina alterniflora	1242	1288	1244	1629	1519	2343	828	727	756	1268	1119	1232	480	1071	3215	1928
Spartina cynosuroides																49
Spartina patens	11	21	17	13	31	107	382	213	486	528	451	411	295	348	444	1406
Spergularia marina															25	
Suaeda linearis				7		97	13	2	12	7		1		9	77	
Teucrium canadense								28	2							
Toxicodendron radicans	55		6				3	1					18	10		
Triglochin maritimum													3	25		
Typha angustifolia	55	18														
unkown sp.			1													

Appendix C: Plant species and attribute list

GenusSpecies	Common	Invasive	Non-Indigenous	HM grass	Salinity	Habitat Affinity	Forb	Grass	Shrub	Vine
Agalinis maritima	Seaside gerardia	0	0	0	0.60	1.00	1	0	0	0
Agropyron pungens	Stiff-leaved quackgrass	0	1	0	0.60	0.83	0	1	0	0
Agrostis stolonifera	Creeping bentgrass	0	0	0	0.40	0.49	0	1	0	0
Ambrosia artemisiifolia	Ragweed	0	0	0	0.40	0.17	1	0	0	0
Ammophila breviligulata	Dune grass	0	0	0	1.00	0.66	0	1	0	0
Aster tenuifolius	Perennial aster	0	0	0	1.00	1.00	1	0	0	0
Atriplex patula	Marsh orach	0	1	0	0.80	0.33	1	0	0	0
Baccharis halimifolia	Groundsel tree	0	0	0	0.80	0.66	0	0	1	0
Calystegia sepium	Hedge bindweed	0	0	0	0.40	0.33	0	0	0	1
Chamaecyparis thyiodes	Atlantic white cedar	0	0	0	0.20	0.66	0	0	1	0
Cyperus filicinus	Slender flatsedge	0	0	0	0.60	0.83	0	1	0	0
Distichlis spicata	Spike grass	0	0	1	1.00	1.00	0	1	0	0
Euthamia graminifolia	Grass-leaved goldenrod	0	0	0	0.40	0.49	1	0	0	0
Festuca rubra	Red fescue	0	0	0	0.40	0.33	0	1	0	0
Glaux maritima	Sea milkwort	0	0	0	1.00	0.83	1	0	0	0
Iva frutescens	Marsh elder	0	0	0	0.80	0.83	0	0	1	0
Juncus gerardii	Black grass	0	0	1	1.00	1.00	0	1	0	0
Limonium nashii	Sea Lavender	0	0	0	1.00	1.00	1	0	0	0
Myrica cerifera	Wax myrtle	0	0	0	0.40	0.49	0	0	1	0
Panicum virgatum	Switchgrass	0	0	0	0.60	0.83	0	1	0	0
Phragmites australis	Common reed	1	1	0	0.60	0.17	0	1	0	0
Plantago maritima	Seaside plaintain	0	0	0	0.60	0.83	1	0	0	0
Polygonum arifolium	Halberd-leaf tearthumb	0	0	0	0.60	0.49	1	0	0	0
Polygonum sagittatum	Arrow-leaved tearthumb	0	0	0	0.40	0.66	1	0	0	0
Prunus virginiana	Choke cherry	0	0	0	0.40	0.33	0	0	1	0
Rosa rugosa	Rugosa rose	1	1	0	0.60	0.49	0	0	1	0
Salicornia europaea	Common glass wort	0	0	0	1.00	1.00	1	0	0	0

