NEERS SPRING 2005 MEETING ABSTRACTS

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VEGETATION AND NEKTON RESPONSE TO DITCH PLUGGING IN TWO MAINE SALT MARSHES: a 5 YEAR FOLLOW-UP

One of the most visually obvious alterations of East Coast salt marshes has been the excavation of ditches for agricultural use and mosquito control. In southern Maine, ditches vary from less than 1 to more than 2 meters wide and up to three or four meters deep. There is evidence that ditching has drained surface water features (e.g. pools and pannes) and has lowered water tables. In an effort to ameliorate these conditions, the Rachel Carson National Wildlife Refuge instituted an experimental program to enhance surface water habitat through ditch plugging; the two sites reported here are the longest-running investigations on ditch plugging in the East. A Before-After-Control-Impact study design was used to evaluate changes in vegetation, nekton, bird use, groundwater levels and surface water areas. All parameters were surveyed in 1999 (Before), 2000 and 2004; limited sampling was done from 2001-2003. Significant vegetation changes (analysis of similarity) were detected in Before-After comparisons for each site, but not until the second (Granite Point, $p<0.0001$) and third seasons (Moody, $p=0.01$) following ditch plugging. In each case, impact areas had more water, less *Spartina patens*, *S. alterniflora*, and *Plantago maritima* (Moody only) following ditch plugging. Groundwater level and salinity data analysis in may illuminate the underlying influences on these changes. Nekton analysis indicates that there was no significant difference in nekton community composition at either site for Before-After analysis. Impact areas, however, did show a significant change from 2000-2002 (both sites) and 2000-2004 (Moody only) that was not recorded in control areas and may be associated with ditch plugging.

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NITROGEN LOADS TO ESTUARIES: USING LOADING MODELS TO ASSESS THE EFFECTIVENESS OF MANAGEMENT OPTIONS TO RESTORE ESTUARINE WATER QUALITY

Nitrogen loading to estuaries is a major concern for coastal planners. As urban development on coastal watersheds continues, estuaries are becoming more eutrophied, and cascading effects are being felt at every trophic level. Managers need to have a suite of effective management tools

that can be applied to coastal watersheds to minimize effects of eutrophication. We have applied a nitrogen loading model (NLM) and an estuarine loading model (ELM) to examine the effectiveness of a suite of potential options to manage nitrogen loads to Waquoit Bay in Cape Cod, Massachusetts. This estuarine system is a case history in which we can explore the relative potential effectiveness of a variety of options, including decreasing inputs from wastewater and fertilizer derived nitrogen, diverting nitrogenous run-off from impervious surfaces, altering zoning ordinances, and preserving forested tracts of land. Conclusions from these types of simulations can be used to set priorities for decision-makers charged with the management of Waquoit Bay. Clearly, the same procedures applied to another watershed/estuary system with different land covers and different estuarine features may differ. Evaluation studies as this need to be done for any particular site, since the watershed/estuary coupling, and the loads delivered to the receiving estuary could differ. The Waquoit Bay case provides an example of a protocol that leads to identification of the most promising management options.

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SUBMARINE HYDROGEOLOGY OF A GLACIATED COASTLINE: CAPE COD NATIONAL SEASHORE

The critical role of ground-water underflow and discharge in a variety of coastal ecosystems has become more widely appreciated within the last decade, but many questions remain. Coastal ground-water discharge may also play a role in coastal erosion. The submarine hydrogeology of Cape Cod National Seashore, including ocean coastline and two estuaries (Nauset Marsh and Pleasant Bay), was investigated to delineate the geometry of the freshwater-saltwater interface in the subsurface. A continuous resistivity profiling (CRP) system was used to detect variations in electrical resistivity caused by fresh (resistive) and salty (conductive) ground water beneath the seafloor. Resistivity data were integrated with subsurface geology interpreted from previous seismic-reflection surveys and onshore drilling studies. Preliminary analysis of the datasets shows: 1) offshore plumes of freshened ground water adjacent to bluffs and areas of greater onshore relief, and where clays deposited in glacial lakes are present beneath the seafloor and act as confining units, 2) discharge of ground water along the shoreline rather than beneath the entire bed of kettle depressions breached by estuaries, and 3) little or no significant shallow discharge of ground water beyond the immediate shoreline of barrier spits. There is also evidence of correlation between areas of submarine ground-water discharge and stretches of shoreline where erosional hotspots are present. This approach can be applied to other coastal and estuarine areas that were formed by glacial processes to characterize ground-water flow in the nearshore environment and to determine whether submarine hydrogeologic phenomena observed on Cape Cod are present elsewhere.

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A STUDY OF LONG-TERM ECOSYSTEM STATE CHANGE AS A RESULT OF PERTURBATION TO WINSEGANSETT MARSH, FAIRHAVEN, MA

Winsegansett East Marsh is a degraded salt marsh located on the eastern shore of Sconticut Neck, Fairhaven, MA, within the Buzzards Bay watershed The upper intertidal, suparatidal, and upland zones have been impaired by rapid encroachment of invasive common reed (*Phragmites australis*), and extensive hydrologic modification (mosquito ditching). Hydrology/water quality monitoring, vegetation mapping, and topographic surveys were conducted during 2003 and 2004 to support a suite of restoration alternatives. These alternatives range from no-action to a variety of means to incrementally remove areas of common reed, with the goal of protecting and enhancing tidal marsh habitat. However, a review of historical maps, aerial photographs and local lore has resulted in the conclusion that a vast area of the upper intertidal marsh previously consisted of a heavily wooded swamp (palustrine wetland). The transgression from this previous ecological state is believed to be a result of a massive perturbation caused by the Great Hurricane of 1938. This storm resulted in a significant storm surge (13 ft.) and extensive wind damage. The current effort is to further quantify the relative change in ecosystem type and function at Winsegansett East Marsh as a result of this system state change. Also, we review other likely areas within the region that may exhibit similar post-1938 succession patterns. This information may influence approaches to ecosystem characterization, and the feasibility of "restoration" in this coastal region of Buzzards Bay.

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REMEDIATION OF EUTROPHICATION BY OYSTERS, *CRASSOSTREA VIRGINICA*

We tested the capacity of oysters to remediate eutrophication by transplanting juvenile oysters into 5 Cape Cod estuaries receiving different N loads. From our empirical data, we estimated the amount of N in oyster tissues at harvest size and compared that number with estuary N in two different forms 1) N loaded to each estuary from land and 2) N in foods (phytoplankton) in each estuary during the time to reach harvest size. del^{13}C in oysters reflected phytoplankton regardless of del^{13}C values in bulk seston and sediment, confirming oysters primarily assimilated phytoplankton N. Oyster shell and soft tissue growth rates were 0.2-0.4 mm d^{-1} and 1.3-5.6 mg d^{-1}, respectively. Based on estuary-specific growth rates and a mean of 8.6% N in oyster tissues, we estimated oysters reach harvest size in 1.3-2.2 years and have 0.2-0.4 g N in their tissues at harvest. Estimated cumulative land-derived N loads to study estuaries during

oyster grow-out to harvest size ranged from $.2x10^4$-$1.4x10^4$ (kg N), and cumulative phytoplankton N ranged from $4.6x10^4$-$21.2x10^4$ (kg N). The number of oysters needed to assimilate all land-derived or phytoplankton N ranged from $1.5x10^7$-$6.7x10^8$. Most estuaries did not have sufficient bottom area to support the number of oysters required for total removal of N in either form. Although oysters alone do not appear to have the capacity for total N remediation, our data suggest they may be used in combination with other N removal measures as part of integrated eutrophication management plans.

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SUBTIDAL POPULATION DISTRIBUTION OF *HEMIGRAPSUS SANGUINEUS* IN CLINTON HARBOR, CONNECTICUT

Hemigrapsus sanguineus has been well documented as an intertidal crab along the Connecticut coastline. However, it's subtidal population distribution has been relatively unknown. In Clinton harbor, *Hemigrapsus sanguineus* has been found regularly in high abundance and in the full range of class sizes at varying depths. Larger more voracious males of this species have been found in traps at carapace widths of up to 45mm-50mm. at depths of 4-5meters year round. This work in progress will provide baseline data to show the population distribution of *Hemigrapsus sanguineus* at subtidal depths within Clinton harbor and lead to further investigation of prey/predator relationships at these depths.

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THE EIGHTMILE RIVER WATERSHED: PROTECTING OUTSTANDING WATER RESOURCE VALUES

The Eightmile River Watershed is a 62 mi^2 watershed that drains to the lower Connecticut River. The lower reaches of the Eightmile River are fresh tidal waters and the river is completely open to the passage of migratory fish because fish ladders have been installed at the two dams in the system. Portions of the watershed are primarily in three towns, Lyme, East Haddam and Salem. The watershed has very little development and in 1995 the three towns joined together and agreed to a compact to protect and preserve the watershed. Subsequently the Land Trusts in the three towns, in cooperation with The Nature Conservancy formed a Coalition to advocate for Wild and Scenic Status for the Eightmile River Watershed. In 2001, Congress passed a bill authorizing a study to determine if the Eightmile River Watershed was eligible and suitable for designation. Since then the study has determined that the Eightmile River Watershed has six outstanding resource values, two of which relate to water – water

quality and hydrology. The study is in its final phases with the preparation of a management plan containing actions that the Towns agree to take to protect the outstanding resource values of the Eightmile River Watershed. Additional management ideas for protecting the waters draining to the lower Connecticut River and the Long Island Sound Estuary will be welcomed.

