A REGIONAL ASSESSMENT OF SALTMARSH RESTORATION AND

MONITORING IN THE GULF OF MAINE


Raymond A. Konisky[1,4]

David M. Burdick[2]

Michele Dionne[1]

Hilary A. Neckles[3]

[1]Wells National Estuarine Research Reserve, Wells, ME, U.S.A.

[2]Jackson Estuarine Laboratory, Department of Natural Resources, University of New Hampshire, Durham, NH, U.S.A.

[3]USGS Patuxent Wildlife Research Center, Augusta, ME, U.S.A.

[4]Address correspondence to Raymond A. Konisky, Wells National Estuarine Research Reserve, 342 Laudholm Farm Road, Wells, ME 04090. Email: rkonisky@wellsnerr.org

## Abstract

Saltmarsh monitoring datasets from thirty-six complete or imminent restoration projects in the Gulf of Maine were compiled to assess regional monitoring and restoration practices. Data were organized by functional indicators and restoration project types (culvert replacement, excavation works, or ditch-plugging) then pooled to generate mean values for indicators before restoration, after restoration, and at reference sites. Monitoring data were checked against the regional standards of a voluntary protocol for the Gulf of Maine. Data inventories showed that vegetation and salinity indicators were most frequently collected (89% and 78% of sites, respectively), but nekton, bird, and hydrologic measures were collected at only about half of the sites. Reference conditions were monitored at 72% of sites. Indicators were analyzed to see if project sites were degraded relative to reference areas, and to detect ecological responses to restoration activities. Results showed that compared to reference areas, pre-restoration sites had smaller tidal ranges, reduced salinity levels, greater cover of brackish plants species, and lower cover of halophyte plants. Following restoration, physical factors rebounded rapidly with increased flood and salinity levels after about one year. Biologic responses were less definitive and occurred over longer time frames. Plant communities trended toward increased halophyte and reduced brackish species at three-plus years following restoration. Nekton and avian indicators were indistinguishable among reference, impacted, and restored areas. Results appeared limited by regional inconsistencies in field practices and relatively few multi-year datasets. To improve future assessment capabilities, regional efforts are being made to encourage greater adherence to the standard protocol throughout the Gulf of Maine saltmarsh restoration community.

**Key words: tidal restoration, regional assessment, monitoring protocols, salt marsh**

## Introduction

Salt marshes in the Gulf of Maine, a region stretching from Cape Cod Bay in Massachusetts to Cape Sable in Nova Scotia, are widely affected by man-made structures like dikes, tide-gates, bridges, and culverts, and other impacts such as dredge-spoil filling and mosquito ditching. As a result, altered saltmarsh hydrology is commonplace, with at least 20% of regional marshes restricted in tidal flow (Roman et. al. 1984, USDA SCS 1994) and well over 50% ditched (Adamowicz and Roman 2002). In an effort to recover lost ecosystem functions, Gulf of Maine coastal managers are actively engaging in saltmarsh restoration practices focused on the return of natural hydrology to impacted marshes. Restoration projects typically fall into one of three general categories: 1) culvert expansion or tide-gate removal (Burdick et al. 1997), 2) earthen excavation of dikes, fill or tidal channels (Burdick et al. 1999), and 3) ditch-plugging with pool creation (Adamowicz and Roman 2002). Federal, state, and provincial agencies have started about 100 saltmarsh restoration projects in the Gulf of Maine since 1990 (Cornelisen 1998), and the practice continues to be a major management emphasis.

Marsh monitoring activities are frequently conducted in conjunction with restoration projects to measure responses of key ecological indicators. Historically, Gulf of Maine saltmarsh restoration projects were done without interstate coordination, and monitoring groups collected data independently according to their own separate protocols. As a result, a coherent regional perspective on tidal wetland restoration has not been possible for the Gulf of Maine. Now, it is increasingly evident that regional assessments are critical to effective decision-making, a concept embraced in particular by many watershed health initiatives (see Stadler-Salt and Bertram 2001, Herbst 2002, and others for 'State of the Bay' reports). These efforts, however, are based on the availability of common ecological data collected in standardized ways, and are most-often directed by a single federal agency or funding source. For the Gulf of Maine, an area spanning three U.S. states and two Canadian provinces, regional coordination of marsh monitoring is entirely a voluntary process. To encourage regional collaboration, the Gulf of Maine saltmarsh restoration community came together in a 1999 workshop to create a common set of marsh monitoring standards (Neckles and Dionne 2000). The resulting protocol identified a comprehensive set of 16 marsh indicators and associated field methods that allowed, for the first time, a regional characterization of saltmarsh ecosystem health (see Neckles et al. 2002 for complete protocol specifications). Monitoring data collected at project sites before and after restoration also provided basic information about ecosystem responses to restoration practices. Our study represents a first synthesis of these data into a regional assessment.

Although voluntary compliance with the standard protocol has been encouraged, we knew that actual field practices varied considerably among the many monitoring organizations in the region. Still, the existence of common measures and methods was expected to provide datasets sufficiently compatible for synthesis. Differences in protocol use, however, did present analytical challenges, and as a result, the rigor of a tightly controlled, repeat-measure study was not possible here. Rather, we took an approach that pooled common data elements for non-impacted (reference) sites, for impacted (before) sites, and for restored (after) sites at annual intervals following restoration activities. This approach allowed us to investigate four issues of regional importance to resource managers: First, we wanted to see how well the standard protocol was being followed in the field, with an eye toward refining the protocol in the future. Second, we compared regional data from reference and impacted marshes to characterize differences between healthy and degraded habitats. Third, we compared before and after restoration data to identify ecological changes attributable to management practices. Lastly, we wanted to see if ecological indicators in restored marshes trended toward conditions observed in reference marshes. Our overall approach, while generalized, therefore allowed us to assess restoration outcomes on a regional scale for the entire Gulf of Maine.

## Methods

Efforts were made to acquire monitoring datasets from all ongoing, complete or pending Gulf of Maine saltmarsh restoration projects from 1995-2003. Some datasets were lost, undecipherable, or unavailable, and therefore our compilation did not represent the entire inventory of regional saltmarsh restoration projects. Data were typically acquired in spreadsheet format, although some datasets were only available in hard copy and required computer entry. Data collection protocols and meta-data listings were also collected to aid interpretation of data. All incoming datasets were cataloged but analysis was limited to protocol indicators with sufficient data for statistical testing (i.e., 25% of sites, Table 1). Datasets were amended to include descriptive information (site, town, state, source, and collection year), categorized by restoration activity (culvert, excavation, or ditch-plug) and identified by project phase (before restoration/impacted, after restoration, or reference site). For reference sites and impacted sites with multiple years of monitoring data, only the most recent year was used; for restored sites, datasets were tracked separately for each year elapsed since completion of restoration activities (until fewer than 25% of sites remained). All incoming data were checked for incomplete or inconsistent values before acceptance. Since sampling frequency varied widely from project to project, field observations were averaged by site and phase prior to analysis.

