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Eelgrass in the great bay estuary, New Hampshire and Maine: Monitoring eelgrass decline and educating local students

Nora Thompson Beem
University of New Hampshire, Durham

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EELGRASS IN THE GREAT BAY ESTUARY, NEW HAMPSHIRE AND MAINE: MONITORING EELGRASS DECLINE AND EDUCATING LOCAL STUDENTS

BY

NORA THOMPSON BEEM
Baccalaureate of Arts, Smith College, 2005

THESIS

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This thesis has been examined and approved.

Thesis Director, Frederick T. Short, Research Professor of
Natural Resources and Marine Sciences

Mimi Larsen Becker, Associate Professor of
Natural Resources and Environmental Policy

Drew Dumsch

Drew Dumsch, Executive Director of
Ecology Education, Inc.

December 3, 2008

Date

The following thesis is dedicated to Philip Banks. Time to come home.

ACKNOWLEDGEMENTS

My thesis would not have been possible without the help of many individuals. First I thank my advisor, Fred Short for all of his help in shaping my project. I also thank my committee members, Mimi Becker and Drew Dumsch for providing their time and effort to review my thesis. In addition, members of the Seagrass Ecology Lab and Cathy Short have all contributed to my thesis through manuscript comments, tank maintenance, statistical and GIS help, and overall moral support.

Financial support from the New Hampshire Port Authority (Pease Development Authority), the University of New Hampshire, the Great Bay Stewards, and UNH's Marine Program were critical in allowing me to conduct my research and the outreach event. The outreach event would not have been possible without the help of Mike Dufilho and Nikki Sarrette as volunteer instructors, the cooperation of the Oyster River Middle School teachers, and the excitement of the ORMS fifth grade students themselves. I also thank the Durham Conservation Commission for allowing students to present their interpretive panel and display it in Durham Town Hall, and the Oyster River Middle School, Jackson Estuarine Laboratory, and Sandy Point Discovery Center for displaying the other interpretive panels. Additionally, thank you to Russ Congalton for printing the panels. Finally, I acknowledge Jon Pennock, Dave Shay, Heather Talbot, and the rest of the Jackson Estuarine Laboratory personnel for their logistical help with the outreach event and their overall support during the past two years.

TABLE OF CONTENTS

LIST OF FIGURES

ABSTRACT

EELGRASS IN THE GREAT BAY ESTUARY, NEW HAMPSHIRE AND MAINE: MONITORING EELGRASS DECLINE AND EDUCATING LOCAL STUDENTS

by

Nora Thompson Beem

University of New Hampshire, December, 2008

Eelgrass monitoring efforts in the Great Bay Estuary (GBE), New Hampshire and Maine, by the New Hampshire Port Authority Mitigation Project (Chp. II) and Nutrient Pollution Indicator (NPI) testing (Chp. III) both confirmed a recent trend of eelgrass decline within the GBE. The decline has been most noticeable in the mid-estuary, where four major tributaries drain into the GBE. Eelgrass beds in proximity to Portsmouth's wastewater treatment facility have also experienced decline, highlighting the effects of such point sources on the eelgrass population.

In an effort to introduce eelgrass, its recent decline and its role in the ecology of the GBE to students in the community, an eelgrass lesson plan was created for local fifth graders (Chp. IV). The experiential lesson was conducted through an outreach event hosted at University of New Hampshire's Jackson Estuarine Laboratory, sharing research with the local community.

CHAPTER I

INTRODUCTION

The objective of my thesis was to facilitate the sharing of scientific knowledge with the local community. I sought to achieve this through scientific assessments, educational efforts, and community outreach.

The Great Bay Estuary (GBE) is an important natural resource forming the border of southern Maine and New Hampshire. The GBE supports a host of organisms, including eelgrass, the dominant species of seagrass found in New England (Short and Short 2003). In addition to being the dominant seagrass, eelgrass is also the dominant primary producer in the GBE. Historically the eelgrass population in the GBE has experienced two major wasting disease events, once in the 1930s and again in the 1980s (Short et al. 1986). While the eelgrass has since recovered from these events, there is evidence that a new stressor is affecting the GBE. Several ongoing field studies are monitoring eelgrass bed dynamics and potential causes of the decline.

The New Hampshire Port Authority (NHPA) Eelgrass Mitigation Project was developed to compensate for the loss of eelgrass habitat resulting from the expansion of the New Hampshire State Port and associated dredging of the Piscataqua River. Recent results from the annual monitoring program show a decline in all plant parameters measured and indicate an overarching factor affecting estuary health (Chp. II).

The Nutrient Pollution Indicator (NPI) was designed as an early indicator of eutrophication and a tool for identifying areas of localized nitrogen loading (Lee et al.

2004). Re-sampling the NPI in 2007 found the loss of four of the twenty eelgrass sites originally sampled in 1999 (Lee et al. 2004). In addition, results highlighted two new areas of localized nitrogen loading in the GBE (Chp. III).

Using the findings of the NHPA and NPI projects, I created a supplemental eelgrass lesson plan utilizing the State of New Hampshire's fifth grade life science objectives (Chp. IV). The lesson plan and associated outreach event provided local middle school students with an understanding of the cascading consequences of the current eelgrass decline.

There are three overall objectives I set out to achieve through my thesis. The first was to better understand contributors to the eelgrass decline in the GBE. The second was to use local natural resources, in this case the GBE and its eelgrass population, to address the State of New Hampshire science education objectives. The final goal was to link the research findings of the University with a practical understanding in the local community. I believe these goals have been met through the following three chapters and associated efforts.

CHAPTER II

SUBTIDAL EELGRASS DECLINES IN THE GREAT BAY ESTUARY, NEW HAMPSHIRE AND MAINE, USA

Introduction

In 1993, the New Hampshire Port Authority (NHPA) Mitigation Project was developed to compensate for the loss of salt marsh, mudflat, and eelgrass (*Zostera marina* L.) habitat, as well as loss of potential habitat, resulting from the expansion of the New Hampshire State Port and associated dredging of the Piscataqua River in the Great Bay Estuary (GBE) on the border of New Hampshire and Maine. Eelgrass was transplanted (2.5 hectares) from 1993 to 1995 in the Piscataqua River and Little Bay, upstream from the Port. By 2000, the surviving transplanted eelgrass (0.8 hectares) had achieved comparability with the nearby natural eelgrass beds used as reference sites for measuring functional equivalence (Evans and Short 2005). The eelgrass transplanted for port mitigation receives annual evaluation as part of a 15-year (1995 to 2010) monitoring program of the NHPA Mitigation Project (Bosworth and Short 1993). The present study focuses on data from 2001-2007.

Eelgrass is found throughout the GBE. Aerial mapping of the estuary in 1992 showed 1,000 hectares of eelgrass (Short 1992), while studies 14 years later found 800 hectares (NHEP 2006). Approximately three quarters of the eelgrass found within the upper GBE, the Great Bay itself, is intertidal, defined here as plant leaves lying on the water surface at mean low water. The eelgrass beds within Little Bay and the Piscataqua

River portions of the GBE are primarily subtidal, remaining submerged even at mean low tide. Within the estuary, it is the subtidal beds that most depend on clear water conditions to survive and thrive. The NHPA monitoring tracks subtidal eelgrass survival and health within the Piscataqua River and Little Bay portions of the GBE; combined with measures of eelgrass status in Great Bay itself (NHEP 2006; Short unpubl.), a picture of the status of subtidal eelgrass throughout the entire estuary emerges. The objective of the present study was to assess recent trends in subtidal eelgrass parameters as indicators of the health of the estuary.