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A TIDAL NODE AND TIDAL ASYMMETRY IN MAINE'S SHEEPSCOT RIVER ESTUARY, RESULTS OF A MODELING AND OBSERVATIONAL STUDY

The Sheepscot River estuary is a complex estuarine system that has served as a supply of cooling water for the Maine Yankee nuclear power plant in Wiscasset, Maine. As part of the plant's decommissioning, Maine Yankee funded a study of radionuclides in the sediment and biota of the Sheepscot River estuary. The work described here, carried out as part of this study, focused on the dynamics of the estuarine system and on the manner in which these dynamics affected the transport of radionuclides introduced to the system. Of particular importance was the indication of a tidal node, corresponding to a minimum of tidal energy, roughly 2 km south of the power plant. It is the product of merging tidal waves that circuit the estuary's largest island. Although such a feature has not been identified in previous estuarine studies, its effect on material transport appears to be significant. Simulated particle tracks indicated that the node acted as something of a barrier to the southward movement of material released from Maine Yankee facility. Another dynamical feature revealed by our study was a tidal asymmetry within the cove that received cooling water and discharged radionuclides during the early 1970s. The asymmetry is characterized by a flood tide flow that is shorter and stronger than the ebb tide flow. Such a flow pattern favors sediment accumulation. Our analysis of core samples confirmed that the cove accumulated sediment at a rate of close to 10 cm/yr. Our study also included modeling of radionuclide uptake by bottom sediments. This revealed easily detectable remnants of historical discharges of Cs-137 distributed over a broad area in a pattern that compared closely with measurements of sediment-bound Cs-137.

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NUTRIENT LOADS AND ELEMENT RATIOS FROM SUBURBAN LAND INPUT OF NUTRIENTS CONTRIBUTED BY GROUND-WATER DISCHARGE TO COASTAL EMBAYMENTS, NORTHEASTERN USA

Saltwater embayments bounded by barrier beaches are common coastal features of southern Rhode Island; Cape Cod, Martha's Vineyard, and Nantucket Island in Massachusetts; and Long Island, New York. These embayments are set in hydraulically transmissive glacial outwash sediments on islands, peninsulas, or the seaward sides of glacial moraines. Typically the primary source of freshwater to these coastal waters is from ground-water discharge. The embayments are threatened by increased nutrient loads to the land in the areas that contribute ground-water recharge to them, as evidenced by decreased seagrass and increased macroalgal growth. A transient reactive-solute-transport analysis of the ground-water discharge to Nauset Bay, Cape Cod indicates N ground-water loads have increased 40 fold from background, whereas P and Si loads are controlled by reaction with the sediments and are near background. N loads to Nauset Bay will double in the next 100 years from N already disposed to the subsurface but not yet transported along deep aquifer flow paths to the coast. Ratios of the elements in loading indicate plant growth will not be N limited in the coming decades.

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SUBMARINE GROUNDWATER DISCHARGE TO SALT POND (CCNS) ESTIMATED FROM CONTINUOUS 222Rn AND SALINITY MEASUREMENTS AND A BOX MODEL

Submarine groundwater discharge (SGD) is the dominant means of freshwater delivery to many coastal embayments on Cape Cod. This discharge is the focus of considerable research, in part because the common practice of domestic wastewater treatment via septic systems has led to elevated levels of nutrients in groundwater. However, SGD is frequently diffuse, rendering it difficult to quantify. SGD was therefore estimated by a variety of means in Salt Pond, a weakly stratified small estuary at the northern (inland) end of Nauset Marsh (CCNS). One approach relied on continuous measurements of radon, which is an excellent tracer of SGD because it is: 1) strongly enriched in groundwater relative to surface water; 2) non-reactive; 3) continuously supplied by long-lived parent isotopes; and 4) it integrates over a wide area. Continuous measurements of radon, salinity (S) and water depth were carried out for four days in June, 2004, in a narrow channel that connects Salt Pond to Nauset marsh. The radon-based SGD estimate was derived using a mass balance approach, corrected for inputs from Nauset Marsh and losses due to gas exchange and decay. SGD quantified using radon and S yielded a pond-integrated estimate of roughly 3 cm/d, a figure that is only slightly lower than a multi-year average flow estimate from a hydrologic model. SGD estimates using seepage meters deployed in shallow waters were more than a factor of two higher than the radon and salinity-based estimates, which may indicate that discharge occurred only in the shallow regions of the pond. The estimated nutrient flux to Salt Pond from groundwater is similar to values estimated for other nearby anthropogenically-impacted coastal waters.

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LAND/OCEAN INTERFACE; A VISION FOR NANTUCKET SHELF

The ocean off the coast of Massachusetts has been the focal point for a growing number of activities and proposals in recent years including offshore aquaculture operations, numerous fisheries, cable and pipeline crossings, sand and gravel mining, and most recently, offshore energy facilities for wind power and LNG terminals. In response these competing and often conflicting uses of ocean space, two national commissions and the Massachusetts Ocean Task Force have recently called for the development of comprehensive ocean management plans. Similar to regional planning initiative on land, these ocean management plans would identify the most appropriate mix of uses for particular ocean ecosystems based on careful assessments of the benefits and impacts of current and proposed activities in those areas or affecting those systems. The Provincetown Center of Coastal Studies (PCCS), with research assistant provided by the Horsley Witten Group, has produced a report that inventories the natural resources and existing and future uses of an area referred to as Nantucket Shelf and suggests that it is a prime candidate for the first such comprehensive ocean management plan off the coast of Massachusetts. This presentation will describe the Nantucket Shelf ecosystem and its physical, social and economic ties to landside activities as well as a potential vision about how it can best be managed to ensure its well being into the future.

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RELATIONSHIPS BETWEEN NITROGEN AND CHLOROPHYLL CONCENTRATIONS IN ESTUARIES AND BAYS

Research in Long Island Sound has revealed seasonal and interannual variations in relationships between chlorophyll *a* and total nitrogen (TN) concentrations and has provided insights into their causes. Data from Boston Harbor/Massachusetts Bay and the Rappahannock River have shown relationships between TN and chlorophyll *a* that are similar to those for Long Island Sound. Additional data from other estuaries and bays are now being analyzed to determine the generality of the response of chlorophyll *a* to nitrogen, including the degree of interannual and system-to-system variability. We will discuss these relationships and factors that may influence

observed differences.

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INTEGRATING SCIENCE AND EDUCATION AT THE PLUM ISLAND ECOSYSTEM LONG TERM ECOLOGICAL RESEARCH (PIE-LTER) SITE

Since 1996, Mass Audubon has conducted a grade 5-12 integrated science and education program with schools in the Plum Island Sound ecosystem and beyond. Under the guidance of Mass Audubon, students monitor transects to analyze vegetation changes, and measure pore-water salinities in relationship to the vegetation. Students monitor the spread of invasive species including the common reed (*Phragmites australis*) and purple loosestrife (*Lythrum salicaria*) and study fish communities. Student's research has paralleled that of LTER and collaborating scientists. Evaluation of the project by Lesley University revealed: Through this project, students and teachers developed a greater connection to the environment and engaged in authentic science. Students developed pride in their ability to do fieldwork, sparking their interest and motivation to learn. Teachers gained new strategies for teaching outdoors and feel well supported. Scientists and conservationists gained better understanding of local ecosystems with student data. Student data is helping to inform salt marsh restoration decisions and are helping to evaluate restoration success as classes monitor before and after restoration. This program is valuable to students, teachers, and scientific and conservation communities. In the future we intend to forge greater links between PIE-LTER science and school curriculum and to strengthen our involvement of urban schools.

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VEGETATION AND *PHRAGMITES AUSTRALIS* CONTROL IN CONNECTICUT RIVER TIDELANDS: ELEVATION, SALINITY AND PLANT COMMUNITIES ALONG A SALINITY GRADIENT.

Phragmites australis (Pa) control on Lower Connecticut River tidelands began in 1995 at the mouth of the Lieutenant River, Old Lyme, CT, with herbicide followed by mowing. Starting in 2001 treatments were expanded to include hydrologic manipulations (digging ponds, filling, plugging and excavating ditches) over much of the Upper and Great Island marshes. This study focuses on vegetation patterns and plant species distribution at three control areas and two unmanipulated reference sites along a ca. 4 km reach of polyhaline to oligohaline marshes. Objectives included 1) identifying factors that may drive or influence plant species distribution and community structure, and 2) evaluating Pa control. Species composition and abiotic factors

(elevation, salinity, peat Eh) were sampled along 18 50m transects, 6 treated (ponds & ditch plugs - PP) 6 untreated (herbicide-mow only - MH) and 6 unmanipulated reference. Species diversity was negatively correlated with salinity. Consistent with literature, elevation was related to species distribution in polyhaline areas. At the low salinities, elevation also appears to influence distribution of some species. Mean elevation at the mesohaline site was significantly greater than either high or low salinity areas; here, there was no apparent relationship between elevation and species occurrence. Water table fluctuations were less and Eh was lower in PP than HM only areas, but in most cases this did not relate to vegetation. In manipulated areas, Pa tended to survive at higher elevations. There was no apparent difference in Pa frequency and cover between PP and HM sites. At the oligohaline area, where pre-treatment data exists, all treatments lowered Pa frequency and cover.