Measures of species richness for vegetation, nekton, and birds were based on the maximum species count observed during the sampling period. Soil salinity datasets were limited to observations taken in 5-20 cm (shallow) salinity wells sampled during the growing season (May – Oct). Tidal measures were standardized as the percentage of unrestricted maximum tidal height achieved in the impacted area (i.e., impacted tidal height above impacted creek bottom divided by reference tidal height above impacted creek bottom). For vegetation, percent-cover values were combined into halophytic or brackish plant groups (based on Tiner 1987 and best professional judgment). Halophyte species include *Aster tenuifolius* (aster), *Atriplex patula* (marsh orach), *Distichlis spicata* (spike grass), *Iva frutescens* (marsh elder), *Juncus balticus* (baltic rush), *Juncus gerardii* (black grass), *Limonium nashii* (sea lavender), *Plantago maritime* (seaside plantain), *Puccinellia maritime* (seaside alkali grass), *Panicum virgatum* (switchgrass), *Salicornia europaea* (glasswort), *Spartina alterniflora* (smooth cordgrass), *Spartina patens* (salt hay), *Solidago sempervirens* (seaside goldenrod), *Sueda linearis* (sea blite), and *Triglochin maritimum* (seaside arrow grass). Brackish plants include *Convolvulus sepium* (hedge bindweed), *Juncus effuses* (marsh rush), *Lythrum salicaria* (purple loosestrife), *Myrica gale* (sweet gale), *Onoclea sensibilis* (sensitive fern), *Phragmites australis* (common reed), *Rosa rugosa* (rugosa rose), *Scirpus* spp. (bulrush), *Spartina pectinata* (slough grass), *Toxicodendron radicans* (poison ivy), and *Typha* spp. (cattail). Plants identified as 'trace' were assigned 0.1% cover. Values recorded as cover-class ranges (i.e., 1-5%, 6-25%, etc.) were transformed to the mid-point value of the range and re-proportioned based on relative species cover to maintain unity. Nekton density measures were limited to samples of known area (i.e., minnow trap data were excluded). Area measures for bird density were estimated from map sources for whole-marsh surveys that did not have survey area recorded.

JMP statistical software was used for analysis (SAS Institute 1997). All data were square-root transformed to increase homogeneity of variance, and checked for assumptions of parametric testing. One-way ANOVA (analysis of variance, Tukey Kramer HSD, $\alpha = 0.10$) was used to detect significant differences between means (reference vs. before/impacted, and before vs. after). Means were generated and reported by type of restoration but not tested for differences due to relatively low numbers of excavation and ditch-plug sites. For indicators with significant differences between reference and impacted sites, trend lines were generated to show expected trajectory of change over time. Shapes of regression lines were based on ecological principles, rather than simply the best statistical fit (Morgan and Short 2001). Trend analysis was based on pooled means from multiple sites and from multiple calendar years (e.g., not repeated measures), and was therefore limited in controlling for natural variation.

## Results

Study Sites. Field data from 36 restoration projects were acquired for the study, including sites in Massachusetts, New Hampshire, Maine, and Nova Scotia, Canada (Figure 1). A total of 8852 field samples were processed. Of the 36 project sites, 22 had completed restoration prior to the 2003 growing season, and 14 projects were pending (4 of the pending sites were subsequently restored in late 2003/early 2004). 20 sites were culvert expansion projects (55% of the database), 10 sites were excavation works (28%), and 6 were ditch-plug locations (17%). Nearly the entire coastal range of the Gulf of Maine was included, from the Eastham/Orleans site on Cape Cod Bay in Massachusetts to the Cheverie Creek site on the Bay of Fundy in Nova Scotia (Figure 1). However, the majority of sites (80%) were located between Boston, Massachusetts and Wells, Maine. Massachusetts contributed the most sites with 16 (44%), followed by 11 in New Hampshire (31%), 8 in Maine (22%), and 1 site in Canada (3%).

Protocol Use. Monitoring measures was most typically conducted for vegetation and soil/sediments indicators (89% and 78% of sites, respectively), followed by nekton (56%), bird (53%), and hydrology measures (42%). Maps were prepared for 50% of the sites. Incidence of data collection varied widely for the 16 protocol indicators, ranging from a high of 89% sites measuring vegetation composition and abundance to a low of 17% sites tracking bird feeding/breeding behavior (Table 1). Eight indicators were measured at the typical site, with as few as two and as many as fifteen. For completed projects, 17 of 22 sites (77%) included before, after, and reference data for at least one monitoring indicator; for planned projects, 9 of 14 sites (64%) included before and reference data. In total, 75% of projects included measures at reference sites. Non-protocol or modified field methods were frequent, especially for nekton and bird indicators (e.g., seine and fyke nets were specified for nekton sampling, but throw traps, lift nets, and minnow traps were also used; counting circles rather than total marsh observations were used for bird surveys). Protocol use and methodological adherence did not appear influenced by geographic region or type of project. For data synthesis, most non-protocol methodology differences were ignored so long as data were compatible or easily converted to standard formats (see Methods), however, alternative field methods likely contributed to observed variability in results.

Soils and Sediments. The response of marsh soils to restoration was assessed using growing-season salinity measured in shallow substrate wells (5 cm to 20 cm). Figure 2 shows the results of salinity comparisons. Salinity means for impacted sites were lower than for reference (ANOVA $p=0.01$, $F=8.97$). After restoration, salinity levels increased and were significantly higher than pre-restoration levels at 2+ years (ANOVA $p=0.02$, $F=6.22$). Restored salinity regimes appeared to approach reference levels after one year ($r^2 = 0.85$). Culvert expansion projects increased marsh salinity levels most consistently over time, although lack of data from excavation projects limited comparisons. Also, ambient marsh salinity levels at ditch-plug sites appeared to be higher than for culvert and excavation locations, although differences between project types were not specifically tested (see Methods).

Hydrology. Tidal hydrology comparisons were based on the height of high tide at impacted sites as a percentage of the maximum unrestricted tide at paired reference areas (e.g., downstream). The mean maximum tidal height for impacted sites was only 38% of reference areas (Figure 3), and differences were highly significant (ANOVA $p<0.001$, $F=53.12$). Height following restoration was 74% of the reference level after 1+ year, a significant increase from pre-restoration levels (ANOVA $p=0.02$, $F=6.61$). Post-restoration results were limited to culvert expansion sites only; tidal heights were not available from excavation works and typically not measured at ditch-plug locations.