Methods

Study Sites

The monitoring sites were located within the Piscataqua River and Little Bay, part of the GBE (Fig. 1). During the 2001-2007 field seasons, the sites monitored included: (i) two transplant sites, Great Bay Fish Pier (T1; 43°06.265'N, 70°47.694'W) and Defense Fuels North (T3; 43°06.693'N, 70°48.433'W); and (ii) three reference sites, Adlington Creek (R2; 43°07.188'N, 70°48.474'W), Dover Point (DP; 43°07.477'N, 70°50.564'W), and Outer Cutts Cove (OCC; 43°05.188'N, 70°45.818'W). The reference site DP was added in 2003 after eelgrass disappeared from a reference site (R1) on the Piscataqua River following the construction of the outfall for a new power generation facility.

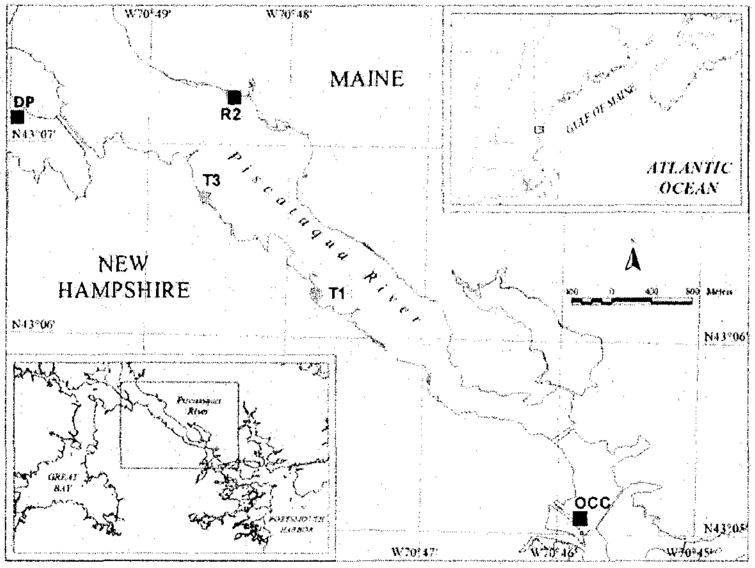


Figure 1. Map of NHPA eelgrass monitoring sites within the Piscataqua River and Little Bay in the Great Bay Estuary, New Hampshire. Squares indicate reference sites and circles indicate transplant sites.

Field Assessment

Eelgrass samples for primary production, three-dimensional canopy structure, and percent cover were collected at all sites every August from 2001-2007. Eelgrass production was assessed by measuring aboveground biomass (g m^{-2}) in three 0.0625 m^2 sub-quadrats of a 1.25 m^2 quadrat haphazardly placed in the eelgrass bed (Bosworth and Short 1993; Duarte and Kirkman 2001). Three-dimensional canopy structure was measured as shoot density (shoots m^{-2}), canopy height (cm, equivalent to 80% of the mean maximum leaf height), and leaf area (cm^2 $shoot^{-1}$) (Duarte and Kirkman 2001).

Laboratory Analysis

Harvested plants were transported to the Jackson Estuarine Laboratory in Durham, New Hampshire. Plant processing included rinsing the plants in fresh water, determining the total number of shoots and dry weight biomass per sub-quadrat, and measuring plant parameters on 10 shoots per sub-quadrat (Evans and Short 2005) including leaf width, sheath length (measured from the meristem to the top of the sheath), and leaf length (measured from the top of the sheath to the leaf tip).

Eelgrass parameters (means ± SE) were tested for statistical significance over time using linear regression analysis starting at maximum biomass. The slope of eelgrass biomass over time as well as correlation coefficients and p-values are reported for each site.

Results

Aboveground eelgrass biomass declined significantly from 2003 to 2007 at all sites except DP. Decline in biomass at OCC and T1 began in 2001, while declines at T3 and R2 began 2 years later (Fig. 2). At DP, reductions in eelgrass biomass were not seen until after 2005. The rate of decline was greatest at transplant site T3, where eelgrass biomass dropped at a rate of 47.5 g m^{-2} yr^{-1} between 2003 and 2007 (Fig. 2).

Eelgrass shoot density, canopy height, and leaf area also decreased significantly at reference and transplant sites. Shoot densities declined at sites T1, R2, and OCC after 2001, at T3 after 2002 and at DP after 2005 (Fig. 3a). Shoot density decline at T1 was greatest, dropping from approximately 300 shoots m^{-2} in 2001 to zero in 2007 (Fig. 3a). All sites showed significant declines in eelgrass mean canopy height and leaf area by 2006, with T1, T3 and R2 beginning to decline after 2004 (Fig. 3b, c).

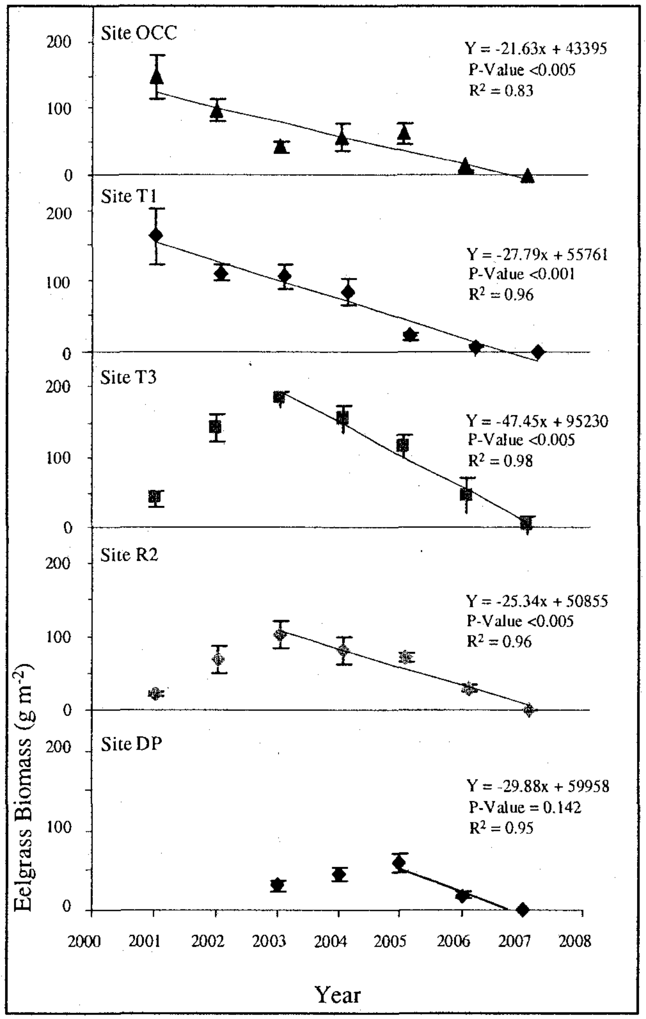


Figure 2. Simple regressions of the effects of time on mean (±SE) eelgrass biomass. Sites are presented moving up-estuary.