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DECREASED CONNECTIVITY IN SALT MARSH CORRIDORS: THE IMPACTS OF ROAD CULVERTS ON ESTUARINE NEKTON COMMUNITIES AND MOVEMENT

Decades of coastal development and impacts to salt marshes from transportation corridors have made tidally-restricted marshes common in New England. In recent years, salt marsh restoration projects have focused upon restoring hydrology through culvert enlargement to return functional values. In order to examine if hydrologically restored salt marshes support nekton communities and their functions, fyke nets were set upstream of tidally restrictive and restored culverts and in paired reference creeks to evaluate upstream nekton assemblages. All marshes supported similar densities of fish (abundance per marsh area flooded); however, densities of the shrimp, *Crangon septemspinosa*, were significantly lower upstream of culverts. A mark-recapture study was conducted to evaluate culvert effects on movement of *Fundulus heteroclitus* in salt marshes. A total of 8,692 fish were marked with an average recapture rate of 15.3%. Recapture data indicated that small culvert size and increased water velocity significantly decreased fish passage rates. Culverts that accelerated flow beyond 0.8m/s decreased *F. heteroclitus* passage rates by 50% to 100%. Increased water velocity through culverts may decrease the rate at which nekton move between upstream and downstream areas resulting in decreased connectivity and segregated nekton populations. When promoting projects to restore tidal hydrology, managers must ensure that new culverts can accommodate the tide without appreciably increasing water velocity to support fish movement and export of marsh derived production.

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IMPLEMENTING COASTAL WATER QUALITY PROTECTION ON CAPE COD: PAST, PRESENT, AND FUTURE

Sustainable coastal water quality is a goal that most can support. Challenges arise when this goal is translated into action. With over 80% of its 400 square mile peninsula contained within estuary watersheds, Cape Cod has struggled with these challenges for many decades. Over that time, local and the county governments have developed regulations and management systems, each in their own way providing small steps toward uniform assessment and estuary-specific management. More recently, the state government has stepped forward with funding for the Massachusetts Estuaries Project. This project provides individual estuary assessments that include watershed delineation, land use and nitrogen loading assessment, benthic habitat characterization, measurement and modeling of tidal flushing, water quality modeling based on citizen-collected data, and development of nitrogen thresholds. The approval of the MEP assessment techniques by the state and federal governments has provided a baseline for the information necessary to move forward in regulatory settings across multiple levels of government. For the state's purposes, the Department of Environmental Protection is using the MEP technical reports as the basis for developing nitrogen Total Maximum Daily Loads under the provisions of the Clean Water Act. Beyond addressing DEP's reporting requirements to the federal Environmental Protection Agency, the regulatory implications of TMDL limits are somewhat less clear. Local regulations for on-site septic systems (i.e., Title 5) and sewer connections, county regulations through the Cape Cod Commission, and state regulations for wastewater treatment plants and evolving discussions about nutrient trading will all need to be resolved into a comprehensive and complementary system addressing the TMDL limits. In addition, since all of the MEP-related TMDLs developed to this point require significantly improved treatment of wastewater, questions also arise about wastewater management costs, funding, and institutional mechanisms. Further issues arise regarding the relationships between growth, additional wastewater infrastructure, and the potential water quality impacts. All of these issues will require public support and changes in the way development and water quality management have occurred on Cape Cod; the challenges are slowly changing and some issues have been better resolved, but the need for action to protect Cape Cod's estuaries remains.

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SEDIMENT RESPIRATION AND NITROGEN CYCLING ALONG A EUTROPHIC GRADIENT IN A SHALLOW, COASTAL ESTUARY

New England coastal areas have experienced rapid land development over the past 100 years. One result of residential and commercial land cover is an increase in non-point source nutrient pollution. In this project we studied sediment respiration and nitrogen cycling in West Falmouth Harbor, a shallow, coastal estuary on Cape Cod. We took sediment cores from sites both with and without eelgrass along a strong eutrophication gradient. We measured in-situ core flux rates

of respiration, ammonification, nitrification and denitrification. After the flux measurements we added allylthiourea, a nitrification block to estimate the rate of nitrification. We also determined nitrification and denitrification potentials. We found that the more eutrophic sites had higher respiration and ammonification. In general, nitrification potentials were low in respect to respiration however, denitrification potentials were high. Our data shows that eelgrass affects aspects of the nitrogen cycle however the affect may change during different seasons. Although some of our data was not conclusive we speculate that increased N loading will increase the amount of ammonium that will be nitrified and then denitrified in coupled microbial processes.

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JAMAICA BAY RIBBED MUSSEL POPULATIONS – TOO MUCH OF A GOOD THING?

Jamaica Bay is a highly eutrophic urban estuary in which high nutrient loading levels and hydrodynamic factors promote high densities of ribbed mussels (), primarily at the lower marsh edge. Mussel density and biomass in fringing marshes sampled in 2004 exceed levels from 10 years ago by a factor of 5X; and mussel aggregations appear to be expanding further into the marsh interior. Although recruitment rates of 0-class mussel remain high and appear unchanged, shell growth rates and individual biomass are lower than in the past, possibly due to crowding-induced reduction in available food. Continuous bank erosion over at least 14 years may have shifted the lower marsh edge to a higher level relative to MLW, which could also reduce growth rates and individual biomass. Evidence for both processes are presented. Observations suggest that dense mussel aggregations armor the marsh edge and elevate it through biodeposition and sediment trapping, thus temporarily protecting the marsh edge from rising sea level. However, when the armored edge is undercut, slumping of the mussel turf occurs, thus exposing the unprotected peat beneath to rapid erosion.

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USING HISTORICAL RECORDS TO RECONSTRUCT A SPECIES PAST, A REVIEW OF RAINBOW SMELT IN THE NORTHEAST UNITED STATES

Critical to effective management of any species is a thorough understanding of its environmental history, particularly how populations have responded to environmental change over time and what protective actions have been attempted. We are constructing an environmental history of rainbow smelt (*Osmerus mordax*) in Connecticut and surrounding regions, including information on distribution, relative abundance, changes to critical habitat, and early conservation efforts. Rainbow smelt have recently been listed as a NOAA Species of Concern, with steady declines in regional fisheries during the last few decades cited as the

primary listing criteria, but little to no information has been reviewed on the historical aspects of this fishery. Our review of the available records indicates a regional population decline in rainbow smelt was identified during the latter part of the 19th century and the early part if 20th century. Regional records document an active commercial fishery, including state funded stock enhancement operations and implementation of protective legislation, in the early 20th century; however, interest in these programs seems to have waned as a result of continued stock declines. Production of an environmental history represents an important component when developing a regional management plan, as it allows managers to make informed decisions by helping create a comprehensive picture of a species past. Comparing the historical picture being created to our present understanding of the species biology and ecology in the Northeast United States will help identify potential reasons and consequences for the dramatic changes to the population over the last several centuries.

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EFFECTS OF EELGRASS (*ZOSTERA MARINA* L.) TRANSPLANT PATCH SIZE ON FISH ASSEMBLAGES

We used the Transplanting Eelgrass Remotely with Frame Systems (TERFS^{TM}) technique to investigate the effects of transplant patch size on fish abundance and species composition. In 2000, as part of a large-scale restoration effort, two sites in New Bedford, Massachusetts, USA, were transplanted with small (single TERFS, 0.25 m^2), medium (four TERFS, 1.42 m^2) and large (nine TERFS, 3.55 m^2) square eelgrass patches. We monitored change in eelgrass patch area, shoot density, fish abundance and fish species composition over 27 months post-transplanting. Minnow traps were used for quantitative sampling in and out of eelgrass transplant areas and caught 717 fish of 12 species. Fish abundance and species composition were significantly higher in transplanted eelgrass compared to unvegetated areas and varied seasonally. Seagrass density and patch area had no effect on fish abundance or species composition; fish abundance was as great in the small patches as in the medium and larger clusters of TERFS. Our results support previous evidence that fish prefer seagrass over unvegetated areas due to foraging opportunities and protection from predators. Additionally, we show that small areas of eelgrass attract equal numbers of fish. Since we recently documented that individual TERFS maximize transplant efficiency and areal expansion, the present study confirms that planting single TERFS is optimal for eelgrass restoration.