GenusSpecies	Common	Invasive	Non-Indigenous	HM grass	Salinity	Habitat Affinity	Forb	Grass	Shrub	Vine
Salicornia virginica	Woody glasswort	0	0	0	1.00	1.00	1	0	0	0
Scirpus americanus	Olney three-square	0	0	0	0.80	0.83	0	1	0	0
Scirpus pungens	Common three square	0	0	0	0.80	0.83	0	1	0	0
Scirpus robustus	Saltmarsh bullrush	0	0	0	0.80	0.83	0	1	0	0
Solidago sempirvirens	Seaside goldenrod	0	0	0	0.80	0.83	1	0	0	0
Spartina alterniflora	Smooth cordgrass	0	0	0	1.00	1.00	0	1	0	0
Spartina cynosuroides	Big cordgrass	0	0	0	0.80	0.66	0	1	0	0
Spartina patens	Salt hay grass	0	0	1	1.00	1.00	0	1	0	0
Spergularia marina	SM Sand spurrey	0	0	0	1.00	0.83	1	0	0	0
Suaeda linearis	Sea blite	0	0	0	0.80	0.83	1	0	0	0
Teucrium canadense	American germander	0	0	0	0.40	0.49	1	0	0	0
Toxicodendron radicans	Poison ivy	0	0	0	0.40	0.33	0	0	1	1
Triglochin maritimum	Saltmarsh arrow-grass	0	0	0	1.00	0.83	0	1	0	0
Typha angustifolia	Narrowleaved cattail	0	0	0	0.60	0.49	1	0	0	0

Appendix D: Avifauna species list and abundance (#) values

Species Name	EOBP-pre 2000	EOBP-pre 2001	EOBP-post 2002	EOBP-post 2003	EOBP-R 2000	EOBP-R 2001	EOBP-R 2002	EOBP-R 2003	EMC-pre 2000	EMC-pre 2001	EMC-pre 2002	EMC-pre 2003	EMC-R 2000	EMC-R 2001	EMC-R 2002	EMC-R 2003
American Crow	7		2	7	3	5	1	3	1	1	4	10	3		6	7
American Goldfinch	10	7	14	10	9	11	10	19	20	9	19	15	15	11	20	14
American Oystercatcher													2			
American Redstart				1												
American Robin	8	1	9	8	11	8	9	11	5	8	17	13	5	6	12	10
Baltimore Oriole		1	1	2	1	2	1	2						1		
Bank Swallow							3							2	1	1
Barn Swallow	4	3	8	2	3	3	2	14	9	10	34	29	10	11	31	43
Belted Kingfisher			2			1			1		4				2	
Black Duck				2					2				2			
Black-Bellied Plover													1	1		
Black-Billed Cuckoo						2										
Black-Capped Chickadee	4	7	8	10	3	2	3	3	3	9	10	6	1	2	5	4
Black-Crowned Night Heron														1		
Blackpoll Warbler																
Blue Jay	4	2	16	3	2	3	6	5	1	2	1	6	1			
Bobolink													2	2	1	
Brown-Headed Cowbird											1	3			1	1
Canada Goose															7	
Carolina Wren	4	2		1			1	4	3		5	2			1	
Cedar Waxwing	2			2	1	2		2	4		9	10	5	8	16	12
Chimney Swift					1		1	2			1					
Chipping Sparrow																
Cliff Swallow			1					1								
Common Grackle	8	2	5	4	14	9	11	19	11	26	35	35	13	14	24	25
Common Tern														1	6	
Common Yellowthroat	3	6	8	5	1	7	5	5	2	4	3	3	2	2	6	5

Species Name	EOBP-pre 2000	EOBP-pre 2001	EOBP-post 2002	EOBP-post 2003	EOBP-R 2000	EOBP-R 2001	EOBP-R 2002	EOBP-R 2003	EMC-pre 2000	EMC-pre 2001	EMC-pre 2002	EMC-pre 2003	EMC-R 2000	EMC-R 2001	EMC-R 2002	EMC-R 2003
Cooper's Hawk				1				1							1	1
Double-Crested Cormorant													1	4	2	1
Downy Woodpecker	1	1	3		2	4	1		1	1	4	2	1		1	
Eastern Kingbird	1	1		1	1	1					2		1	2		2
Eastern Towhee																
Eastern Wood-Pewee					3											
European Starling	6	1		3	3	1			3		9	19		1	17	2
Forster's Tern																
Gray Catbird	8	9	13	9	5	2	6	9	6	9	5	7	2	3	2	6
Great Black-backed Gull																1
Great Blue Heron										1	1		1			
Great Crested Flycatcher				2			1									
Great Egret																
Greater Yellowlegs													1			
Green-Backed Heron		3	1	1		1	1								2	
Hairy Woodpecker		1														
Herring Gull													3	1	4	2
Horned Lark																
House Finch		2	2	2	1	7	4	5	3	3	13	8	8	4	18	15
House Sparrow								1			4	11		2		16
House Wren						1			1	1					1	
Killdeer						8	2									
King Rail							2									
Laughing Gull													1		7	3
Least Sandpiper		1			14	40	6	4						2	2	1
Least Tern														1	6	1
Lesser Yellowlegs																