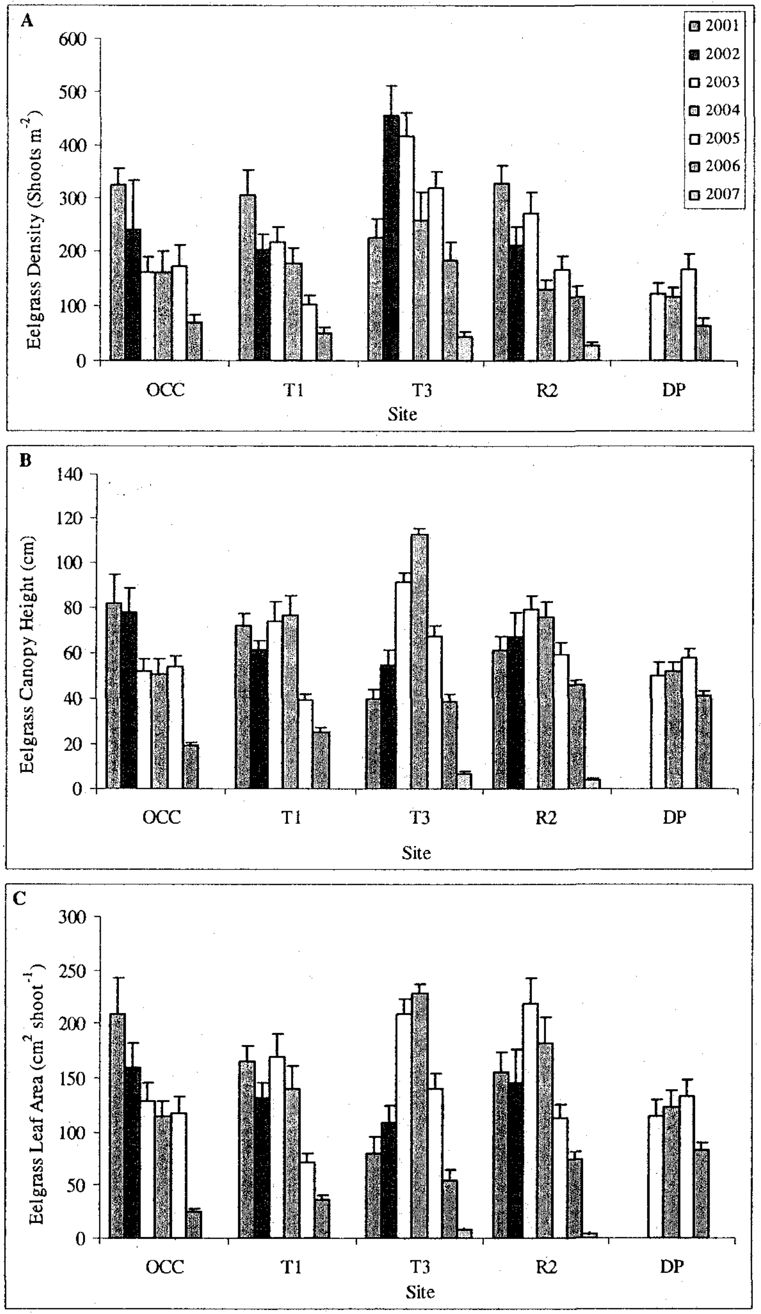


Figure 3. Mean (±SE) eelgrass three-dimensional canopy structure at transplant (T1, T3) and reference (DP, R2, OCC) sites from 2001 through 2007. Sites are presented from the Gulf of Maine to up-estuary, left to right.

Discussion

The eelgrass data collected for the first six years (1995-2000) of the Port Mitigation Project showed successful expansion of transplanted eelgrass beds to levels equivalent to the reference sites (Evans and Short 2005). However, beginning in 2001, some sites, both transplant and reference, experienced declining plant parameters, particularly biomass (Fig. 2). Evidence at both categories of sites sampled and from additional eelgrass monitoring in the GBE (NHEP 2006) indicates that the trend of eelgrass decline was not isolated to the NHPA project sites but included eelgrass throughout the estuary. Overall, eelgrass areal cover in the GBE declined 17 percent between 1996 and 2004, with most of the loss occurring between 2001 and 2004 (NHEP 2006).

In the Piscataqua River, all four eelgrass sites sampled exhibited significant decline between 2003 and 2007. By 2007, two of the Piscataqua River sites (OCC, T1) and the site in Little Bay (DP) were completely devoid of vegetation with eelgrass barely surviving at the other two monitoring sites (T3, R2). None of the sites, including T3 and R2, showed any eelgrass in the 2008 monitoring. Eelgrass biomass for Great Bay itself showed a significant decline from 2001 to 2004 (NHEP 2006), continuing through 2007 (Short unpubl.).

The overwhelming subtidal eelgrass decline at both reference and transplant sites and across all plant parameters measured indicates the losses are likely the result of an overarching factor affecting eelgrass health. The New Hampshire Estuaries Project (NHEP) has reported an increase of over 6,000 acres in impervious surfaces in the GBE watershed from 2000 to 2005 (NHEP 2006), contributing to increases in runoff, turbidity and nutrients (Paul and Meyer 2001; Steinke et al. 2007). A 59% increase in dissolved inorganic nitrogen documented over the past 25 years, predominantly from increased wastewater inputs (NHEP 2006), has further decreased water quality in the GBE.

Seagrass growth and health are directly affected by water quality (Orth et al. 2006; Wazniak et al. 2007). Efforts must be made to reduce nitrogen and sediment loading to the GBE in order to reverse these demonstrated eelgrass losses.

CHAPTER III

ANALYSIS OF THE EELGRASS NUTRIENT POLLUTION INDICATOR (NPI) IN A DEGRADING ESTUARY: GREAT BAY ESTUARY, NEW HAMPSHIRE AND MAINE, USA

Introduction

Dispersed in shallow coastal waters, eelgrass ecosystems perform a number of ecologically important functions (Hemminga and Duarte 2000; Green and Short 2003). The physical structure of the plants, both below and aboveground, helps to stabilize sediments and filter particulate matter from the water column (Short and Short 1984). The eelgrass canopy reduces wave energy and slows water currents, allowing suspended material to collect within the eelgrass bed (Fonseca et al. 1982; Koch 2001). Densely growing plants offer protection to juvenile fish and invertebrate species from predation, while the leaves and detritus are the basis of an important estuarine food chain. Some species, such as lobster, burrow in the mud beneath the eelgrass beds (Heck and Orth 1980; Short et al. 2001). Blue mussels, bay scallops (Heck et al. 1995), flounder, and cod (Gotceitas et al. 1997; Evans and Short 2005) have all been shown to utilize eelgrass meadows as critical nursery habitat.