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POPULATION DYNAMICS OF THE ATLANTIC HORSESHOE CRAB, *LIMULUS*

POLYPHEMUS, IN CAPE COD ESTUARIES

The Atlantic horseshoe crab, *Limulus polyphemus* is harvested by the biomedical industry for *Limulus* Amoebocyte Lysate (LAL) a blood compund used to detect endotoxins, for scientific research on vision, and bait for the eel and conch fisheries. The population status of *Limulus* along the east coast of the United States is unclear but suggestions have been made that they are in decline. We have used stage-structured matrix modeling to improve our understanding of *Limulus* population dynamics in three Cape Cod estuaries (Stage Harbor, Pleasant Bay, and Barnstable Harbor) with differing harvest pressures. The results suggest that a low to moderate level of harvest is sustainable, particularly if timing and size-specificity of the harvest are taken into consideration. The model also suggests that efforts should be made to avoid harvesting crabs prior to sexual maturity, as older juveniles are more sensitive than other stages to changes in survival rate. The information the model provides will hopefully assist local and regional fisheries managers in establishing appropriate regulations for the horseshoe crab fishery.

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DEVELOPING AN INDEX OF BENTHIC CONDITION FOR THE COASTAL GULF OF MAINE

The USEPA's National Coastal Assessment has sampled benthic assemblages each summer since 2000 in estuaries and coastal areas of the U.S. Gulf of Maine. A multimetric index was developed that will be used as an indicator of benthic condition. During the first two years, states (ME, NH, MA) sampled benthic assemblages at 182 stations with a 0.01-m^2 Young-modified Van Veen grab and sieved the samples through a 0.5-mm mesh. Stepwise and canonical discriminant analyses were used with several candidate measures of diversity and community structure, such as Shannon-Wiener H', taxonomic distinctness, and relative proportions of pollution-indicative and pollution-sensitive taxa. The aim was to use the benthic community metrics to discriminate sites with low and high benthic environmental quality (BEQ; based on the concentrations of metal and organic contaminants in the sediments, total organic carbon, sediment toxicity, and dissolved oxygen level of the bottom water). The benthic metrics were first normalized for habitat effects; e.g., the quadratic 90th percent quantile regression used to correct for salinity differences, which models a dip in species richness in mesohaline waters. We developed seven candidate benthic indices that correctly classified a minimum of 80% of the stations. Independent datasets from Boston Harbor-Massachusetts Bay and Casco Bay were then used to help select the best index from amongst the candidates. The Gulf of Maine coastal benthic index will provide environmental managers a way to make both spatial comparisons and year-to-year comparisons of benthic community condition.

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IMPACTS OF CADMIUM AND NICKEL ON DIATOM COMMUNITIES IN FOUNDRY COVE AND CONSTITUTION MARSH, HUDSON RIVER, NEW YORK

Foundry Cove and Constitution Marsh are located on the east side of the Hudson River, 85 km upriver from lower Manhattan. The marsh is a contiguous area of emergent marsh plants and mud flats. Between 1965 and 1971, cadmium and nickel were discharged into Foundry cove by Marathon Battery Company. An estimated 53 metric tons of cadmium and nickel were deposited in the cove which became a designated Superfund site in 1994. The dredging and restoration of the cove was completed in 1996. Have heavy metals affected diatom communities in Foundry Cove and adjoing Constitution Marsh? Surface sediments were collected in triplicte from 15 sampling sites on 18 occassions from September 1997 to October 1998. The sediments were digested of organic matter using a CEM MDS 2000 microwave digester and cadmium and nickel levels were determined using a Perkin Elmer ICP 3000XL. Approximately 150,000 diatoms were identified and enumerated. These data were analyzed using Bray-Curtis Similarity, MDS ordination and diversity indices. Results show that the diversity of benthic diatoms is not affected by the metals. However, the areas of the marsh with higher cadmium-nickel concentrations had similar communities indicating that the three dominant diatoms, *Navicula gregaria, Cyclotella meneghiniana, Cocconeis placentula var. lineata* may be more tolerant.

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PERFORMANCE OF DENITRIFYING SEPTIC SYSTEMS AT THE MASSACHUSETTS ALTERNATIVE SEPTIC SYSTEM TEST CENTER

The Massachusetts Alternative Septic System Test Center began operation in September 1999 for the purpose of testing advanced onsite septic systems purporting to remove nitrogen from wastewater. Six technologies, Amphidrome^{R}, MicroFAST^{R}, Waterloo Biofilter^{R}, EcoRUCK, and WasteFlow^{R} were installed and tested in triplicate. Testing was biweekly for two years, and results are reported. In addition, a standard septic tank leach trench system was similarly tested. Beginning in 2001, the Test Center initiated testing under a protocol jointly developed by EPA and the National Sanitation Foundation (NSF) and referred to as the Environmental Technology Verification. The Test Center conducted this 14 month protocol on five technologies including Bioclere^{R}, Amphidrome^{R}, Waterloo Biofilter^{R}, Septitech^{R}, and ReCip^{R}. Summary results of these tests are also reported. In addition, a number of technologies have entered less formal protocols to examine different aspects of their performance (for instance seasonal use) and these results are presented.

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MASSACHUSETTS ESTUARIES PROJECT: SCIENCE TO SUPPORT ESTUARINE MANAGEMENT

The Massachusetts Estuaries Project (MEP), through the SMAST-UMASSD is providing the scientific and technical support to the MA DEP for the development and implementation of policies on nitrogen sensitive embayments. The 6-year program is performing the linked watershed-embayment data collection and modeling required for the management and restoration of the 89 embayment systems comprising the coastline of southeastern Massachusetts. The overarching project goal is the protection/restoration of the habitat health of the region's estuarine systems through watershed-embayment nitrogen management planning. The technical assessment of individual estuaries potential to assimilate nutrients without impairment is the critical first step of a municipal planning process that culminates in watershed/nutrient management plans. The technical assessment includes both use of biological indicators and linked watershed and estuarine hydrodynamic and water quality models. The Project is bringing new technologies, approaches and regulatory guidance forward to reduce the present costs of on-going community efforts in estuarine restoration. Based upon the first 2 years of effort, it appears that most of the region's estuaries show at least some impairment of nutrient related health. However, it also appears that the amount of nitrogen management needed for embayment restoration is less than previously thought and that attenuation of nitrogen during transport is serving as a "nitrogen buffer" in many systems. Analysis completed by MEP indicates that combinations of both traditional (wastewater facilities) and non-traditional nitrogen management approaches (wetland restoration, dredging, etc.) can be used to reduce nitrogen loads to estuarine waters.

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MOUNT HOPE BAY SYMPHONY IN DM

Mt. Hope Bay is an estuary driven by the complex interaction of natural and manmade forces. The dynamics within the Bay are like an orchestra - multiple themes blend together into a symphony. Various themes include solar and tidal cycles, freshwater input and wind turbulence. This presentation will focus on spatial and temporal characteristics of the Bay, including: (a) Spatial homogeneities: What areas of the Bay show similar changes over time? What are the spatial correlations? Over what spatial extent(s)? (b) Spatial heterogeneities: Do different parts of the Bay behave differently? If so, how? (c) Time constants. In homogeneous regions, how stable are conditions? When changes occur, over what time scale(s) do they occur? These questions may be addressed by looking at: (a) sea-surface temperature from NASA's Landsat 5

and Landsat 7 Thematic Mapper (TM) satellite imagery of the Bay taken over , and (b) time-series data from NOAA's Physical Oceanographic Real-Tine System (PORTS). Quantitative techniques are used to isolate distinctive features of the Bay, including: (a) Spatial correlations are characterized and described through singular-value decomposition (SVD). The singular values, Dm, describes the relative importance of both major and minor features, while the singular vectors illustrate how major and minor temperature patterns interact through time. (b) Temporal correlations are examined through the fast Fourier transform (FFT), and the maximum entropy method (MEM), and illustrate how sea-surface temperatures change over different time scales, including annual, monthly, weekly, daily and hourly variations.

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NEKTON UTILIZATION OF NEW ENGLAND HIGH MARSHES, THE IMPORTANCE OF LOW ELEVATION MARSH PLATFORM

Physical characteristics of salt marshes, such as elevation and topography, can greatly influence nekton utilization of these areas. New England salt marsh habitats, with high tidal amplitude, generally have two distinct zones of marsh elevation. The first zone, located adjacent to open water, is lower in elevation and dominated by the flooding tolerant macrophyte *Spartina alterniflora*. The second zone is higher in elevation and dominated by other macrophytes species less tolerant to tidal flooding. Using flume nets, densities of dominant species of nekton were quantified using the area of the lower elevation zone. Nekton was collected from tidal tributaries of the Rowley River, MA (Plum Island Sound) during the summers of 2003 and 2004. Nekton sampling occurred on spring high tides, which flooded the entire marsh surface, and the area of low elevation salt marsh, distinguished by the presence of *S. alterniflora* and lower elevations, was measured. Fish densities were compared to determine if there was any relation to the amount of low marsh present.

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A REGIONAL ASSESSMENT OF SALTMARSH RESTORATION AND MONITORING IN THE GULF OF MAINE

Saltmarsh monitoring datasets from 36 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) and pooled for mean values for indicators before restoration, after

restoration, and at reference sites. Monitoring data were checked against 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 3+ years following restoration. Nekton and avian indicators were similar among reference, impacted, and restored areas. Results appeared limited by regional inconsistencies and relatively few multi-year datasets, leading to new efforts for increasing protocol adherence throughout the Gulf of Maine.