Vegetation. Three metrics for vegetation comparisons were analyzed: a) combined percent cover of salt-tolerant plants (halophytes), b) combined percent cover of brackish plants, and c) plant species richness. Vegetation results are shown in Figures 4a-c.

a) Halophyte Cover. Total percent cover of halophyte species was lower in impacted areas than in reference marshes (ANOVA $p=0.01$, $F=6.90$). Halophyte species appeared reduced for the first two years following restoration, presumably in response to the initial disturbance of reintroduced saltwater flooding, and then rebounded in the third and later years. This pattern was observed for culvert and excavation sites, but halophyte cover in ditch-plugs seemed to increase one year post-restoration followed by a subsequent decline. Trend analysis ($r^2=0.57$) suggested that halophyte plants would require 4-5 years before total cover approached reference levels (Figure 4a). However, it was not clear from this study if impacted plant communities would ever attain reference composition levels following restoration activities.

b) Brackish Plant Cover. Total percent cover of brackish plants was higher in impacted areas than in reference marshes (ANOVA $p=0.02$, $F=6.02$). Brackish species appeared to be reduced immediately in response to restoration activities, but did not rebound in later years like halophytes. Similar to the halophyte response, trend analysis ($r^2=0.92$) suggested that brackish plant cover would be reduced to reference levels in 4-5 years following restoration (Figure 4b). In general, brackish cover at ditch-plug sites appeared lower than at culvert and excavation project locations.

c) Species Richness. Observed numbers of plant species were not statistically different among reference, impacted, and post-restoration sites (Figure 4c). Plant species richness at impacted marshes may have been greater than at reference marshes, especially for excavation sites ($8.8 \pm 1.3$, versus $6.6 \pm 0.5$ species at reference sites). Richness appeared to be reduced following restoration, although lack of significant differences between reference and impacted sites led us to forego trend analysis.

Nekton. Nekton datasets were analyzed for a) fish density and b) nekton species richness, shown in Figures 5a-b. In addition, nekton datasets were cataloged to identify individual species (fish, crabs, and shrimp) observed during Gulf of Maine marsh monitoring visits.

a. Fish Density. Mean fish density for impacted sites was 6.3 $\pm$ 1.9 fish/$m^2$ before restoration, 5.6 $\pm$ 1.7 fish/$m^2$ one year after restoration, and 5.1 $\pm$ 2.5 fish/$m^2$ two years or more following restoration, and all means were within the reference range (Figure 5a). No significant differences in fish density were detected among reference, impacted, and restored sites. Density was variable among project types, especially for impacted/before measures, with ditch-plug sites appearing higher and culvert sites lower than reference areas. This variation may be an artifact of differences in sampling methods or area sampled, but low fish utilization seemed likely at tidally restricted sites in the region (i.e., culverts).

b. Nekton Species Richness. Mean species richness for nekton samples were in a narrow range, with 3.6 species at reference sites, and 3.0-3.6 species at impacted and restoration sites (Figure 5b). Like fish density, nekton species richness showed no significant differences among treatments. Nekton richness by project type ranged from a high of 4.2 to a low of 3.0 species. Considering the inventory of regional nekton species cataloged (twenty-four total), eighteen species of fish and six species of crustaceans were collected and identified (Table 2).

<u>Birds.</u> Two metrics for avian comparisons were analyzed: a) bird density per hectare, and b) bird species richness. Results are shown in Figures 6a and 6b.

a) Bird Density. Mean bird densities for impacted and restored sites were within one standard error of reference sites (14.6 $\pm$ 7.1 birds/ha), with no significant differences found among treatments (Figure 6a). Results suggested that bird use may have increased immediately after restoration (17.7 $\pm$ 6.7 birds/ha), but counts appeared lower in subsequent years especially for culvert projects. Overall bird density also appeared lower in general for ditch-plug sites, due perhaps to methodological differences.

b) Bird Species Richness. Like density measures, avian species richness at impacted and restored sites was at or near the reference range of 12.5 $\pm$ 2.0 birds (Figure 6b). No significant differences were detected among treatments, although richness may have slightly declined on average following restoration. Bird species richness for ditch-plug sites again seemed reduced compared with measures at culvert and excavation sites.

## Discussion

Project data represented a wide range of geographic coverage, although the great majority of sites were within 100 miles of Boston, Massachusetts. This distribution may reflect regional economics and a longer history of mitigation and proactive coastal projects in the southern Gulf of Maine (Cornelisen 1998). Of the 36 projects studied, culvert expansion was the favored technique (55%), likely due to the simplicity of the approach and more than twenty years of regional experience in identifying and improving these sites (Sinicrope et al. 1990, Roman et al. 2002, Warren et al. 2002). However, as most of the undersized culverts in the region are replaced, future restoration emphasis may shift toward excavation and open marsh water management projects. It is therefore important to continue focus on all restoration types in future regional assessments. Among specific indicators, monitoring was most often done for vegetation (89%) and salinity (78%) measures, and these measures provide somewhat of an analytical foundation for assessing abiotic and biotic marsh responses. Unfortunately, regional inconsistencies among monitoring organizations were prevalent and likely contributed to data variability and low statistical significance of results, especially for faunal indicators. These findings add further impetus to the regional goals of encouraging greater use of the protocol and increasing adherence to protocol methods.

Results of our regional assessment add to the conventional management views that impacted marshes differ ecologically from reference sites, and that restoration practices can reverse degrading impacts and put marshes on a trajectory toward recovery. In particular, marshes with altered hydrology were measurably different from reference sites for physical indicators of salinity regime and tidal flooding. While reference areas experienced a strongly polyhaline regime (Figure 2), impacted sites maintained the lower salinity levels of mesohaline conditions (Roman et al. 1984, Portnoy and Giblin 1997). Following restoration, salinity levels increased and became similar to polyhaline reference levels. This response is well documented for culvert projects (Roman et al. 1984, Sinicrope et al. 1990, Burdick et al. 1997), but little corroborating information is available for salinity changes at excavation and ditch-plug sites. Tidal hydrology exhibited a similar response to salinity, with lower tidal heights in impacted areas and significantly increased flooding following restoration (Figure 3). Both salinity and tidal hydrology responses were fairly rapid, with physical changes observed within a year or two of restoration (Sinicrope et al. 1990, Burdick et al. 1999). However, restored tidal flood levels remained diminished relative to potential tidal heights (74% of reference tidal height, Figure 3), suggesting that tidal hydrology did not recover as completely as marsh salinity. This hydrologic response is likely due to the somewhat compromised nature of tidal restoration in highly impacted areas like the Gulf of Maine. With long-term subsidence of restricted marsh surfaces and encroaching public structures, the complete elimination of restrictive tidal barriers is often not a realistic or desirable restoration outcome at all (Burdick et al. 1999, Boumans et al. 2002).