Species Name	EOBP-pre 2000	EOBP-pre 2001	EOBP-post 2002	EOBP-post 2003	EOBP-R 2000	EOBP-R 2001	EOBP-R 2002	EOBP-R 2003	EMC-pre 2000	EMC-pre 2001	EMC-pre 2002	EMC-pre 2003	EMC-R 2000	EMC-R 2001	EMC-R 2002	EMC-R 2003
Mallard						1			4		1	8	4		3	1
Mourning Dove	1	1	9	5	5	11	19	20	3	3	41	13	1	3	33	2
Mute Swan																
Nashville Warbler					1											
Northern Bobwhite	1		1		1	1	4	1	2	1	3	1	1	2	5	2
Northern Cardinal	5	4	2	9	3	4	5	8	4	10	7	14	1	5	6	5
Northern Flicker					3		2	5	1		4	3			1	1
Northern Harrier									1							
Northern Mockingbird			1	1	1	1	3	3	1	1	4		3	1	9	1
Northern Rough-Winged Swallow								1		2						
Northern Waterthrush				1												
Orchard Oriole								1								
Osprey																1
Piping Plover																
Purple Finch														1		
Red Knot																
Red-Breasted Nuthatch				1		1										
Red-Tailed Hawk				2		2		3			1				1	
Red-Winged Blackbird	42	17	32	41	24	26	50	207	17	26	33	23	16	36	27	30
Ring-Billed Gull																
Ring-Necked Pheasant						1										
Rose-Breasted Grosbeak																1
Salt-Marsh Sharp-Tailed Sparrow					1					1						
Savannah Sparrow																
Semipalmated Plover													2			
Semipalmated Sandpiper						5										
Sharp-Shinned Hawk		1														

Species Name	EOBP-pre 2000	EOBP-pre 2001	EOBP-post 2002	EOBP-post 2003	EOBP-R 2000	EOBP-R 2001	EOBP-R 2002	EOBP-R 2003	EMC-pre 2000	EMC-pre 2001	EMC-pre 2002	EMC-pre 2003	EMC-R 2000	EMC-R 2001	EMC-R 2002	EMC-R 2003
Short-Billed Dowitcher																
Snowy Egret																1
Solitary Sandpiper			1				1	1								
Song Sparrow	3	3	9	5	8	8	12	10	6	5	5	11	3	6	5	7
Spotted Sandpiper						1					2		2		1	1
Swamp Sparrow								1								
Tree Swallow	1					2	1	3	1	1	5	7	5	1	4	6
Tufted Titmouse										1						
Willet													1	1		
Willow Flycatcher									1				2	2	5	2
Wood Duck									1							
Yellow Warbler		1			1	2		2	2	3	1	3	1	2	1	2

Species Name	MSLP-pre 2000	MSLP-pre 2001	MSLP-R 2000	MSLP-R 2001	BGIC-R 2000	ECG-R 2002	ECG2-R 2003
American Crow	5	10	1	5	15	4	2
American Goldfinch	11	18	16	15	12	3	24
American Oystercatcher							
American Redstart							
American Robin					1		9
Baltimore Oriole	1						1
Bank Swallow			1			40	21
Barn Swallow	20	2	25	4	30	13	9
Belted Kingfisher		1		1			
Black Duck							2
Black-Bellied Plover		1				50	
Black-Billed Cuckoo							
Black-Capped Chickadee		2					7