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NUTRIENT SOURCES IN THE GULF OF MAINE MACROTIDAL ESTUARIES WITH SPECIAL CONSIDERATION OF DISTRIBUTIONS IN COBSCOOK BAY, MAINE

The nutrient distribution in the highly productive, macrotidal Cobscook Bay, located in the northern Gulf of Maine, was investigated through a series of spring-neap cruises during the spring, summer and fall of 1995. Sampling design included three, five station transects at major constrictions in the Bay and 21 peripheral stations in the principal coves and sub-embayments. Results indicate that Cobscook Bay is nutrient rich throughout the year and is potentially eutrophic. Plots of salinity against nitrate show that this is a totally natural circumstance brought about by an abundant supply of nutrients, most importantly nitrate, from the adjacent Gulf of Maine. Predictive nutrient algorithms fitted with a hydrodynamic model emphasize the high nitrate water entering the Bay from the seaward end and diminishing in concentration with distance from the mouth. The plant biomass produced is heavily grazed resulting in high ammonium concentrations from excretion and regeneration. The high ammonium concentrations and its incomplete re-utilization by the phytoplankton strongly suggest that plant biomass is controlled by grazing. In other words, despite a high natural nutrient loading, natural grazing processes serve to limit the accumulation of plant material and potential eutrophication.

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ECOSYSTEM MODELING IN COBSCOOK BAY, MAINE: A BOREAL, MACROTIDAL ESTUARY

In the mid-1990s an interdisciplinary, multi-institutional team of scientists was assembled to address basic issues concerning biological productivity and the unique co-occurrence of many unusual ecological features in Cobscook Bay, Maine. Cobscook Bay is a geologically complex macrotidal system located on the international border at the mouth of the Bay of Fundy. The Bay area is biogeographically complex due to present temperature regimes as well as historical, climatological and physiographic changes since the last glaciation. Early investigators recognized the resulting zoological richness and a significant portion of the collection and taxonomic description of North American marine fauna was centered in the northern Gulf of Maine. The strategy adopted by the scientific team was to synthesize the known information on Cobscook Bay, focus new field research on information needs related to basic forcing functions and biological primary productivity, and to organize the information in an energy systems model, to evaluate the flows of energy and materials through the ecosystem, and relate them to the inflows of physical energy using the accounting quantity, emergy. As a consequence of this process, diverse new and existing data have been combined, and analyzed, leading to new ways of thinking about the functioning of Cobscook Bay and macrotidal estuaries. The principal finding is that an extraordinary convergence of natural energies creates ideal conditions for supporting the development of ecological organization found in few, if any, other estuarine systems.

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MULTITASKING BIVALVES -- THE DELICIOUS FILTER FEEDERS

The watershed on Cape Cod is considered sole source -- precipitation. The evidence of impacts of rapid development onshore are to be found in the nearshore esturaine waters much like the scenario elsewhere. Shellfish populations serving as sentinels in local waters are in decline due to the usual factors of eutrophic conditions, low recruitment and increased harvest pressure. Oysters *(Crassostrea virginica)* grown in large quantites on bottom establish a microhabitat that provides for several avenues of nitrate reduction simultaneously. While managing nitrogen loading requires significant planning efforts, Massachusetts communities have the opportunity and are increasingly accepting the responsibility for managing shellfish populations. Cape Cod

towns are approaching the problem as a regional issue and are greatly assisted by Barnstable County through its Cooperative Extension Service and Woods Hole Sea Grant. A cooperative effort between these agencies and the town of Eastham's Aquaculture Technology & Training Center provided a pilot program to produce significant numbers of shellfish seed for interested towns to deploy in an effort to remediate the cumulative negative impacts and attempt to stabilize the populations. With the success of this program other species are being investigated and the goal is to provide cost effective methods to a delicious solution.

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RECHARGE AREAS TO WELLS, PONDS, STREAMS, AND COASTAL WATER BODIES, CAPE COD, MASSACHUSETTS

Between 2001 and 2003, the U.S. Geological Survey (USGS) assisted the Massachusetts Estuary Project and its partners by delineating the physical recharge areas to the coastal water bodies on Cape Cod. These physical recharge-area delineations include (1) areas contributing recharge directly to coastal water bodies, (2) areas contributing recharge to ponds and streams upgradient of the coastal water bodies, (3) areas for which recharge is intercepted by pumped wells, and (4) estimates of subsurface travel times. Using previously developed numerical models of ground-water flow, as well as a particle-tracking tool, recharge areas to 234 coastal water bodies, 184 ponds, and 40 streams on Cape Cod were delineated. Recharge areas also were determined for pumped public-water supply wells currently (2003) in operation. Most ground water on Cape Cod—69 percent—discharges at the coast, 25 percent discharges to streams, and 6 percent is withdrawn at pumped wells. The percentages of water discharging at streams and the coast or withdrawn at pumped wells varies, depending upon the particular ground-water lens under consideration. About 25 percent of water passes through ponds before discharging. Areas at the water table where recharged water discharges to a pond, stream, or coastal water body within 10 years of recharge account for about 51 percent of the total recharge area on Cape Cod. Ground-water-flow patterns on Cape Cod are affected primarily by the geometry of the coast and the locations of ponds and streams. As a result, recharge areas to coastal water bodies consist of multiple components and have complex travel-time patterns.

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CAN TOP FISH PREDATORS LINK COMPONENTS OF ESTUARY FOOD WEBS

Can top fish predators impact estuary food webs? Trophic cascades were once thought to be common only in aquatic systems with discrete homogeneous habitats, vulnerable prey and simple grazing food webs. Because of strong physical gradients, dominance of detrital foodwebs and heterogeneous habitats, trophic cascades were thought not to operate in estuaries.

However, cascades have now been documented in a wide range of systems. Striped bass are abundant, large-bodied, physiologically-tolerant, top predators that undertake a seasonal, coast-wide feeding migration. The current, high abundance of these piscivores in estuaries facilitates this test of top down effects and thereby has the potential to extend existing knowledge of the circumstances under which species interactions affect the food web. Here, we review criteria by which evidence for top down effects should be evaluated in these systems and show data from both Massachusetts and Connecticut estuaries.

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EXPERIMENTAL NUTRIENT ENRICHMENT OF A NORTHERN MASSACHUSETTS SALT MARSH: VEGETATION MAPPING AND PLANT COMMUNITIES OF TREATMENT AND CONTROL CREEKSHEDS

Anthropogenic nutrient loading of estuaries is being experimentally mimicked in the tidal salt marshes of Plum Island Sound, MA, with the objective of understanding impacts of moderate N and P enrichment (70uM NO_3, and 5uM PO_4, ca. 10X and 5X ambient) on a number of ecosystem functions. Changes in vegetation patterns and in individual species distribution and dominance are predicted as one set of responses to eutrophication. To test this hypothesis, detailed baseline vegetation maps have been made using high resolution GPS for marshland bordering two creeks: experimental (nutrient enriched) and control (ambient creek water only). GPS points were collected as plant community borders were walked in the field. GPS points were then overlaid on 0.5 m resolution orthographic photos using GIS. Cover and area were calculated by species and major community type. A second baseline data set includes species frequency and cover along 50 X 1 m strip transects, six distributed along each creek. Comparisons between transect data and GPS maps suggest transects are reasonable samples for the entire creek. Transect data also suggests that, after one year of manipulation, plant community structure is very similar in the experimental and control creeks.

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A BIOSOCIAL APPROACH TO UNDERSTANDING AND RESOLVING ESTUARINE AND COASTAL-WATERSHED CONFLICTS

Ambiguous legislation, inconclusive science, jurisdictional disputes, and conflicting attitudes and values of stakeholders have contributed to the increasing frequency and intensity of environmental disputes in estuarine and coastal areas. Allocation and management decisions related to land use, water allocation, agriculture, suburban development, fishing, recreation, restoration, and dam removal are especially contentious. In many of these disputes, stakeholders

hold different meanings, attitudes, and values concerning contested resources, and, as a result, they advocate for competing policy preferences in the political process. These conflicts can best be addressed through integration of biological and social science perspectives. Especially intractable conflicts emerge when allocation decisions, made on the basis of legally required biological and economic criteria, involve underlying issues related to social, cultural, and symbolic considerations. Important steps in understanding watershed-related conflicts are to identify and understand biological relationships and impacts as well as to clarify differences in social meanings, attitudes, and values of stakeholders. In this presentation we propose an interdisciplinary approach that integrates the biological and social sciences in addressing estuarine and coastal conflicts.