Biologic marsh indicators exhibited weaker signals than physical measures, as seen in comparisons between impact and reference sites and between pre- and post-restoration conditions. Plant communities showed the strongest biologic results, with fewer salt-tolerant plants and more brackish species at impacted sites (Figures 4a-b). This conversion of salt marsh to brackish marsh in tidally restricted marshes is well documented (Roman et al. 1984, Sinicrope et al. 1990, Burdick et al. 1999), and increasingly a management concern in New England (Warren et al. 2002, Burdick and Konisky 2003). However, differences in plant species richness between reference and impacted areas were not detected, although more plant species may have been present in impacted sites. Since impacted sites have lowered salinity and flood levels (and therefore less physical stress), it follows that growing conditions at these sites are favorable to more plant species than at unaltered salt marshes (Bertness and Ellison 1987). Further, tidally restricted marshes can contain remnant saltmarsh habitat nearest the tidal source (Burdick et al. 1999), adding to site diversity. Following restoration, conditions appeared to favor halophyte species at the expense of brackish plants, with some intolerant species excluded altogether (e.g., *Lythrum salicaria*). These responses are in line with restoration goals and expectations, as well as findings from other tidal reintroduction projects and regional studies (Sinicrope et al. 1990, Burdick et al. 1997, Adamowicz and Roman 2002, Roman et al. 2002, Warren et al. 2002, Konisky and Burdick 2004). In addition, it was evident that plant communities respond at slower rates than physical factors, and that long-term monitoring is needed to identify steady-state conditions following restoration.

Responses of nekton and bird indicators to restoration activities in the Gulf of Maine showed highly variable and inconclusive results. Measures of faunal density and species richness for nekton and birds did not produce detectable differences among reference, impacted, and post-restoration sites. Other researchers studying faunal response to tidal restriction and restoration have reported similarly mixed results. Roman et al. (2002) found lower nekton utilization of tidally restricted marshes in Connecticut, but Eberhardt (2004) in Maine and New Hampshire did not. In most studies, however, restored marshes appeared similar to reference marshes for nekton use (Dionne et al. 1999, Burdick et al. 1997, Adamowicz and Roman 2002, Roman et al. 2002, and Warren et al. 2002). Our analysis suggested that restored, impacted, and reference sites were all comparable in terms of fish density and nekton richness, although fish use may have been reduced at tidally restricted (culvert sites, Figure 5a). Further, the occurrence of fish does not necessarily translate into functional equivalence. If fish avoid hydrologic restrictions, restricted marshes may not export as much fish production as reference marshes (Dionne et al. 1999, Eberhardt 2004). Further, nekton responses to tidal restrictions may be species-specific. Our compilation showed that 7 of 24 nekton species were found only at reference sites and 3 species were found only at restored sites (Table 2), suggesting that impacted sites may be less favorable habitat for certain regional species of nekton.

For bird communities, we saw no differences in density and species richness among reference, impacted, and post-restoration sites. Avian responses to saltmarsh habitat alterations are not well studied and poorly understood. Of the few regional studies to survey bird use of impacted and restored marshes, Adamowicz and Roman (2002) and Warren et al. (2002) both reported inconclusive results. Given that faunal signals are inherently difficult to detect, we believe that tighter protocol adherence, more surveys, and longer-term monitoring are all needed before a clear picture of biologic responses to restoration emerges in our region.

## Conclusions

In September 2004, we reconvened a second gathering of the Gulf of Maine saltmarsh restoration community to review these study results, to encourage greater protocol participation, and to recommend future protocol revisions. The workshop attracted fifty attendees, many of whom were involved in the initial drafting of the protocol five years earlier. Feedback from the workshop indicated strong support for continued regional collaboration and monitoring standards. The presentation of our results demonstrated to attendees the value of common measures and consistent practices, and the critical role of standards in assessing regional outcomes. In addition, we were able to provide managers with a set of ecological reference benchmarks for gauging the relative health of saltmarsh sites throughout the Gulf of Maine region. The benefits of cooperation, and the potential for regional assessment, are now increasingly evident.

In summary, results of our study show that saltmarsh restoration practices in the Gulf of Maine are helping degraded marshes recover lost functional attributes. Critical ecological characteristics of salt marshes like tidal flooding and salinity levels clearly rebound following management activities, and native salt-tolerant plants reclaim habitat to the detriment of brackish invaders. Whether we are ultimately successful at restoring all biological communities and ecological functions, however, remains inconclusive. At this time, regional inconsistencies in sampling methodology and a lack of long-term studies limit our abilities to draw inferences and conclusions. Going forward, we expect that improved regional cooperation and tighter adherence to standard methods will allow us to advance beyond this first step, toward a more complete understanding of saltmarsh restoration ecology and efficacy in the Gulf of Maine.

## Acknowledgements

The authors thank the NOAA Restoration Center and the Gulf of Maine Council on the Marine Environment for project funding. The 2004 protocol workshop was sponsored by the Regional Association for Research on the Gulf of Maine (RARGOM). Marsh monitoring organizations contributing data to this study include Cape Cod Volunteer Monitoring Program (Falmouth, MA), Ecology Action Centre (Halifax, Nova Scotia), Jackson Estuarine Laboratory (Durham, NH), Massachusetts Audubon Society (Wenham, MA), Massachusetts Office of Coastal Zone Management (Boston, MA), New Hampshire Coastal Program (Portsmouth, NH), New Hampshire Volunteer Monitoring Program, (Portsmouth, NH), Salem Sound Coastwatch (Salem, MA), U.S. Fish and Wildlife Service (Falmouth and Wells, ME), and the Wells National Estuarine Research Reserve (Wells, ME). Several independent researchers also provided datasets, namely Alyson Eberhardt, Rickey Holt, Greg Shriver, and Rob Vincent. In addition, Andrea Leonard at the Wells NERR provided support in many aspects of database compilation. The authors gratefully acknowledged all supporters and contributors to this project.