Species Name	MSLP-pre 2000	MSLP-pre 2001	MSLP-R 2000	MSLP-R 2001	BGIC-R 2000	ECG-R 2002	ECG2-R 2003
Black-Crowned Night Heron							
Blackpoll Warbler							1
Blue Jay		1	1	2	1	3	6
Bobolink				1	3		
Brown-Headed Cowbird							
Canada Goose							
Carolina Wren						1	6
Cedar Waxwing	2					3	4
Chimney Swift							
Chipping Sparrow							1
Cliff Swallow							
Common Grackle	2	14	1	12	1	1	32
Common Tern	1	2		4		57	1
Common Yellowthroat	2	6	4	5			6
Cooper's Hawk			1				
Double-Crested Cormorant			1	12		3	
Downy Woodpecker	1						
Eastern Kingbird	1	1	1	1	5	2	
Eastern Towhee	1	2	3	3	1		
Eastern Wood-Pewee							
European Starling			8		40		1
Forster's Tern						1	
Gray Catbird		1		4	2		6
Great Black-backed Gull		1		2		4	
Great Blue Heron	1	1	1		2	5	3
Great Crested Flycatcher							
Great Egret			2				

Species Name	MSLP-pre 2000	MSLP-pre 2001	MSLP-R 2000	MSLP-R 2001	BGIC-R 2000	ECG-R 2002	ECG2-R 2003
Greater Yellowlegs	1	2	2	6	15	134	4
Green-Backed Heron				2	1		
Hairy Woodpecker							
Herring Gull	3	5	2	3	1	92	1
Horned Lark						3	
House Finch	3		2		9	1	16
House Sparrow							3
House Wren							
Killdeer	1		1		1		
King Rail							
Laughing Gull						43	
Least Sandpiper	3	4	2	3	2	136	17
Least Tern				2		10	
Lesser Yellowlegs				3		1	10
Mallard	1	2				3	
Mourning Dove	5	4	10	1	7	2	3
Mute Swan			31	14			
Nashville Warbler							
Northern Bobwhite		3		1	1		
Northern Cardinal					1		7
Northern Flicker	1	1	1	1			
Northern Harrier		2			1		
Northern Mockingbird	1	1	4	1	2		1
Northern Rough-Winged Swallow						1	
Northern Waterthrush							
Orchard Oriole							
Osprey			7	9	1	2	

Species Name	MSLP-pre 2000	MSLP-pre 2001	MSLP-R 2000	MSLP-R 2001	BGIC-R 2000	ECG-R 2002	ECG2-R 2003
Piping Plover						1	
Purple Finch					1		
Red Knot						1	
Red-Breasted Nuthatch							
Red-Tailed Hawk					1	9	
Red-Winged Blackbird	16	33	19	31	1	18	21
Ring-Billed Gull						1	
Ring-Necked Pheasant							
Rose-Breasted Grosbeak							
Salt-Marsh Sharp-Tailed Sparrow	2	1	2	6	29	1	1
Savannah Sparrow						4	1
Semipalmated Plover						1	12
Semipalmated Sandpiper						300	11
Sharp-Shinned Hawk							
Short-Billed Dowitcher			2	1		1443	
Snowy Egret	2	2		1		2	4
Solitary Sandpiper							
Song Sparrow	7	19	5	13	6	3	9
Spotted Sandpiper							1
Swamp Sparrow							
Tree Swallow	31	5	18	6	117	9	7
Tufted Titmouse							
Willet	4	3	10	4	1	12	
Willow Flycatcher					1		
Wood Duck							
Yellow Warbler		1		2	2	1	4