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EFFECTS OF EUTROPHICATION ON CONCENTRATIONS AND SPECIATION OF COPPER, ZINC, AND LEAD IN WEST FALMOUTH HARBOR

Eutrophication may alter concentrations of potentially toxic heavy metals in estuary sediments by creating conditions favoring relatively stable species, such as low redox potential, and by reducing sediment-trapping submerged vegetation. We measured sediment concentrations of total and labile Cu, Pb, and Zn in West Falmouth Harbor, a Cape Cod estuary, using cores from vegetated and unvegetated sites in the eutrophied inner harbor and the relatively pristine outer harbor. We also analyzed C, S, P, Mn and Fe. The Inner Harbor was more reducing than the Outer, with higher concentrations of C, S, P, and metals. Depth profiles for the metals generally resembled those of sulfur. In the Outer Harbor, concentrations of most components were higher in the vegetated than in the unvegetated site. Concentrations of all components were similar between the vegetated and unvegetated Inner Harbor sites. Labile:total metal ratios showed no clear pattern with redox potential or vegetation, but reduced metal concentrations were higher in the Inner Harbor. Despite probable baseline differences between Inner and Outer Harbor sediments, eutrophication appears to increase heavy metal retention, perhaps via increased C inputs from algal blooms and slowed decomposition, increased sulfide formation, and sediment stabilization. Sediment trapping and C contribution by vegetation may explain increased retention of most components in the vegetated Outer Harbor site, but in the Inner Harbor its effect may be dwarfed by that of benthic algae. The possibility that eutrophication reversal may mobilize heavy metals accumulated in sediments merits investigation.

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TIDE: TROPHIC CASCADES AND INTERACTING CONTROL PROCESSES IN A DETRITUS-BASED AQUATIC ECOSYSTEM

Eutrophication and changes in species composition are currently two of the most influential stressors effecting estuarine ecosystems. Alterations of these factors may lead to the accretion or sinking of a marsh with respect to sea-level rise. The TIDE project investigates the long-term fate of coastal marshes by examining the interactive effects of nutrient enrichment and the removal of a top-level consumer in marshes of Plum island Sound. In 2000-2003, baseline data was collected on four branched tidal creek systems. In 2004, two branches of one creek were fertilized with moderate to high nutrient loads (70 um NO_3 and 5 um PO_4) and 80% of the mummichogs were removed from one branch. These branches were compared to a reference system that was not fertilized. In the first year, these manipulations may have increased creek bank *S. alterniflora* growth and marsh surface invertebrate communities. Algal biomass and species composition, bacterial productivity and mudflat invertebrates did not change. In 2005, a second set of creeks will be subjected to the same treatments. A ^{15}N addition is also planned to investigate the fate of the added nitrogen. These and other integrated field measurements will be used to develop an ecosystem model that will predict the cumulative effects of the stressors on marshes over decades. The information gathered by the TIDE project will aid in protecting existing healthy marshes, safeguarding fisheries and biodiversity, and restoring impacted marshes.

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STATUS OF TIDAL RESTORATION EFFORTS FOR 2500 ACRES OF RESTRICTED WETLANDS ON OUTER CAPE COD

Cape Cod National Seashore has been cooperating with the outer Cape towns of Wellfleet, Truro and Provincetown, the Massachusetts Wetland Restoration Program, the NOAA Restoration Center and many other agencies to restore tidal range, salinity and native estuarine

biota to several large, historically restricted salt-marsh estuaries. Partial tidal restoration has been underway since 1999 at 200-acre Hatches Harbor (Provincetown), and at 720-acre East Harbor (Truro), while the restoration of the Cape's largest, and probably best-studied diked estuary, 1100-acre Herring River (Wellfleet), is still in the planning stages. Typically, on-the-ground implementation has been slow because of the serious lag between scientific assessments and planning on the one hand, and community acceptance of what is perceived as a fundamental physical change. However, recent successes at Hatches and East Harbors, and sustained public education, have engendered local interest and support for expanding the program. A critical step for all of our projects has been the identification, through hydrodynamic modeling and inter-agency planning, of a replacement culvert configuration that allows incremental and controlled tidal restoration, and thereby accommodates social concerns and an adaptive management response.

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DEVELOPMENT OF A LONG-TERM MONITORING PROGRAM FOR BENTHIC MACROFAUNA AT THE CAPE COD NATIONAL SEASHORE

Design of a monitoring plan for benthic macrofauna at the National Seashore requires information on the distribution of physical habitats and faunal assemblages within the park, interactions between macrofauna and biotic and abiotic variables, and parameters necessary to determine sampling protocols for fauna. Sampling has been completed at a large number of “inventory” sites utilizing a minimal density of samples and at four “parameter” sites with a high density of samples. Restoration of tidal flow to a near-freshwater lagoon (Pilgrim Lake)was followed by estuarine benthos colonization after a lag of one year. Samples from the undiked Pamit River provided a basis for projecting changes to the diked Herring River after proposed restoration. A low diversity of species and dominance by opportunistic species was found in deep areas of three drowned kettle hole ponds. Data from parameter samples showed the vertical distribution of organisms in cores, the relative number of individuals retained on different sieves, and the distribution of organisms over small ranges of tidal elevation.

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MONITORING THE DEEP EDGES OF EELGRASS (*ZOSTERA MARINA* L.)MEADOWS AS AN INTEGRATED ASSESSMENT OF ESTUARINE WATER QUALITY

Assessing long term changes in water quality parameters (suspended sediments, chlorophyll, Secchi disk depth) can be difficult, given the high variability associated with these parameters over both short and long time periods. Many monitoring programs record only weekly or

monthly measurements, and these snapshot records often prove inadequate to describe water quality changes over the long term. In contrast, assessing a parameter in the estuary that integrates long-term environmental conditions may provide a better overall indicator of estuarine water quality. Eelgrass (*Zostera marina* L.) is a submerged flowering plant whose depth limit is predominantly controlled by the amount of light it receives. Eelgrass effectively integrates all water quality parameters that reduce the amount of light reaching the plants. The proposed research will test the potential for using monitored changes in the location of the deep edge of eelgrass meadows as an integrated assessment of estuarine water quality. The objectives of this proposal are to measure seasonal changes in the location of the deep edge of eelgrass meadows, and to test the sensitivity of the deep edge of eelgrass meadows to changing light conditions. Eelgrass is a critical component of estuarine ecosystems throughout temperate North America, and using this species as the basis for a water quality index could provide a useful indicator of ecosystem health.

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USING THE NEW ENGLAND SPARROW WATER-QUALITY MODEL TO EVALUATE NITROGEN FLUXES TO COASTAL WATERS

The U. S. Geological Survey (USGS), in cooperation with the U.S. Environmental Protection Agency (USEPA) and the New England Interstate Water Pollution Control Commission, developed a New England-wide water-quality model called SPARROW (Spatially Referenced Regressions on Watershed Attributes) to help establish total maximum daily loads, develop nutrient criteria, and assess riverine nutrient fluxes to coastal waters. SPARROW is a spatially detailed regression model that relates phosphorus and nitrogen loads at river monitoring stations to nutrient sources and watershed characteristics. These relations are then used to predict nutrient loads in unmonitored streams. Model results show that among New England drainages to coastal waters, the Connecticut River has the largest annual nitrogen flux, 16,200 metric tons. The Merrimack (9,600 metric tons), Kennebec (7,400), and Providence/Blackstone River (4,500) drainages follow in order of magnitude. The model also provides quantitative data on the contribution of different sources in the watershed to the predicted fluxes. For example, in the Connecticut River the model estimated that atmospheric deposition contributes 49 percent of the nitrogen flux, municipal wastewater contributes 23 percent, and developed and agricultural lands each contribute 14 percent.USEPA researchers found that predictions for nitrogen concentrations using SPARROW results agree with observed nitrogen concentrations in selected New England estuaries. The model also is being used in the development of nitrogen load allocations for the Upper Connecticut River Basin as part of Long Island Sound restoration

efforts. Currently USGS is preparing data CDs and a SPARROW web site so that all model input data and results will be readily accessible.

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DEVELOPMENT OF WATERSHED-BASED PLANS FOR MASSACHUSETTS

As part of a recently awarded contract with the Massachusetts Department of Environmental Protection (MADEP), Applied Technology & Management (ATM) and BETA Engineering have been tasked with the development of Watershed-Based Plans (WBPs) for each of Massachusetts' twenty-seven planning basins. The WBPs, which will provide the funding basis for all future nonpoint source (CWA section 319) projects in Massachusetts, will include subwatershed compilations of all existing water quality studies, total maximum daily load (TMDL) analyses, and various state and local watershed plans. As part of the WBP development, ATM will also identify where nonpoint source data gaps exist in each of the subwatersheds and, where necessary, will apply watershed loading computer models to establish estimates of nutrient loads. Each of the 27 planning basins will be partitioned by USGS 12-digit hydrologic cataloging units (HCUs), of which there are approximately 250 in Massachusetts. For each 12-digit HCU, the WBPs will identify (a) the nonpoint source categories contributing to pollutant loads, (b) estimates of the load reductions required, (c) the appropriate nonpoint source best management practices (BMPs) available to achieve those reductions, (d) estimates and sources of funding required, (e) education/public outreach approaches, (f) prioritized schedules for the implementation of BMPs, (g) interim milestones for assessment of BMP activities, (h) criteria for assessment of load reduction progress, and (i) monitoring plans. Data from the final WBPs will be publicly accessible via an internet-based GIS application that will allow the user to select a 12-digit watershed and retrieve the pertinent information.