Seagrass declines have been documented both worldwide (Short and Wyllie-Echeverria 1996; Green and Short 2003; Orth et al. 2006), and locally in New England (Short and Burdick 1996; Short et al. 1996; Deegan et al. 2002). Loss of critical eelgrass habitat, the dominant seagrass species in New England, has been attributed to nitrogen loading (Orth and Moore 1983; Short et al. 1995; Deegan et al. 2002), increased housing development (Short and Burdick 1996; Short et al. 1996), wasting disease events (Short et al. 1986; Short et al. 1987) and grazing by Canada geese (Rivers and Short 2007). Shoreline development, characterized by impermeable ground cover such as asphalt and concrete, reduces an area's natural ability to absorb rain and runoff, promotes soil erosion, and leads to higher sediment and nutrient loads entering the estuary (Lee and Olsen 1985).

Nitrogen (N) in estuarine and coastal waters along the U.S. northeastern seaboard (Maine to Virginia) has increased fivefold over the past century from 200 to 1,000 kg N km^{-2} $year^{-1}$ (Jaworski et al. 1997). Two of the largest contributors to N loads are septic and wastewater discharge (Short and Burdick 1996; Kennish et al. 2007), contributing up to 75% of water column N pollution (Driscoll et al. 2003). In the past 15 years, impervious surfaces in the Great Bay Estuary (GBE) rose from 4.7% to 8.0% of the watershed's land area. During this same time period, water column N levels have increased 59% (NHEP 2006). The recent growth in population and development in the GBE watershed has increased the flow into sewage treatment facilities, increasing N loading (Driscoll et al. 2003; Trowbridge 2006a; NHPA 2006).

The GBE has historically supported significant eelgrass habitat (Short et al. 1986). Wasting disease in the 1930s and again in the 1980s drastically depleted the estuary's standing stock of eelgrass (Short et al. 1986; Short et al. 1987). While eelgrass within the GBE rebounded after both of these wasting disease events, the current environmental stressors associated with shoreline development (N loading, impervious surfaces and suspended solids) are increasing annually and show no sign of decline in the near future.

Declining trends of eelgrass within the GBE motivated monitoring efforts, including Lee et al.'s (2004) nutrient pollution indicator (NPI). The NPI is an index that correlates to N increases based on plant response to changes in leaf N content and leaf mass (Lee et al. 2004). Individual NPI values are determined by calculating the ratio of leaf N content to leaf mass. Eelgrass beds exposed to comparatively higher levels of N exhibit greater NPI values. The NPI values serve as an early indicator of eutrophication, highlighting areas of excess nutrient loading. NPI measurements, rather than water column N, are used to measure eutrophication because direct measures of water column nutrients are generally ineffective. Water column N is rapidly utilized by phytoplankton and submerged vegetation, as well as diluted through tidal currents, leading to the underestimation of eutrophication (Tomasko et al. 1996).

Measurements of the NPI within the GBE in August 1999 showed NPI values increasing significantly with distance up-estuary from the coast (Lee et al. 2004). Measurements of N loading within the GBE have shown a steady increase over the past 25 years (NHPA 2006), and monitoring of eelgrass beds in the mid-estuary has shown substantial decline in eelgrass beds (Beem and Short 2008). To assess the current state of nutrient loading in the GBE on the eelgrass population, we retested the NPI of the original study sites in 2007 and compared the present trends with those from 1999.

Methods

Study Sites

The GBE is located on the border of New Hampshire and Maine (43°05’N, 70°50’W). It has a maximum depth of 3.4 meters and a mean tidal range of 2.0 to 2.7 meters (Roman et al. 2000). The original NPI eelgrass methodology executed in 1999 (Lee et al. 2004) involved sampling 20 eelgrass beds within the GBE, from the seaward reference point at the mouth of the Piscataqua River up-estuary to the Great Bay (Fig 4).

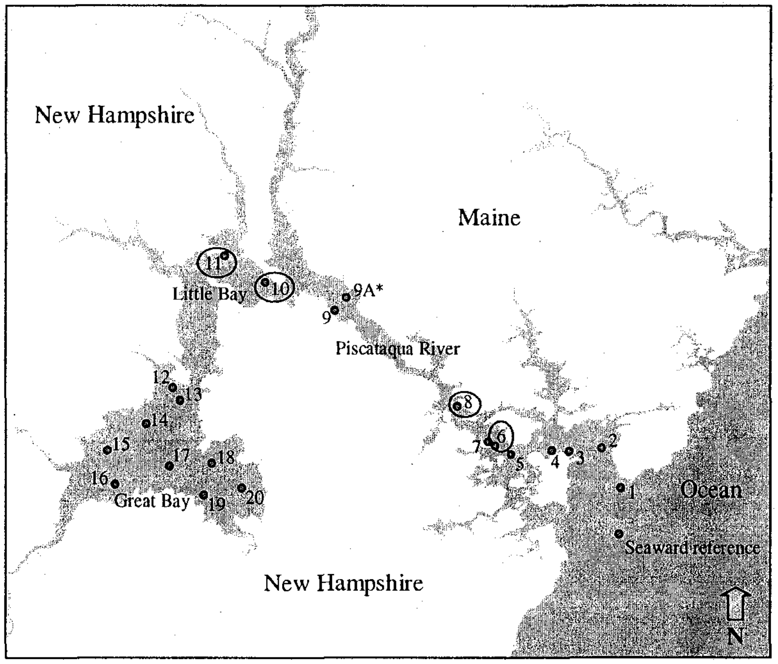


Figure 4. Location of the study sites within the Great Bay Estuary sampled in August 1999 and 2007. The dots represent sites sampled both years, circles indicate sites devoid of vegetation in 2007, and the asterisk (*) indicates the new site sampled in 2007. The seaward reference point was used to calculate distance from the coast for each study site.

The current study resampled all of the original sites (Fig. 4, Appendix B) where eelgrass still grew. Four of the original sites no longer supported eelgrass beds (6, 8, 10 & 11). In addition, one of the sites (9) had such low eelgrass density that complete sampling was not possible. To address this issue, an alternative site (9A) close to the low-density site was added.

Eelgrass Collection

Eelgrass collection and processing followed the protocol in by Lee et al. (2004). On August 27 and 29, 2007, ten mature terminal eelgrass shoots were collected from each study site using a hook sampler. Due to the low density of eelgrass at site 9, only four shoots were collected. Site 9A was sampled to ensure representative sampling from that area of the estuary. Eelgrass was transported to the Jackson Estuarine Laboratory in a cooler for processing and measurement. Prior to processing, plants were rinsed with fresh water.

Plant Measurements

For all of the plants collected, the number of leaves per shoot was counted. Sheath length was measured to the nearest 1.0 mm and sheath width to the nearest 0.2 mm. The length of the first five leaves and longest intact leaf on each shoot were measured to the nearest 1.0 mm. The width of the longest intact leaf was measured to the nearest 0.2 mm. Percent wasting disease was estimated for each leaf measured (Burdick et al. 1993).