Appendix E: Avifauna species and attribute list

Species Name	WetlandDependant	AerialForager	NeotropicalMigrant	Resident	Tolerant
American Crow	0	0	0	1	1
American Goldfinch	0	0	0	1	0
American Kestrel	0	1	0	0	0
American Oystercatcher	1	0	0	0	0
American Redstart	0	1	1	0	0
American Robin	0	0	0	0	1
Baltimore Oriole	0	0	1	0	0
Bank Swallow	0	1	1	0	0
Barn Swallow	0	1	1	0	0
Belted Kingfisher	1	0	0	0	0
Black and White Warbler	0	0	1	0	0
Black Duck	1	0	0	1	0
Black-Bellied Plover	1	0	1	0	0
Black-Billed Cuckoo	0	0	1	0	0
Black-Capped Chickadee	0	0	0	1	1
Black-Crowned Night Heron	1	0	1	0	0
Blackpoll Warbler	0	0	1	0	0
Blue Jay	0	0	0	1	1
Bobolink	0	0	1	0	0
Bonaparte's Gull	1	0	0	0	0
Broad-Winged Hawk	0	1	1	0	0
Brown-Headed Cowbird	0	0	0	0	0
Canada Goose	1	0	0	1	1
Carolina Wren	0	0	0	1	0
Cedar Waxwing	0	1	0	0	0
Chesnut-Sided Warbler	0	1	1	0	0
Chimney Swift	0	1	1	0	1
Chipping Sparrow	0	0	0	0	0
Clapper Rail	1	0	1	0	0
Cliff Swallow	1	1	1	0	0

Species Name	WetlandDependant	AerialForager	NeotropicalMigrant	Resident	Tolerant
Common Grackle	1	0	0	0	0
Common Tern	1	1	1	0	0
Common Yellowthroat	1	0	1	0	0
Cooper's Hawk	0	0	0	0	0
Double-Crested Cormorant	1	0	0	0	0
Downy Woodpecker	0	0	0	1	1
Dunlin	1	0	1	0	0
Eastern Bluebird	0	0	0	0	0
Eastern Kingbird	1	1	1	0	0
Eastern Meadowlark	0	0	0	0	0
Eastern Phoebe	0	1	1	0	0
Eastern Towhee	0	0	0	0	0
Eastern Wood-Pewee	0	1	1	0	0
European Starling	0	0	0	1	1
Field Sparrow	0	0	0	0	0
Forster's Tern	1	1	1	0	0
Gadwall	1	0	0	1	0
Glossy Ibis	1	0	1	0	0
Golden-Crowned Kinglet	0	0	0	0	0
Gray Catbird	0	0	1	0	0
Great Black-backed Gull	1	0	0	1	1
Great Blue Heron	1	0	0	0	0
Great Crested Flycatcher	0	1	1	0	0
Great Egret	1	0	1	0	0
Greater Yellowlegs	1	0	1	0	0
Green-Backed Heron	1	0	1	0	0
Hairy Woodpecker	0	0	0	0	0
Herring Gull	1	0	0	1	1
Horned Lark	0	0	0	0	0
House Finch	0	0	0	1	1
House Sparrow	0	0	0	1	1

Species Name	WetlandDependant	AerialForager	NeotropicalMigrant	Resident	Tolerant
House Wren	0	0	0	0	1
Indigo Bunting	0	0	1	0	0
Killdeer	1	0	1	0	0
King Rail	1	0	1	0	0
Laughing Gull	1	0	1	0	0
Least Sandpiper	1	0	1	0	0
Least Tern	1	1	1	0	0
Lesser Yellowlegs	1	0	1	0	0
Little Blue Heron	1	0	1	0	0
Mallard	1	0	0	1	1
Marsh Wren	1	0	0	0	0
Merlin	0	1	0	0	0
Mourning Dove	0	0	0	1	1
Mute Swan	1	0	0	1	1
Nashville Warbler	0	1	1	0	0
Northern Bobwhite	0	0	0	1	0
Northern Cardinal	0	0	0	1	1
Northern Flicker	0	0	0	0	0
Northern Harrier	1	1	0	0	0
Northern Mockingbird	0	0	0	1	1
Northern Rough-Winged Swallow	1	1	1	0	0
Northern Waterthrush	1	1	1	0	0
Orchard Oriole	0	0	1	0	0
Osprey	1	1	1	0	0
Ovenbird	0	0	1	0	0
Pine Warbler	0	1	1	0	0
Piping Plover	1	0	1	0	0
Prairie Warbler	0	1	1	0	0
Purple Finch	0	0	0	0	0
Purple Martin	0	1	1	0	0
Red Knot	1	0	1	0	0