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N CONTENT AND C/N RATIOS IN *SPARTINA ALTERNIFLORA* AND *SPARTINA PATENS* IN RESPONSE TO NITROGEN AND PHOSPHOROUS FERTILIZATION IN A NORTHERN MASSACHUSETTS SALT MARSH

Long-term effects of increasing anthropogenic nutrient input on estuarine systems are a growing concern. This problem is being studied in a multidisciplinary investigation on the Plum Island

Sound tidal marshes of Ipswich and Rowley, MA, through experimental eutrophication of tidal marsh creeks. NO_3 and PO_4 were added to flooding tidal water of Sweeney Creek (target concentrations 70 uM & 5uM, ca. 10X & 5X ambient); West Creek was the untreated control. A second pair of creeks will be added in 2005. Creeksheds are ca. 12 ha. CHN analysis was run on the shoots of tall (Sat) and stunted (Sas) *Spartina alterniflora* and *Spartina patens* (Sp) collected from all four creeks in June, July and August 2004. Roots and rhizomes from early September 2003 (before treatment) and 2004 were also sampled in Sweeney and West. Pooling all creeks, shoot N content of Sat was ca. 2x Sp; Sas was intermediate; N in roots/rhizomes was lower in Sas than Sat or Sp. Among creeks there were no N or C/N differences in Sat shoots in Jun, Jul & Aug. Sas from Sweeney had greater N and lower C/N in all three months, but differences were significant only in Aug. The pattern was similar for Sp, but significant differences only in June. N and C/N in Sat roots/rhizomes from Sweeney and West were similar in 2003, but Sweeney samples had significantly greater N and lower C/N in 2004; there were no significant differences between creeks for Sas in either year. Together, these results suggest increased plant uptake of N in the treated creek, but this proposition must be tested with additional years at Sweeney and West along with the new replicate creek pair to go on line in 2005.

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GLOBAL SEAGRASS MONITORING UPDATE

SeagrassNet, the global seagrass monitoring network, has now been operating for 4 years, starting in the Western Pacific and expanding to the Americas (USA, Brazil, Mexico, Belize) and elsewhere. The website (www.SeagrassNet.org) is up and running with quarterly data submitted electronically to the database and instructions for monitoring updated periodically. Versions of the monitoring manual with appropriate species references have been published for the Western Pacific and the Caribbean. Three workshops have been held (Philippines, Kosrae (FSM) and Indonesia), bringing together SeagrassNet team leaders from across a region to update their monitoring skills and to learn advances to the protocol. An international seagrass herbarium has been established at the Smithsonian Institution in Washington, D.C. Initial analysis of the data shows some interesting trends, including seasonal species shifts in tropical areas (Micronesia), loss of seagrass due to algal invasion (Brazil), seagrass die-back from elevated water temperatures (Papua New Guinea), and severe grazing impacts from herbivores (USA). The SeagrassNet program has demonstrably increased awareness of the seagrass habitat and its importance worldwide. Future plans include SeagrassNet as a monitoring program in National Estuarine Research Reserves and National Parks in the U.S. and further sites internationally.

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HABITAT MAPPING IN A RHODE ISLAND COASTAL LAGOON AS PART OF THE BAYMAP PROJECT

Narragansett Bay and the south-shore coastal lagoons in Rhode Island lack a comprehensive inventory of their geology, habitats, biological communities, and archeology. In an effort to address this need, the first year of the RI SeaGrant funded BayMap project focused on Ninigret Pond, a shallow coastal lagoon in Charlestown, Rhode Island. Eelgrass beds and their neighboring habitats were mapped using bathymetry and side scan sonar data. These areas were then ground-truthed using underwater video cameras and sediment profile images. It was found that eelgrass grows in the pond commonly in areas less than five feet deep. In areas greater than five feet deep, either heavy boat traffic (evident by propeller scars) or depth could be limiting eelgrass growth. In order to thoroughly characterize the habitats, it will be necessary to determine Benthic Habitat Quality from the sediment profile images, and to complete a biological survey of the various habitats to determine how each community functions. By achieving a greater understanding of habitat dynamics, researchers will be able to recognize and effectively monitor potential problems within the habitat.

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OBSERVATIONS ON THE INTERSPECIFIC INTERACTIONS OF *AMBLYRHYNCHUS CRISTATUS* IN LAS ENCANTADAS.

Las Encantadas or the Galapagos Islands hold a special place in the history of science. It was on these islands in 1835 that Charles Darwin first began formulating the ideas that would lead to his theory on the origin of species by means of natural selection. On an expedition in July, 2004 we visited 10 of the 21 islands that make up this archepeligo on the equator 650 miles off the coast of Ecuador. *Amblyrhynchus cristatus*, the marine iguana, was found on all the islands visited. All the iguanas were found within a short distancd from the shore. A majority of the iguanas were found lying on the rocks and sand warming their bodies. Iguanas were observed entering and leaving the sea water and feeding on chlorophyte algae both intertidally and subtidally. The iguanas ranged in size from 60 cm in length on Genovesa Island to over 100 cm in length on Isabella Island. Iguanas were seen in the presence of numerous other species. Only the Galapagos hawk was observed to attack the iguanas. Of humans, the iguanas had no fear.

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RESPONSES OF *PHRAGMITES AUSTRALIS* TO TIDAL RESTORATION AT CAPE

COD NATIONAL SEASHORE

In North America, restriction of tidal flow into coastal salt marshes has facilitated the establishment of the non-native, invasive strain of *Phragmites australis* (common reed). Attempts to restore these systems have met with varying degrees of success from the standpoint of reducing the abundance of this species. At Cape Cod National Seashore (Massachusetts), two large salt marsh restoration projects (Hatches and East Harbors) have hitherto resulted in significant shifts in the distribution of *Phragmites* rather than reductions in overall population size. In this regard, substantial mortality has been observed along the seaward edge of existing populations while expansion has occurred upslope, into areas where freshwater communities had previously existed. *Phragmites* appears to be exploiting a niche where salinities are high enough (~12-25 ppt) to suppress competition from salt-intolerant species but low enough to cause little physiological stress for the reed. Consequently, significant reductions in *Phragmites* may only be achievable where steep elevation gradients near the marsh periphery limit upslope migration and when the vast majority of where the basin can be flooded with near full-strength seawater. Otherwise, once *Phragmites* populations have become established in tidally-restricted systems, they may be extremely difficult to treat with hydrologic restoration alone.

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ANALYSIS OF COASTAL WATER QUALITY WITH A MULTIPLE SENSOR INSTRUMENTED CATAMARAN (MUSIC) AND REMOTE SENSING

We are developing a method for the rapid synoptic assessment of the relative state of eutrophication in shallow coastal waters. The technique relies upon determinations of near-surface water column chlorophyll concentrations as derived from spectral analysis of ground-truthed imagery from an aerial hyperspectral sensor. Our project, conducted at the Waquoit Bay National Estuarine Research Reserve (WBNERR) on Cape Cod, hopes to provide managers with a new tool for region-wide assessment of these areas. The goal is to develop a cost-effective means for rapidly assessing the relative eutrophic condition of shallow coastal embayments on a regional scale. This method will have wide application as an aid for evaluating coastal water quality conditions. This project directly addresses nutrient enrichment and eutrophication and habitat degradation, loss, and habitat restoration. The primary platforms for this effort were a novel, towed, catamaran called MUSIC (Multiple Sensor Instrument Catamaran), and aircraft imagery data acquired using a hyperspectral camera system. The MUSIC instrument package provides data on the spatial heterogeneity in near surface chlorophyll distribution and other water quality parameters. We will discuss results, challenges, shortfalls, and recommendations for improvement of the technique.

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THOUGHTS ON HOW TO INITIATE A COMMUNITY-BASED RESTORATION EFFORT AND THEN KEEP IT ACTIVE, GROWING AND SUSTAINABLE.

The Southold Project in Aquaculture Training has been utilizing a large group of community volunteers to help Cornell Cooperative Extension Marine Programs division with shellfish enhancement and restoration efforts. The success of this program is evident in the membership, logged training hours, fundraising and community awareness, including high media coverage. S.P.A.T. works on a 12 committee principle with chairpersons for each, which also make up the advisory board. Many communities on the East Coast have been inquiring about or initiating similar programs to address issues of water quality, stock enhancement and restoration. It becomes quite obvious that the various elements of any community-based program differ from group to group and the configuration of the S.P.A.T. does not necessarily fit the needs or abilities of every township or organization. This presentation will attempt to address the fundamental elements of a community-based approach to environmental stewardship issues and will offer potential techniques and insights on the most effective way of utilizing a volunteer workforce in order to get important projects completed. It will also offer guidelines on how to turn a successful pilot project into a long-term, sustainable program.