Area normalized leaf weight (mg dry weight cm^{-2} leaf area), or leaf mass, was determined for each shoot. Six 10 cm long sections of constant width were cut from the second and third youngest leaves and dried at 60°C for 48 hours. The dried leaf sections were weighed to determine leaf mass (Olsen and Sand-Jensen 1993; Lee et al. 2004).

Nitrogen Analysis

To measure the leaf nitrogen (N) content of each plant, the dried leaf sections used for the leaf mass measurement were ground in a Thomas Scientific® Wiley Mill using a stainless steel 40 mesh sieve with a 1.0 mm diameter. The samples were stored in

20 ml scintillation vials with the lids loose in an oven at 20°C to keep the specimens at a constant weight while waiting to process. Between 1.5 and 2.5 mg of the ground samples were weighed on a Perkin Elmer® AD6 Autobalance Controller. The weighed samples were transferred into aluminum foil boats housed in 5x8mm plastic cylinders prior to combustion. The aluminum foil boats were then folded tightly using forceps and combusted in a PerkinElmer® Series II CHNS/O Analyzer 2400. The elemental analyzer uses the Pregl-Dumas method to combust the samples in a pure oxygen environment and measures the volume of nitrogen gas produced (PerkinElmer 2005). It then converts the gaseous volumes into percent weight based on the original mass of the sample.

Distance from Coast

A geographical measurement, distance from coast (m), was created to quantify the estuarine gradient. The ocean endpoint (43° 05'12"N, 70° 68'86"W) was set on the New Hampshire coastline. Using an ArcGIS 9 ArcMap of the Great Bay Estuary, the distance of each study site from the ocean endpoint was calculated (Appendix B).

Statistics

Simple regression analysis of mean leaf length, leaf N content and leaf mass against distance from the coast was calculated to identify any spatial gradients. Mean leaf length was also regressed against leaf N and leaf mass. NPI for each site was calculated by dividing leaf N content by leaf mass. The NPI values were regressed against distance from the coast to identify estuarine gradients. The 2007 results were then compared with 1999 results to determine any significant differences. In addition, the 2007 NPI values were analyzed using a Tukey's multiple comparison test to determine where the differences occurred within the GBE. Level of significance for all tests was p=0.05.

Results

Study Sites

The GBE was analyzed in three sections; the lower-, mid-, and upper-estuary. The lower estuary included sites 1-8 and the upper estuary, or Great Bay proper, included sites 12-20. The mid-estuary, made up of Little Bay and the Piscataqua River, included sites 9-11. However, two of the four sites in the mid-estuary, sites 10 and 11, were devoid of eelgrass by 2007; a site, 9A, was added in 2007 due to low eelgrass density at the original site 9. The absence of eelgrass resulted in insufficient data to draw conclusions about the mid-estuary.

Leaf N content and leaf mass

The mean leaf N content of eelgrass ranged from 1.4 to 2.6% (Fig. 5), showing no significant trend with distance up-estuary ($y=-4*10^{-6}x+1.95$; $R^2=0.02$; $p=0.59$).

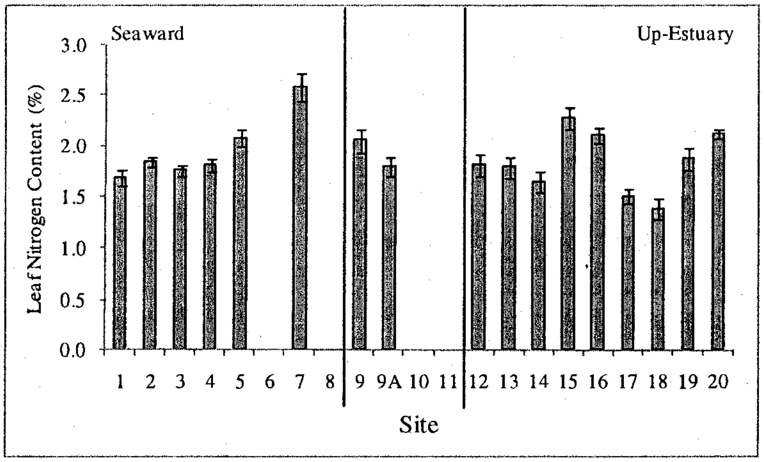


Figure 5. Eelgrass leaf N (±SE) at sample sites within the Great Bay Estuary. Sites 1-8, lower estuary; 9-11, mid-estuary; 12-20, upper estuary.

Eelgrass leaf mass ranged from 2.0 to 5.8 mg dry wt cm^{-2} (Fig. 6) and was significantly lower ($p<0.001$) with distance up-estuary (Fig. 7).

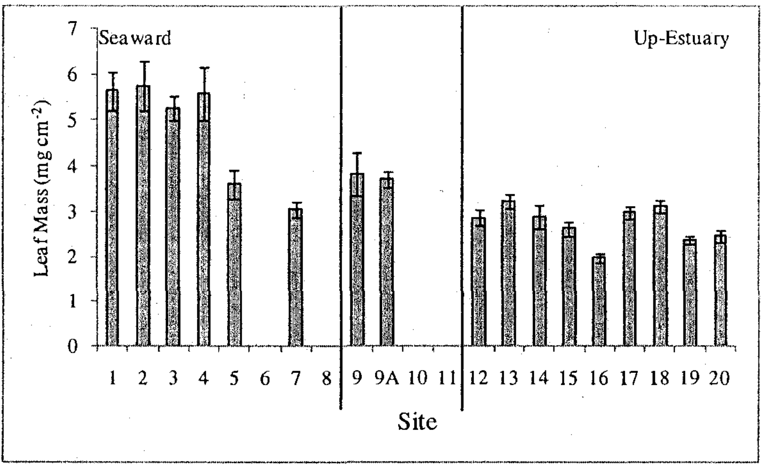


Figure 6. Eelgrass leaf mass (±SE) at sample sites with the Great Bay Estuary. Sites 1-8, lower estuary; 9-11, mid-estuary; 12-20, upper estuary.

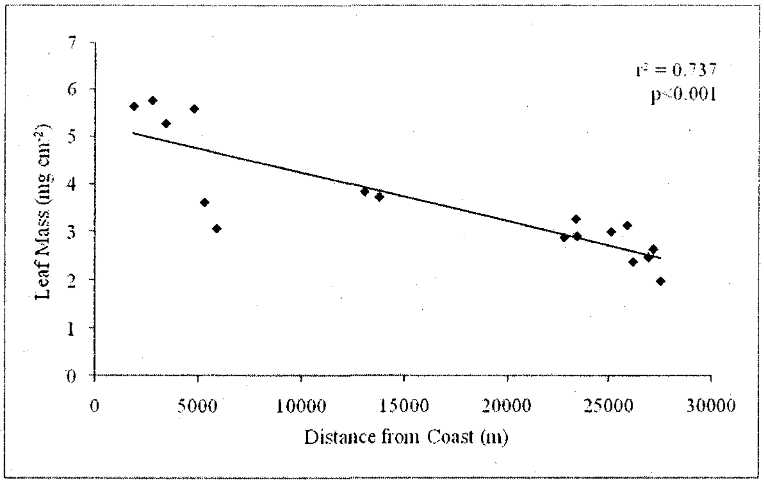


Figure 7. Simple regression of the effects of distance up-estuary on eelgrass leaf mass.