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Table 1. Ecological monitoring indicators from the Gulf of Maine standard protocol and frequency of collection at regional restoration sites.

| **Functional Area** | **Protocol Core Variables (% of sites with monitoring data)** | **Additional Variables** |
|---|---|---|
| Map | Map location, key features, cover types, sample area, manipulations, and documentation (50%) | Geo-referenced detail |
| Hydrology | Tidal signal (42%)<br>Elevation (22%) | Tidal creek cross-section<br>Water table depth<br>Surface water characteristics<br>Current profiles |
| Soils and Sediments | Pore-water salinity (78%) | Organic matter<br>Sediment accretion rate<br>Sediment elevation<br>Redox potential<br>Sulfide |
| Vegetation | Composition (89%)<br>Abundance (89%)<br>Height of species of concern (22%)<br>Density of species of concern (22%)<br>Photo stations (19%) | Aboveground biomass<br>Stem density (all species)<br>Proportion flowering |
| Nekton | Composition (56%)<br>Species richness (56%)<br>Density (36%)<br>Length (47%; mummichog-only)<br>Biomass (36%; mummichog-only) | Fish growth<br>Fish diet<br>Larval mosquitoes |
| Birds | Density (53%)<br>Species richness (25%)<br>Feeding/breeding behavior (17%) | Passerines/other cryptic species<br>Birds in the buffer<br>Waterfowl in winter |

Table 2. Nekton species observed during Gulf of Maine marsh monitoring, including presence in reference sites, impacted sites (before restoration), and restored sites.

| Scientific Name (common name) | Reference | Impacted | Restored |
|---|---|---|---|
| **Fish** | | | |
| *Alosa aestivalis* (blueback herring) | X | | |
| *Alosa pseudoharengus* (alewife) | X | | |
| *Alosa sapidissima* (American shad) | | | X |
| *Anguilla rostrata* (American eel) | X | X | X |
| *Apeltes quadracus* (fourspine stickleback) | X | X | X |
| *Cyprinodon variegatus* (sheepshead minnow) | X | | |
| *Fundulus heteroclitus* (mummichog) | X | X | X |
| *Fundulus majalis* (striped killifish) | X | X | |
| *Gasterosteus aculeatus* (threespine stickleback) | X | X | X |
| *Gasterosteus wheatlandi* (blackspotted stickleback) | X | X | |
| *Lepomis* sp. (sunfish) | X | | |
| *Menidia beryllina* (tidewater/inland silverside) | | | X |
| *Menidia menidia* (Atlantic silverside) | X | X | X |
| *Microgadus tomcod* (Atlantic tomcod) | | X | |
| *Morone americana* (white perch) | X | | |
| *Mugil cephalus* (striped mullet) | X | | |
| *Pseudopleuronectes americanus* (winter flounder) | X | | |
| *Pungitius pungitius* (ninespine stickleback) | X | X | X |
| **Crustaceans** | | | |
| *Callinectes sapidus* (blue crab) | | | X |
| *Carcinus maenas* (green crab) | X | X | X |
| *Crangon septemspinsosa* (sand shrimp) | X | X | X |
| *Hemigrapsus sanguineus* (Asian shore crab) | X | | X |
| *Palaemonetes pugio* (grass shrimp) | X | X | X |
| *Palaemonetes vulgaris* (grass shrimp) | X | X | |

Figure 1. Map of Gulf of Maine monitored saltmarsh sites included in regional restoration assessment.

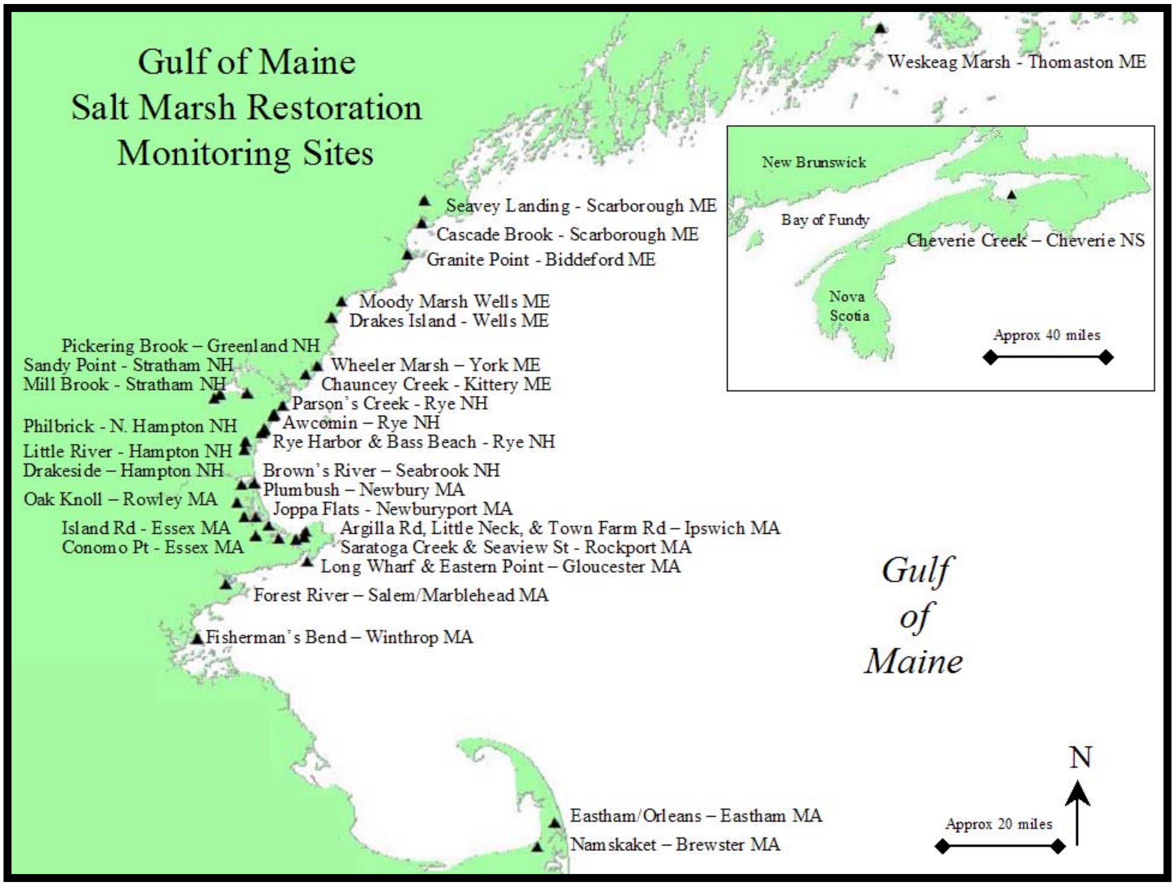


Figure 2. Pore-water salinity monitoring measures (mean + 1 SE) for reference and impacted (before) marshes, and response to restoration (after). Reference values (mean $\pm$ 1 SE) shown as dashed lines. Means also shown by project type (C:culvert, E:excavation, and D:ditch-plug), with number of sites in parentheses. Trend line shows expected trajectory of salinity changes at restoration sites. *Before and reference means are different; **Before and after means are different (Tukey Kramer HSD, α = 0.10).