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RESPONSE OF BENTHIC NUTRIENT FLUXES IN BOSTON HARBOR AND MASSACHUSETTS BAY TO SEWAGE TREATMENT IMPROVEMENTS, INCLUDING OUTFALL RELOCATION

In 1985, the EPA and the Department of Justice sued the Commonwealth of Massachusetts for violating the 1972 Clean Waters Act because of the deplorable condition of Boston Harbor. The Massachusetts Water Resources Authority came under court order to clean up the harbor. This began a multi-stage and multi-million dollar project that included cessation of sludge disposal within the harbor (late 1991), construction of a new secondary treatment plant (phased in between 1997 and 2001) and relocation of the effluent outfall through a 9-mile tunnel extending into Massachusetts Bay (Sept. 2000). We have been studying benthic metabolism in depositional sediments of the harbor and the bay since 1992. In the first years of monitoring, sediment respiration rates and DIN fluxes were among the highest measured in coastal systems, and exhibited large variability. High rates were fueled by large stores of organic matter in the sediments, accelerated at times by high rates of bioturbation. In recent years, both rates and variability have declined as organic matter stores have been metabolized and the animal community has begun to mature beyond the colonizing stage. In Massachusetts Bay, benthic fluxes are much lower than in the harbor, and have changed little during the monitoring

program. Variability in this system has been driven by region-wide processes such as storms and by decadal-scale cycles in infaunal abundances. As the stages of clean-up of Boston Harbor near completion, its appears that sediment metabolism in the harbor is approaching a new equilibrium characterized by moderate fluxes, whereas little or no response to the relocation of the outfall has been observed to date in Massachusetts Bay sediments.

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GEOMORPHOMETRIC PATTERNS AND TRAJECTORIES OF TIDAL MARSH CONDITION

Biotic and geomorphic characteristics of tidal marshes change over time in response to long-term trends in factors such as sea level change, sediment supply, and organic matter preservation. When viewing this landscape, we expect to find conditions ranging from maximum development and equilibrium with sea level to failure and rapid conversion to open-water habitat. Characterizing and analyzing these conditions will provide useful information for the management and restoration of these vital landscapes. To that end, we used geomorphometric measures of tidal marsh hydrography as the basis for trajectories of development and degradation. Substituting space for time, we selected tidal marshes in the Plum Island Sound estuary in northeastern Massachusetts that represent different development stages. The sample sites included an infilling state, a filled state with subsequent human impact, and a degraded state. We mapped the tidal creeks, ditches, connected ponds, and isolated ponds from 2001 color aerial photography. We also mapped ponds from 1952-1953 topographic survey sheets. Defining sample boundaries based on interfluvial areas, we calculated marsh:water area ratio, drainage density, pond density, mean pond size, and mean pond surface area ratio. Analyzing the maps and metrics by state order, we illustrate development and degradation patterns and trajectories for northern macrotidal marshes. The results reveal an oscillation of marsh condition with time. Comparing the pond metrics for the two time periods corroborates the notion of large pond development as features indicative of tidal marsh degradation. Extending the trajectories with other observations, however, reveals a potential path to marsh regeneration.

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WATERSHED/ESTUARY COUPLING: BIOLOGICAL, CHEMICAL, AND ISOTOPIC EVIDENCE, AND SOME USEFUL APPROACHES FOR MANAGEMENT

Changes in land use and cover on watersheds such as those on Cape Cod prompt increases in

nitrogen transport to receiving estuaries. Urban sprawl and loss of forest are particularly important in setting rates of increase loading of estuaries. Land-derived nutrients move down-estuary, undergoing transformations and losses, and these concentrations and fluxes variously affect estuarine species. In general, sessile bottom organisms, including large algae and invertebrates, are most affected by land-derived nitrogen. Fish may or may not be affected, and plankton—including copepods and comb-jellies—may appear uncoupled to land-derived inputs, if flushing times within the estuaries are short. A number of tools and approaches are available for managing impacts of land-derived nutrient loads. Successful management of loads requires adequate estimation of loads, and understanding the sources and transport of terrestrial nutrients, which in general, for Caper Cod, at least, implies constraining wastewater nitrogen sources.

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SPARTINA ALTERNIFLORA AND *SPARTINA PATENS* PRODUCTION IN RESPONSE TO EXPERIMENTAL EUTROPHICATION IN A NORTHERN MASSACHUSETTS ESTUARY

Production estimates of tall and stunted *Spartina alterniflora* (Sat & Sas) and *Spartina patens* (Sp) were made for a pair of creeks, Sweeney and West, within the Plum Island Sound, MA complex of tidal marshes. Flooding tidal water in Sweeney was enriched in nitrogen (NO_3 to 70uM) and phosphorus (PO_4 to 5 uM); West Creek received ambient Plum Island Sound water (NO_3 at ca. 7uM, PO_4 at ca.1 uM). Seven times from May to September, above ground growth and production were estimated by collecting ca.150 shoots of each Sat, Sas, & Sp from both creeks. Each shoot was washed with tap water to remove sediments, measured to the nearest 0.5 cm, dried at 70C and weighed. End of season stem densities were measured (24 samples per species per creek). Below ground production was estimated with in-growth cores: 8 Sat and 4 Sas and 4 Sp cores per creek. Cores were in place from early June until early September. End of season plant height was greater in the treated creek (Sweeney) than control (West) for Sat, Sas, and Sp, as was the g cm-1 shoot for Sat and Sas. Stem densities and below ground production did not differ significantly between creeks for Sat, Sas and Sp. Calculated above ground production (stems m^{-2} * cm $stem^{-1}$ * g cm^{-1}) was consistently greater for Sweeney than West; shoot/root ratios were greater in Sweeney than West for Sat and Sp. These results suggest a growth response by Sat, Sas, and Sp to the experimental eutrophication. Results from a replicate pair of unfertilized creeks may complicate this interpretation.

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A QUARTER CENTURY OF LESSONS LEARNED: RESTORING ESTUARINE WETLANDS IN CONNECTICUT

By 1970 dikes, tide gates, causeways, and culverts had significantly reduced or eliminated the tidal prism for ca.1000 ha of tidelands in over 100 sub-estuaries of Long Island Sound. With the loss of tides these wetlands converted from *Spartina* dominated communities to near monocultures of *Phragmites australis*, or *Typha* spp., and their ecological connections to Long Island Sound were minimal. In the late 1970s municipal administrators in the Town of Fairfield and the state Department of Environmental Protection (DEP), quite independently took initial, tentative steps to re-connect some restricted marshes to the larger Long Island Sound ecosystem. Results of these early restoration efforts have been documented through a number of scientific investigations spanning over 20 years; in most cases, returning tides restores biotic communities and ecological functions, although these may return independently and at quite different rates. This success spurred formation of a DEP unit directed specifically at tideland restoration. Tidal action has now been returned to ca. 700 ha of marshland in over 75 different sub-estuaries of the Sound. Low-lying properties, long protected from tidal flooding by dikes and gates, present locally particular political and technical challenges to tidal restoration. In some systems, self-regulating tide-gates allow return of tidal flooding to large areas of marshland, restoring ecological functions while protecting especially flood-prone areas. *Phragmites* has also invaded brackish tidelands free of tidal restrictions and major disturbances. Restoration of such brackish marshes is technically and scientifically more problematic than in higher salinity systems.

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ASSESSMENT AND PLANNING APPROACHES IN WATERSHED ASSESSMENT: THE EMBAYMENT EUTROPHICATION CASE STUDY

With an increasing recognition that many environmental stressors, though localized in origin, are spatially expansive in terms of ecosystem impacts, ecological risk assessors are developing new methods and adapting commonly used methodologies to larger scales. In many cases the standard ecological risk assessment approach can be adapted and applied to larger scales and non-hazardous waste stressors. An ecological risk assessment organized around background research, framing the assessment through conceptual modeling and endpoint selection, estimating exposure, predicting effects and combining all of the pieces into the assessment of risk can not only be powerful for assessing risk, but is also a valuable planning and communication tool. In this paper, the investigation of a common watershed-scale stressor, nutrient loading, is explored using an accessible, yet powerful predictive modeling tool. Using a previous study of Massachusetts embayments as a case study, the susceptibility to eutrophication and nitrogen loading are determined. The tool is presented as an example of tools

that might be employed to assess larger scale stressors. In addition to presenting a watershed-scale assessment tool for the evaluation of current conditions, the paper demonstrates how risk assessment models may used to begin to consider management options through alternative futures analyses. GIS offers the opportunity to illustrate potential future conditions, inform planning decisions and serve to communicate options, risks and final decisions to a wide audience.

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LINKING NITROGEN ISOTOPIC PATTERNS TO WATERSHED LAND-USE IN WAQUOIT BAY, MA ESTUARIES

We compared the stable nitrogen isotopic ratio ($d^{15}N$) of water column ammonium and nitrate in two sub-estuaries of the Waquoit Bay system subjected to different rates of land-derived N loading. The watersheds of these two sub-estuaries, Childs River and Quashnet River, vary in their degree of urbanization, which leads to differences in both amount and sources of nitrogen delivered to the estuary. We took advantage of previous work to show that patterns previously observed in the $d^{15}N$ of DIN in groundwater were maintained in estuarine water. Finally, we surveyed existing data on biomass and $d^{15}N$ of primary producers to suggest potential mechanisms leading to observed patterns in $d^{15}N$ of DIN and primary producers. The isotopic data reliably indicated the degree of urbanization of the watershed.