Relationship between NPI and plant parameters

The NPI, defined as the ratio of eelgrass leaf N content to leaf mass, ranged from 0.31 to 1.10 (Fig. 8) and increased significantly with distance up-estuary ($p=0.009$; Fig. 9), although several peaks occurred throughout the GBE. Site 7 was significantly higher (p=0.003) than all sites in the lower estuary except site 5 (Fig. 8). In the upper estuary, site 16 was significantly higher (p<0.001) than all sites except 15 and 20 (Fig. 8).

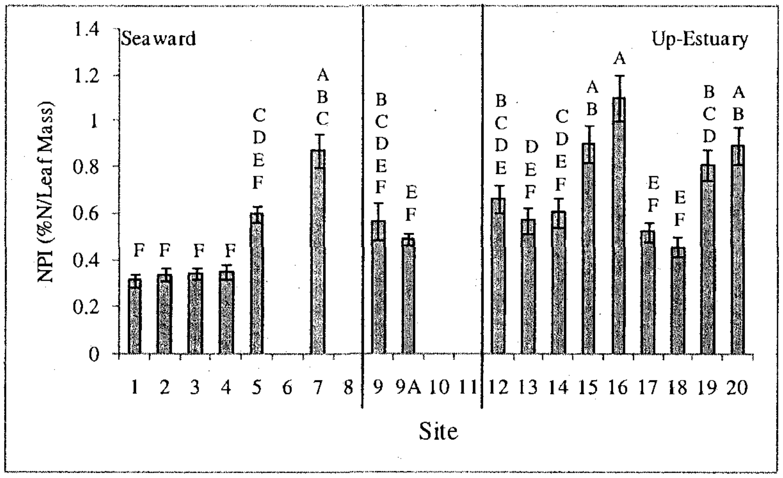


Figure 8. Eelgrass NPI (±SE) at sample sites within the Great Bay Estuary. Sites with the same letter are not significantly different from one another ($p<0.05$). Sites 1-8, lower estuary; 9-11, mid-estuary; 12-20, upper estuary.

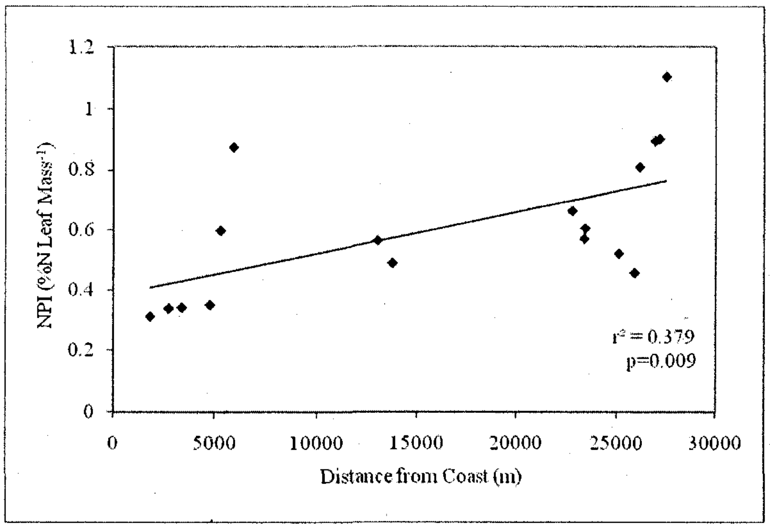


Figure 9. Simple regression of the effects of distance up-estuary on the NPI.

Discussion

Analysis of NPI values in the GBE showed an estuarine gradient similar to the one seen in the original sampling (Lee et al. 2004). The significant trend of decreasing leaf mass with distance up-estuary (Fig. 7) was also present in the 1999 data (Lee et al.

2004) However, the current gradient showed additional NPI peaks at site 7 in the lower estuary and 16 in the upper estuary, both of which are associated with areas of excessive N loading. Within the GBE, wastewater treatment facilities (WWTFs) are the single greatest contributor of excess N and are responsible for 34% of the N loading in the estuary (Trowbridge 2006a). The Portsmouth WWTF, the largest in the region, drains its effluent directly into the lower estuary near site 7.

Tributaries are another major contributor of N, carrying excess nutrients into the estuary from upstream sources, including WWTFs. Seven rivers empty into the GBE, contributing 49% of the total N load – over 540 tons annually (Trowbridge 2006a) - to the estuary. Among these tributaries, the Lamprey, Squamscott, and Winnicut Rivers empty into the upper estuary, and carry with them nearly half (47%) of all tributary contributions of N (Trowbridge 2006a). The remaining 4 tributaries, the Cocheco, Salmon Falls, Oyster, and Bellamy Rivers, drain into the mid-estuary, carrying with them 285 tons of N, 53% of tributary N loading (Trowbridge 2006a). The large amount of tributary-derived N into the mid-estuary likely contributed to the loss of eelgrass from sites within this portion of the estuary between 1999 and 2007 (Beem and Short 2008).

The remaining 17% of the total N loading in the GBE is attributed to nonpoint source runoff (12%), atmospheric deposition (3%) and groundwater inputs (2%) (Trowbridge 2006a). The comparatively greater contribution of WWTFs and tributaries (83%), although not mutually exclusive, highlights these factors as important sources of N loading in the GBE.

The highest NPI value observed in 2007 was at site 16, and was higher than all sites in the upper estuary except 15 and 20 (Fig. 8). Site 16 was located in Great Bay proper between the mouths of the Lamprey and Squamscott Rivers. Combined, these two rivers contribute roughly 225 tons of N into the estuary annually (Trowbridge 2006a), over 40% of all tributary loading. The proximity of site 15 to 16 explains the similar results, as both sites were under similar influences. Site 20 was located on the opposite side of Great Bay from these sites, near the Winnicut River and the Portsmouth Country Club's golf course and was not significantly different from the other site at the eastern end of the upper estuary (site 19).

The NPI value at site 7 was higher than all other sites in the lower estuary except 5 (Fig. 8). Site 7 was bordered by two unvegetated sites (sites 6 & 8), that supported eelgrass in 1999 (Lee et al. 2004). Together, the 3 sites span the area of the Portsmouth WWTF. Site 5 was located directly downstream from site 7 and the bare site 6, and was under similar conditions, if slightly more distant from the WWTF outfall.

Nitrogen loading within the GBE has implications extending beyond the eelgrass population. Studies in Waquoit Bay, Massachusetts, found that excess N has not only decreased eelgrass biomass, but that the decline in eelgrass has led to significant decreases in fish and decapod abundance, biomass, and diversity (Short and Burdick 1996; Deegan et al. 2002). Similar trends are currently occurring in the GBE; monitoring of nutrient enrichment in the GBE has shown a 59% increase in dissolved inorganic nitrogen (DIN) over the past 25 years (NHPA 2006). Data from 1998 through 2004 showed a decline in 4 of the 5 juvenile fish species monitored in the GBE (Trowbridge 2006b).