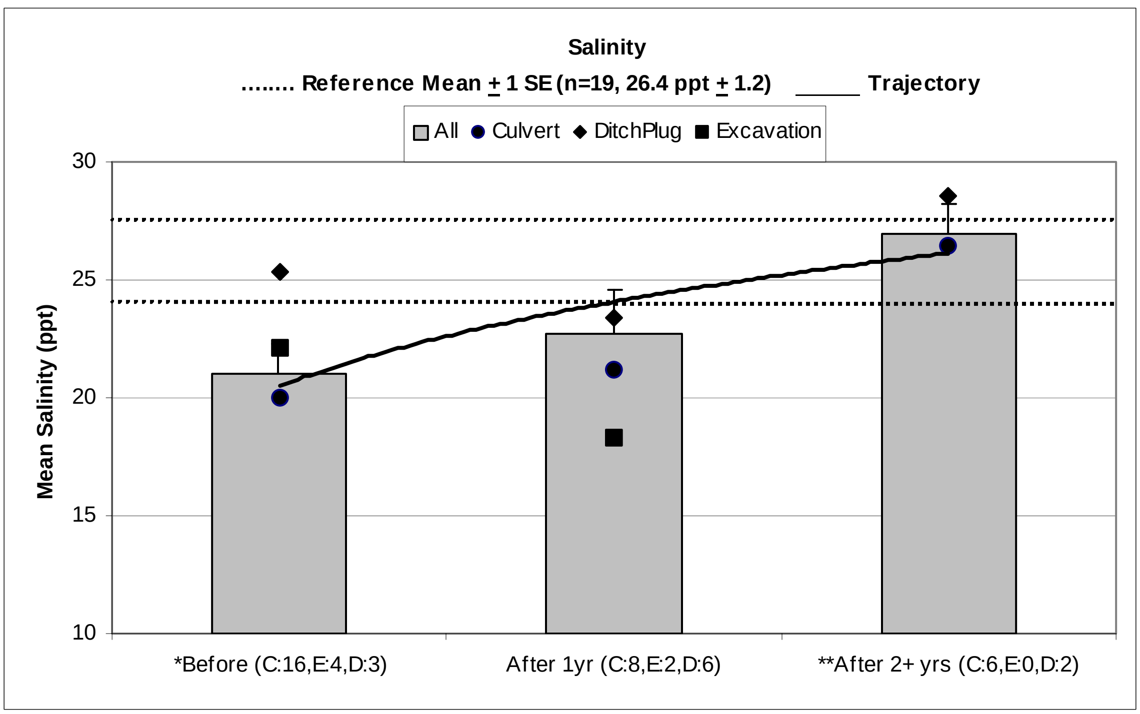
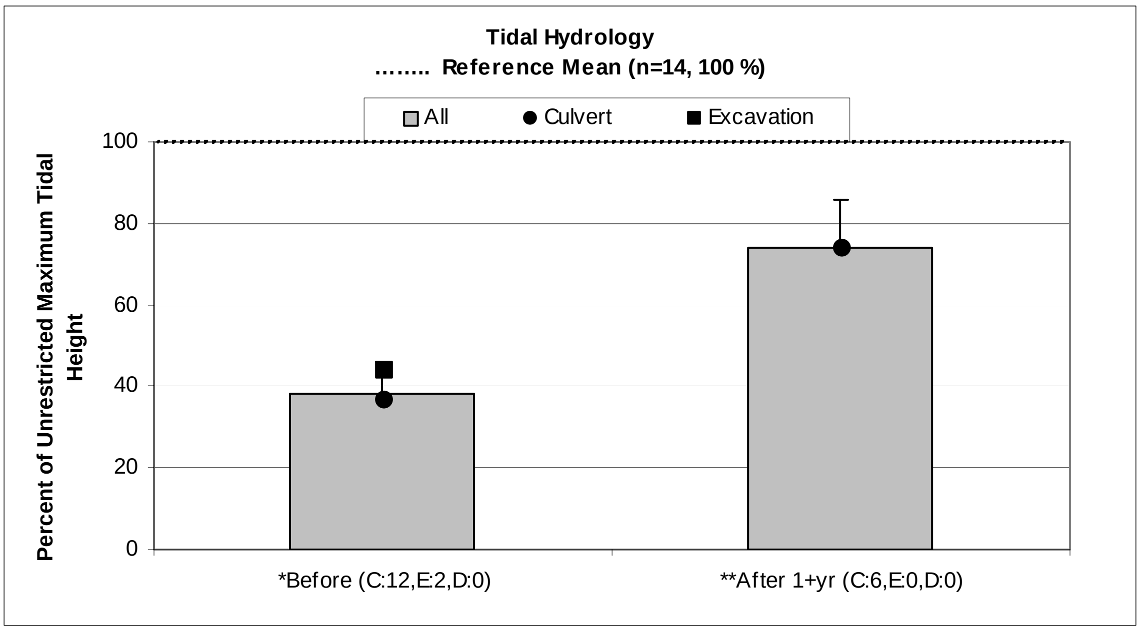
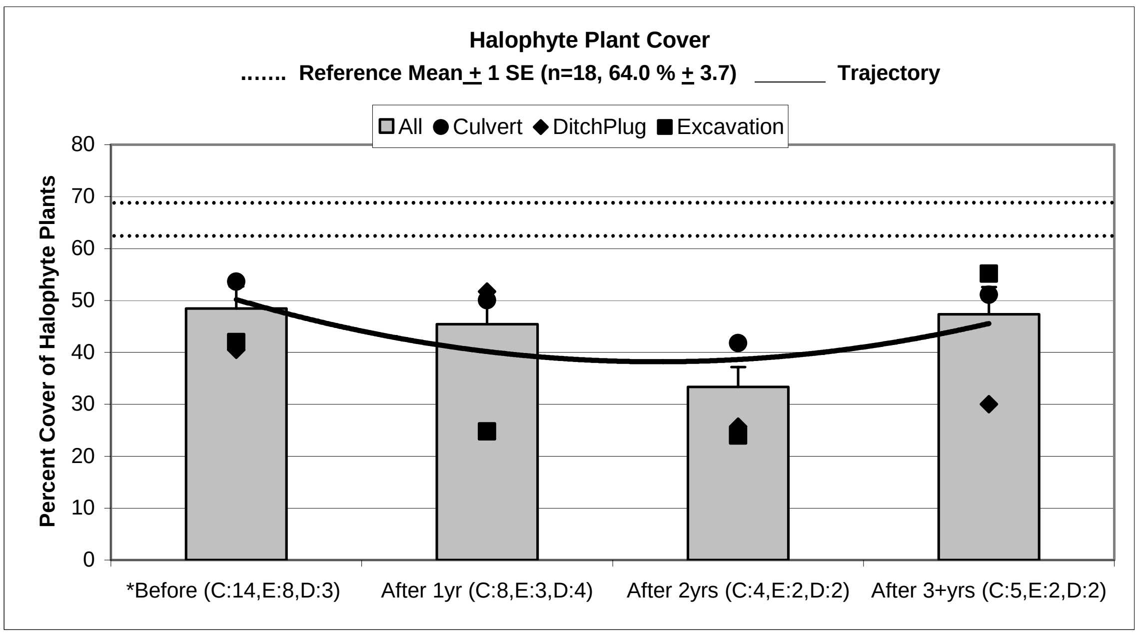
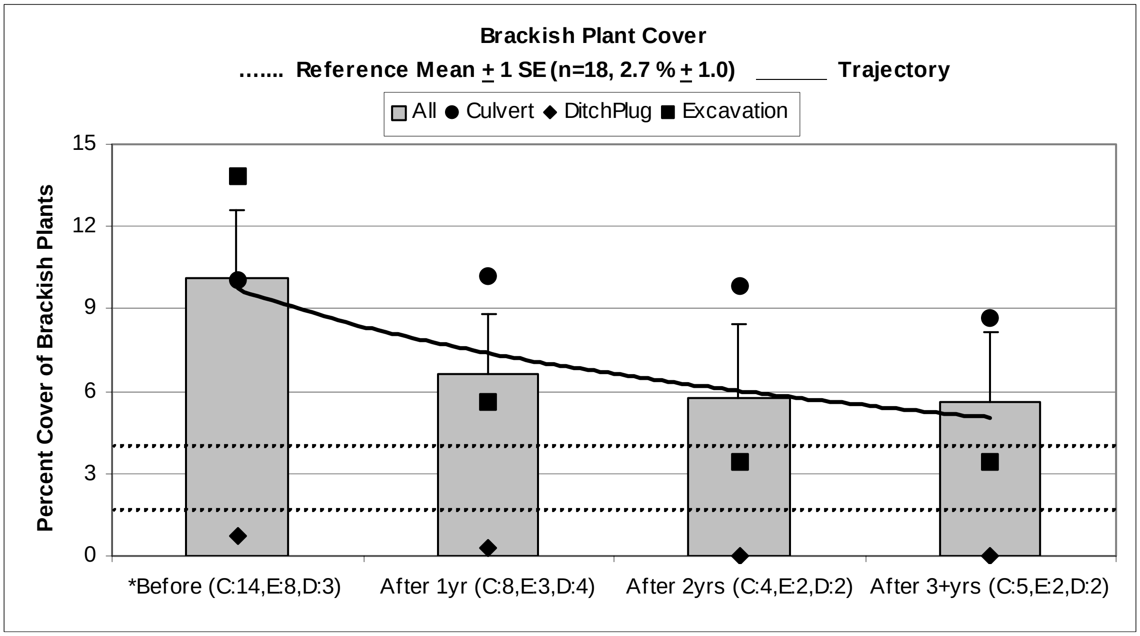