Species Name	WetlandDependant	AerialForager	NeotropicalMigrant	Resident	Tolerant
Red-Breasted Nuthatch	0	0	0	0	0
Red-Eyed Vireo	0	1	1	0	0
Red-Tailed Hawk	0	1	0	1	0
Red-Winged Blackbird	1	0	0	0	0
Ring-Billed Gull	1	0	0	1	1
Ring-Necked Pheasant	0	0	0	0	1
Rock Dove	0	0	0	1	1
Rose-Breasted Grosbeak	0	0	1	0	0
Ruddy Turnstone	1	0	1	0	0
Salt-Marsh Sharp-Tailed Sparrow	1	0	0	0	0
Sanderling	1	0	1	0	0
Savannah Sparrow	0	0	0	0	0
Scarlet Tanager	0	0	1	0	0
Seaside Sparrow	1	0	0	0	0
Semipalmated Plover	1	0	1	0	0
Semipalmated Sandpiper	1	0	1	0	0
Sharp-Shinned Hawk	0	0	0	0	0
Short-Billed Dowitcher	1	0	1	0	0
Snowy Egret	1	0	1	0	0
Solitary Sandpiper	1	0	1	0	0
Song Sparrow	0	0	0	1	1
Spotted Sandpiper	1	0	1	0	0
Swamp Sparrow	1	0	0	0	0
Tree Swallow	0	1	1	0	0
Tufted Titmouse	0	0	0	1	1
Virginia Rail	1	0	1	0	0
Warbling Vireo	1	1	1	0	0
Water Pipit	1	0	1	0	0
Whimbrel	1	0	1	0	0
White-Breasted Nuthatch	0	0	0	1	0
Willet	1	0	1	0	0

Species Name	WetlandDependant	AerialForager	NeotropicalMigrant	Resident	Tolerant
Willow Flycatcher	1	1	1	0	0
Wilson"s Warbler	0	1	1	0	0
Wilson's Phalarope	1	0	1	0	0
Wood Duck	1	0	0	0	0
Wood Thrush	0	0	1	0	0
Yellow Warbler	1	1	1	0	0
Yellow-Billed Cuckoo	0	0	1	0	0
Yellow-Crowned Night Heron	1	0	1	0	0
Yellow-Rumped Warbler	0	1	1	0	0

Appendix F: Nekton species list and abundance (#) values

Species Name	EOBP-pre 2000	EOBP-pre 2001	EOBP-post 2002	EOBP-post 2003	EOBP-R 2000	EOBP-R 2001	EOBP-R 2002	EOBP-R 2003	EMC-pre 2000	EMC-pre 2001	EMC-pre 2002	EMC-pre 2003	EMC-R 2000	EMC-R 2001	EMC-R 2002	EMC-R 2003
alewife		1												2		
American eel	18	63	42	46	20	31	11	14		1	2					1
American sand lance											1				1	64
Atlantic cod																1
Atlantic mackerel																104
Atlantic menhaden							7				5				50	28
Atlantic needlefish																
Atlantic silverside	26			1	187	71	1	10	684	310	145	32	357	675	519	135
blue crab			1													
blueback herring									3	2	2	1	43	75		19
fourspine stickleback	1				2	3			33	37	29	283	245	26	22	14
green crab	28	20	29		14	15	15		17	76	41	35	24	93	20	12
Japanese shore crab																
mummichog	479	1648	722	74	123	771	122	159	200	222	354	208	1248	1031	1638	1210
ninespine stickleback	2	1	4		2	1										
northern pipefish																
permit																
rainwater killifish																
red hake													1			
sheepshead minnow	3	158	118		1	10	55	5	2		10		7		4	
spider crab																
spotfin killifish																
striped killifish	4	75	6	3	7	53	3	40	5		3	5	17	1	6	13
striped mullet													1			
threespine stickleback								1	15	24	22	17	52	28	8	
white mullet															8	
white perch					1											
winter flounder				2				1							2	