Between 1999 and 2007, four of the twenty original eelgrass study sites lost their eelgrass. Two of these sites (6 & 8) were in the lower estuary, near the outfall of the

Portsmouth WWTF. The other two sites where eelgrass disappeared were in the mid-estuary, where over half of tributary contributions of N enter the GBE (Trowbridge 2006a; Beem and Short 2008). The current results further highlight the contributions of WWTFs and tributaries to N loading in the GBE and their effects on nearby eelgrass beds, identifying two new sites of concern (7 & 16). If the current trends of increasing N continue in the GBE, these eelgrass beds may be lost as well.

CHAPTER IV

CREATION OF AN EELGRASS LESSON PLAN TO SUPPLEMENT LOCAL MIDDLE SCHOOL SCIENCE CURRICULUM

Introduction

The terms “experiential education,” “environmental education,” and “place-based learning” all describe educational techniques that utilize a hands-on approach to education as a supplement for classroom teaching. The increasing shift towards these methods of education is reflected in the New Hampshire Science Literacy Curriculum Framework, the State’s guidelines for science education. The Framework highlights 10 broad goals of kindergarten through grade 12 education (K-12) science education, the first of which is for students to use “inquiry strategies” to investigate and better understand the natural world (NHDOE 2006). Inquiry strategies are methods used in the pursuit of information, and include making observations, testing hypotheses, and estimating outcomes (NWREL 1997). Other relevant goals include 1) ensuring students will be able to practice basic data collection methods used by scientists to obtain information and 2) allowing students to explore the natural world (NHDOE 2006).

The NH Science Literacy Curriculum Framework further describes science standards specific to grade levels. For middle level science, grades 5-8, the overarching goal is for “students to identify and shape their understanding of the world (NHDOE 2006, p. 8).” The objective is to be achieved through eight avenues, three of which relate directly to experiential education; these three are to 1) provide students with frequent opportunities to engage in inquiry, 2) use experiments and observations to gather information, and 3) provide students ample opportunities for experimentation and data collection (NHDOE 2006).

The Oyster River Cooperative School District (ORCSD), composed of students from the towns of Durham, Lee, and Madbury, New Hampshire, already shows a commitment to experiential education: the Oyster River Middle School (ORMS) sends its fifth grade students to a 4-day residential program at Ferry Beach Ecology School in the fall and to Squam Lake Natural Science Center for a day in the winter. In addition to these fieldtrips, ORMS teachers work to incorporate experiential learning into classroom teaching through the use of curriculum and activity guides such as Project WET, Project WILD, and Project Learning Tree. My interest in experiential science education led to my collaboration with ORMS and the creation of a supplemental science lesson based upon my research on eelgrass within the Great Bay Estuary (GBE).

The GBE is located on the southern border of New Hampshire and Maine, and is home to a host of organisms, including eelgrass (*Zostera marina* L.), the dominant species of seagrass in the northeastern U.S. (Green and Short 2003) and the primary aquatic plant in system. Seagrass grows in intertidal and shallow subtidal portions of marine and estuarine waters, forming dense patches known as meadows or beds. Seagrass meadows are highly productive and perform a number of important functions in shallow, coastal waters. In New England, eelgrass beds help to stabilize sediment and filter the water column (Short and Short 1984), reduce wave energy (Fonseca et al. 1982), and provide a nursery habitat for juvenile fish and invertebrates (Heck and Orth 1980; Gotceitas et al. 1997). Unfortunately, eelgrass within the GBE has been declining steadily since 2001 (Beem and Short 2008), which affects eelgrass' ability to perform these ecological functions within the estuary.

The supplemental lesson, created to address the importance of eelgrass in the GBE, was designed for fifth graders and focused on both the ecological role of eelgrass and the effects of humans on the estuary, also referred to as "human impact." The lesson was conducted during a 2.5 hour outreach event at the University of New Hampshire's Jackson Estuarine Laboratory.

Following the outreach event, interested students were given the opportunity to take the information learned at the event and create interpretive panels to display throughout the community. The panels highlighted the role of eelgrass in the GBE, factors contributing to the current decline in eelgrass, and potential actions/ behavior modifications to lessen human impact on the estuary. Through the outreach event and interpretive panels, students learned about the role of eelgrass in the GBE, increasing their knowledge and interest in preserving the estuary. In addition, the supplemental lesson met several of the overarching goals and specific objectives of the New Hampshire Science Literacy Curriculum Framework for middle level science (5-8 grades). The relevant goals focused on the importance of experiential education, including observation and data collection, and were fulfilled through the hands-on design of the activities conducted during the outreach event.

Methods

Curriculum Development

Creation of a supplemental lesson plan required the creation of experiential activities that provided students with information about eelgrass. Both the New Hampshire Science Literacy Curriculum Framework and the ORMS science "Curriculum at a Glance" were used to determine the appropriate age level and focus of the lesson. Fifth graders were ultimately chosen as the target audience because eelgrass fit well into their life science unit. A review of both documents highlighted interactions between organisms and the effects of human-induced change as two primary foci for fifth grade science (NHDOE 2006).

A date in early June was decided upon for the outreach event; students would be learning about factors that influence water quality and the weather would be warm enough for students to be outside for several hours. The experiential lesson plan created for the outreach event (Appendix C) combines basic estuarine and eelgrass ecology with the effects of human behavior to create a story explaining the recent decline in eelgrass within the GBE.

Outreach Event

The outreach events held on June 5 and 6, 2008, involved two groups of 40 students each day, teaching all 160 fifth graders over two days. To lower the student to teacher ratio as much as possible and maximize student involvement, the lesson was designed using three learning stations: eelgrass ecology, water quality, and human impact. Groups of 13-14 students rotated through the stations, remaining with the same instructor for continuity. The water quality and human impact stations required little in the way of set-up, while preparation for the eelgrass ecology station began three weeks prior to the events. Because eelgrass is a marine plant growing within the waters of the estuary, it was not feasible for students to visit natural beds. To address the issue, six 1 m^3 mesocosm tanks were planted with eelgrass for student exploration (Davis and Short 1997), but required several weeks to acclimate to the tanks.

The eelgrass ecology station was designed to introduce students to the physical structure of eelgrass as well as its role as nursery habitat for juvenile fish and invertebrates. The water quality station provided students with a hands-on opportunity to measure various water quality parameters, similar to the *in-situ* measurements taken by researchers at Jackson Estuarine Laboratory. Because the water testing was done on floating docks, all participants were first outfitted with PFDs to ensure safety. Finally, the human impact station highlighted both the beneficial and detrimental impacts humans can have on a natural system. Full descriptions of activities and their objectives can be found in Appendix C.

Feedback on the effectiveness of the outreach event was gathered from conversations with the ORMS teachers and students following the event. In addition, interested students were given the opportunity to create interpretive panels to display throughout the community. Discussions during afterschool work on the panels and interpretation of student artwork also contributed to determining the effectiveness of the lesson plan and outreach event.

Results

Outreach Event

Prior to breaking the students into the smaller groups for the learning stations, all 40 participants were introduced to the abiotic requirements of eelgrass through *Oh Eelgrass* (Appendix C). The activity illustrated the effects of both excess and limited resources, such as nutrients and light, on an eelgrass population.