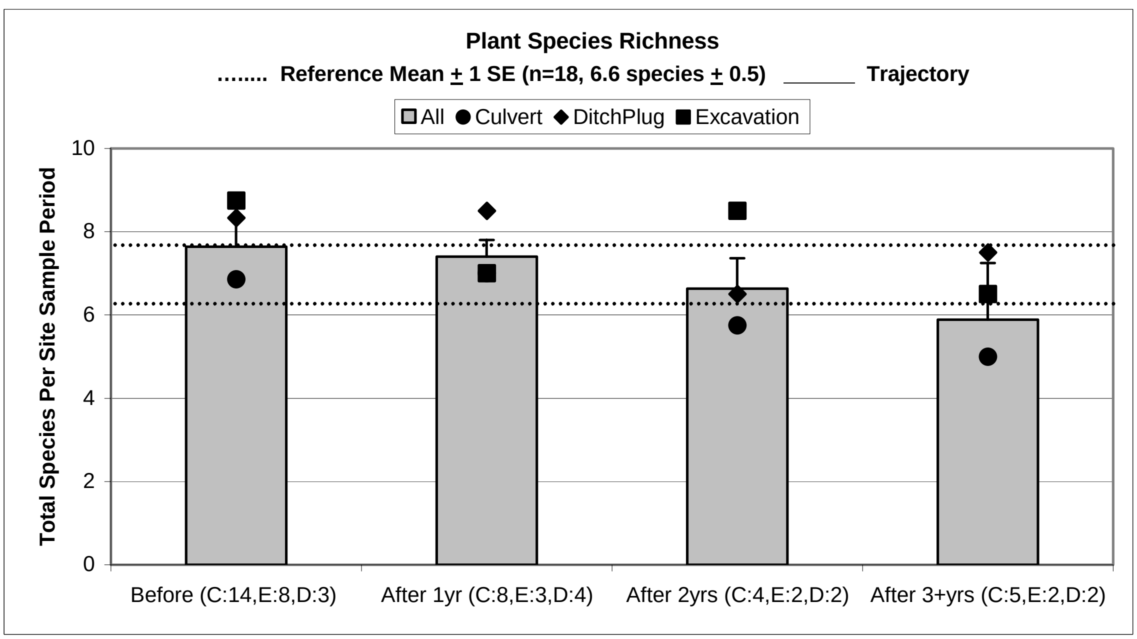
Figure 3. Hydrology monitoring measures as a percent of unrestricted maximum tidal height (mean + 1 SE) for reference and impacted (before) marshes, and response to restoration (after). Reference mean shown as dashed line. Means also shown by project type (C:culvert, E:excavation), with number of sites in parentheses. *Before and reference means are different; **Before and after means are different (Tukey Kramer HSD, $\alpha = 0.10$).