Species Name	MSLP-pre 2000	MSLP-pre 2001	MSLP-R 2000	MSLP-R 2001	ECG2-R 2003	ECG-R 2002
alewife		88		22		
American eel	2	2	1	2	10	
American sand lance						
Atlantic cod						
Atlantic mackerel						
Atlantic menhaden					53	92
Atlantic needlefish			2	15		
Atlantic silverside	250	1098	2729	2716	4713	70
blue crab	9	15	3	8		
blueback herring				2	8	1
fourspine stickleback	5	93	6			
green crab		4	4	11	24	17
Japanese shore crab	1					
mummichog	158	864	11	139	12712	6250
ninespine stickleback						
northern pipefish		1	1	1		
permit			2			
rainwater killifish	18	65	10	38		
Red hake						
sheepshead minnow	35	25	39	86	9	126
spider crab		1		1		
spotfin killifish			1			
striped killifish	1	38	11	89	3769	473
striped mullet						
threespine stickleback		9	2		1	3
white mullet		4	6	23		
white perch	7					
winter flounder	7		11			

Appendix G: Nekton species and attribute list

Common_Name	Crabs	Mummichog	Non-mummichog	Resident	Transient	Anadramous	Catadramous	Killifishes	Silversides	Sticklebacks	Herrings	Cods
alewife	0	0	1	0	1	1	0	0	0	0	1	0
American eel	0	0	1	0	1	0	1	0	0	0	0	0
American sandlance	0	0	1	0	1	0	0	0	0	0	0	0
Atlantic cod	0	0	1	0	1	0	0	0	0	0	0	1
Atlantic mackeral	0	0	1	0	1	0	0	0	0	0	0	0
Atlantic menhaden	0	0	1	0	1	0	0	0	0	0	1	0
Atlantic needlefish	0	0	1	0	1	0	0	0	0	0	0	0
Atlantic silverside	0	0	1	0	1	0	0	0	1	0	0	0
blue crab	1	0	0	0	1	0	0	0	0	0	0	0
blueback herring	0	0	1	0	1	1	0	0	0	0	1	0
fourspine stickleback	0	0	1	1	0	0	0	0	0	1	0	0
green crab	1	0	0	1	0	0	0	0	0	0	0	0
Japanese shore crab	1	0	0	0	1	0	0	0	0	0	0	0
mummichog	0	1	1	1	0	0	0	1	0	0	0	0
ninespine stickleback	0	0	1	1	0	0	0	0	0	1	0	0
northern pipefish	0	0	1	0	1	0	0	0	0	0	0	0
permit	0	0	1	0	1	0	0	0	0	0	0	0
rainwater killifish	0	0	1	1	0	0	0	1	0	0	0	0
red hake	0	0	1	0	1	0	0	0	0	0	0	1
sheepshead minnow	0	0	1	1	0	0	0	1	0	0	0	0
spider crab	1	0	0	0	1	0	0	0	0	0	0	0
spotfin killifish	0	0	1	1	0	0	0	1	0	0	0	0
striped killifish	0	0	1	1	0	0	0	1	0	0	0	0
striped mullet	0	0	1	0	1	0	0	0	0	0	0	0
threespine stickleback	0	0	1	1	0	0	0	0	0	1	0	0
white mullet	0	0	1	0	1	0	0	0	0	0	0	0
white perch	0	0	1	0	1	0	0	0	0	0	0	0
winter flounder	0	0	1	0	1	0	0	0	0	0	0	0