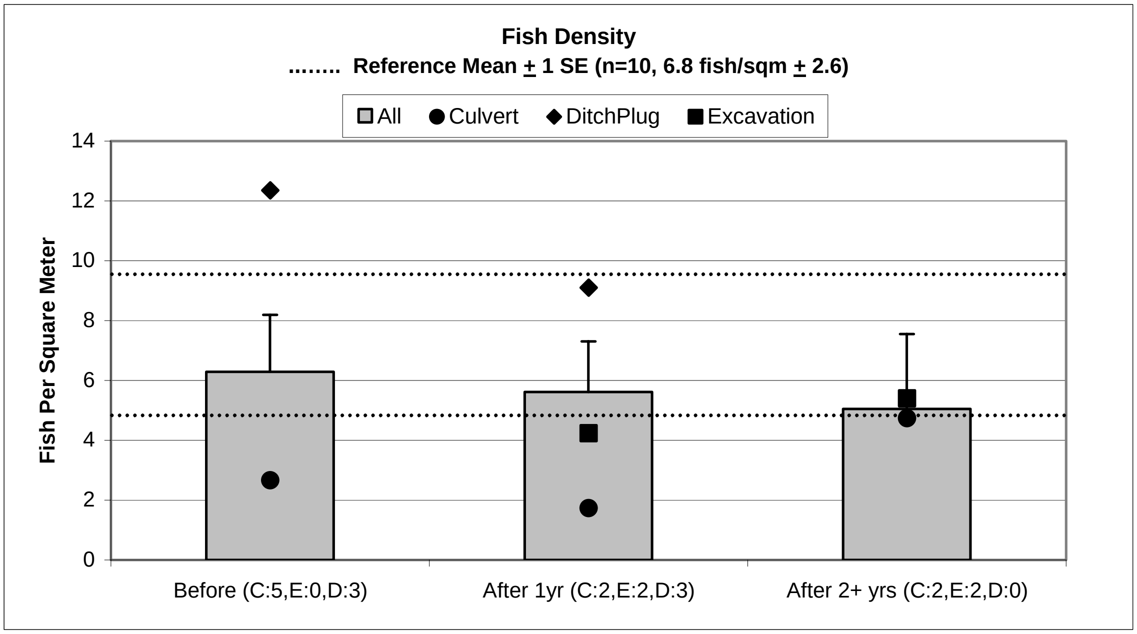
Figures 4a-c. Vegetation monitoring measures of a) halophyte cover, b) brackish species cover, and c) plant species richness, with mean values (+ 1 SE) for reference, impacted (before), and restored (after) sites. Reference values (mean ± 1 SE) shown as dashed lines. Means also shown by project type (C:culvert, E:excavation, and D:ditch-plug), with number of sites in parentheses. Trend lines (4a-b) show expected trajectory of plant cover changes at restoration sites. *Before and reference means are different (Tukey Kramer HSD, $\alpha = 0.10$).

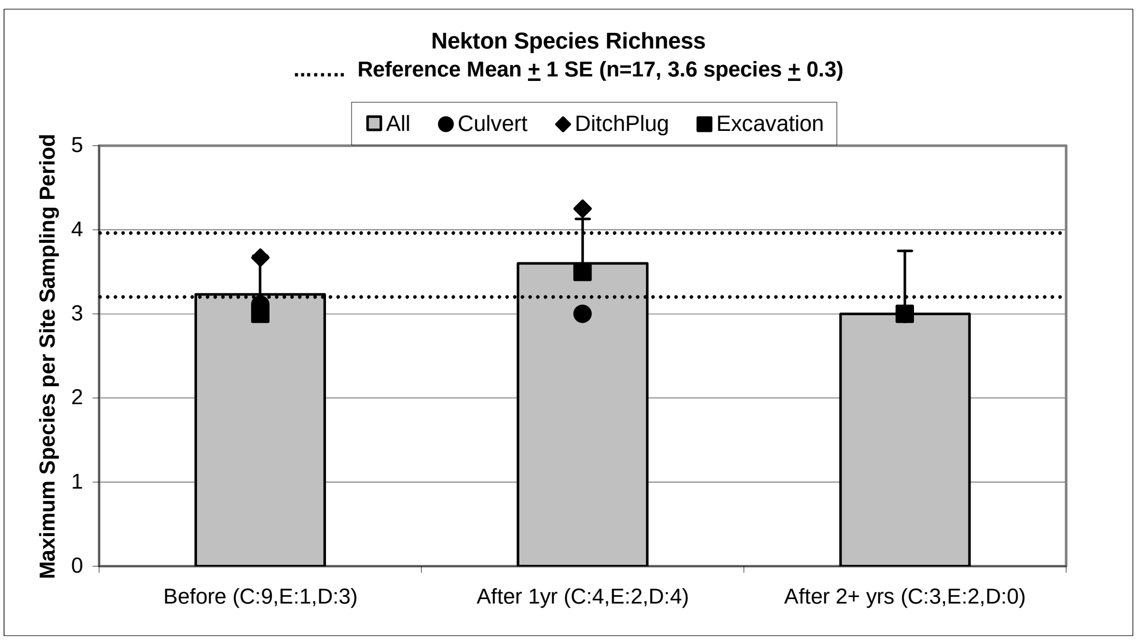



Brackish Plant Cover
....... Reference Mean + 1 SE (n=18, 2.7 % + 1.0) ______ Trajectory
All Culvert DitchPlug Excavation
Percent Cover of Brackish Plants
15
12
9
6
3
0
*Before (C:14,E:8,D:3)
After 1yr (C:8,E:3,D:4)
After 2yrs (C:4,E:2,D:2)
After 3+yrs (C:5,E:2,D:2)


Plant Species Richness
........ Reference Mean + 1 SE (n=18, 6.6 species + 0.5) ______ Trajectory
All Culvert DitchPlug Excavation
Total Species Per Site Sample Period
10
8
6
4
2
0
Before (C:14,E:8,D:3)
After 1yr (C:8,E:3,D:4)
After 2yrs (C:4,E:2,D:2)
After 3+yrs (C:5,E:2,D:2)

Figures 5a-b. Nekton monitoring measures of a) fish density, and b) species richness, with mean values (+ 1 SE) for reference, impacted (before), and restored (after) sites. Reference values (mean ± 1 SE) shown as dashed lines. Means also shown by project type (C:culvert, E:excavation, and D:ditch-plug), with number of sites in parentheses.



Figures 6a-b. Avian monitoring measures of a) bird density and b) species richness, with mean values (+ 1 SE) for reference, impacted (before), and restored (after) sites. Reference values (mean + 1 SE) shown as dashed lines. Means also shown by project type (C:culvert, E:excavation, and D:ditch-plug), with number of sites in parentheses.