At the eelgrass ecology station, large tanks planted with eelgrass introduced students to eelgrass and provided an opportunity to measure plant parameters and participate in activities. *Predator Snapshot* (Appendix C) emphasized the nursery role of eelgrass, comparing the effectiveness of bare sediment with vegetated tanks for fish habitats. Students were even given the chance to step into the role of juvenile fishes trying to escape predation during *Camouflage* (Appendix C). Both activities addressed the fifth grade science objectives of exploring organism interactions and dependence upon one another (NHDOE 2006).

The water quality station provided students with an opportunity to measure salinity, temperature, and turbidity of the GBE. Salinity was measured using a hydrometer, temperature with a thermometer, and turbidity with a secchi disk. An YSI meter, an electronic data collector, was used after sampling to compare results for temperature and salinity. The comparison was conducted by recording student results on a white board and adding the YSI measurements next to them. The difference in the level of precision sparked a discussion among students regarding human bias and reliable measurements. Comparison of data collection methods is another objective of the New Hampshire Science Literacy Curriculum Framework for fifth graders (NHDOE 2006). In addition, the data for each parameter was compared with ideal and survival ranges for eelgrass (Appendix C) to determine the quality of the area for eelgrass habitat. The comparison of water quality parameters in the GBE with eelgrass requirements touched on the fifth grade objective addressing the direct effects of water quality on living things (NHDOE 2006).

The human impact station reviewed the cumulative effects of individual actions during *Clean up the Bay!* (Appendix C). The activity also focused on the effort and problems associated with cleaning up a degraded system compared with preventative methods. *Habitat Hopscotch* (Appendix C) illustrated the effects of habitat fragmentation, transforming students into juvenile fish seeking shelter in eelgrass beds throughout the bay. The two activities were designed to focus on the objective exploring the consequences of human-caused change in natural systems (NHDOE 2006).

The outreach events culminated in a second large group activity, involving all 40 students. *Stressful Situation!* (Appendix C) illustrated the effects of environmental stressors on eelgrass and linked the effects of human activity on the degrading water quality and the recent decline in eelgrass in the GBE.

Interpretive Panels

In the week following the outreach events, students were invited to share their new understanding of the GBE with the greater community through the creation of 3x4' interpretive panels. The panels presented a combination of text and student artwork (Fig. 10) and highlighted 1) the role of eelgrass in the GBE, 2) contributors to the current eelgrass decline, and 3) possible mitigation efforts and behavioral changes to conserve eelgrass within the GBE. More than a dozen students participated in the creation of the panels, which culminated in a student presentation to the Durham Conservation Commission. Creation of the interpretive panels addressed the state objective focusing on data presentation (NHDOE 2006). Versions of the panels were displayed at Durham Town Hall, Oyster River Middle School, Sandy Point Discovery Center, Jackson Estuarine Laboratory, and the University of New Hampshire.

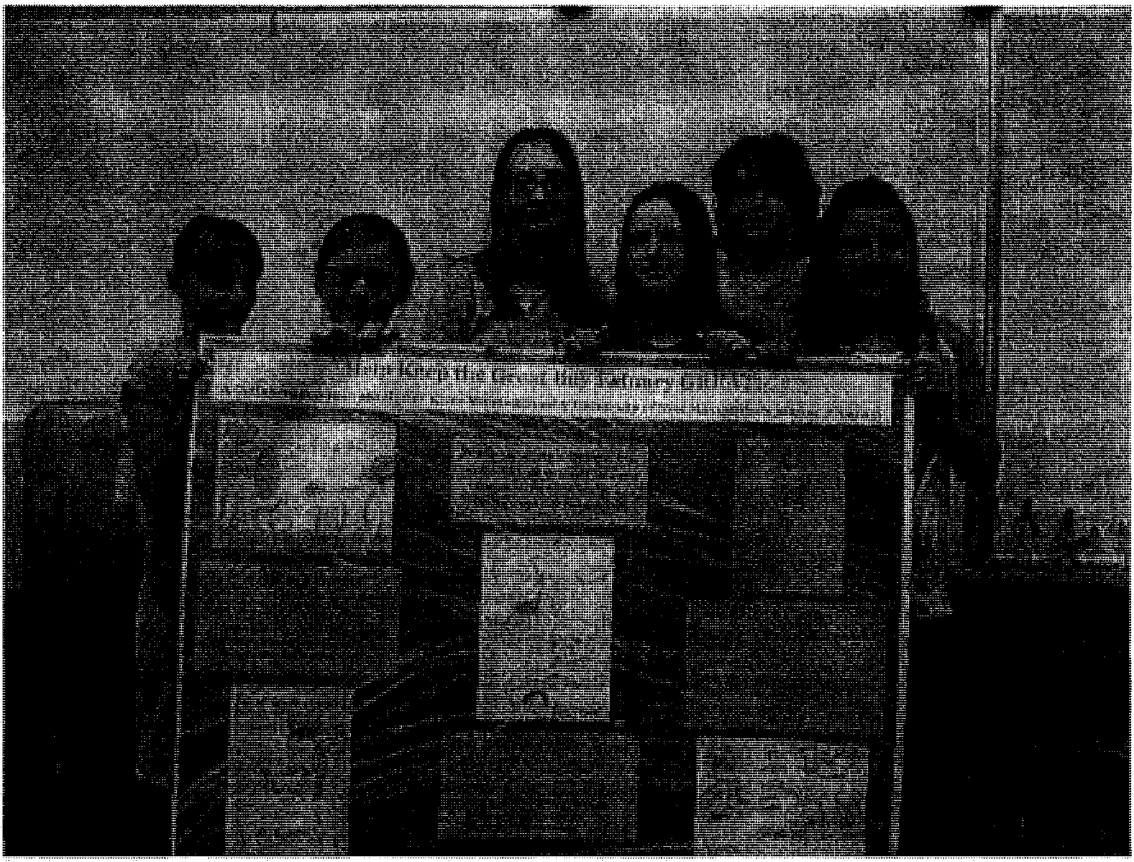


Figure 10. ORMS students posing with a completed interpretive panel.

Student Response

To evaluate what students took away from the lesson plan and associated outreach event, I sought to determine which functions of eelgrass they valued most and what human impacts the students perceived as having the greatest effect on the estuary. Information used for the assessment was a combination of student responses during the outreach event, information presented on the interpretive panels, and interpretation of student artwork.

The importance of eelgrass as a nursery habitat for juvenile fish was clearly depicted in the students' artwork (Fig. 11) and in their responses. The stronger connection with eelgrass functions associated with animals reflects people's ability to relate better to animals than plants. The link between eelgrass and higher trophic levels provided the students something more tangible for the students to focus upon and better appreciate the foundation role of eelgrass in the estuary. Some of the students came away from the outreach event with the impression that fish in the GBE eat eelgrass, which is not the case. While the misconception was not picked up during the outreach event, several student drawings illustrated fish eating eelgrass, allowing me to realize the problem. Future outreach events should emphasize that while eelgrass provides important habitat fish in the GBE, it is not a food source for the fish.

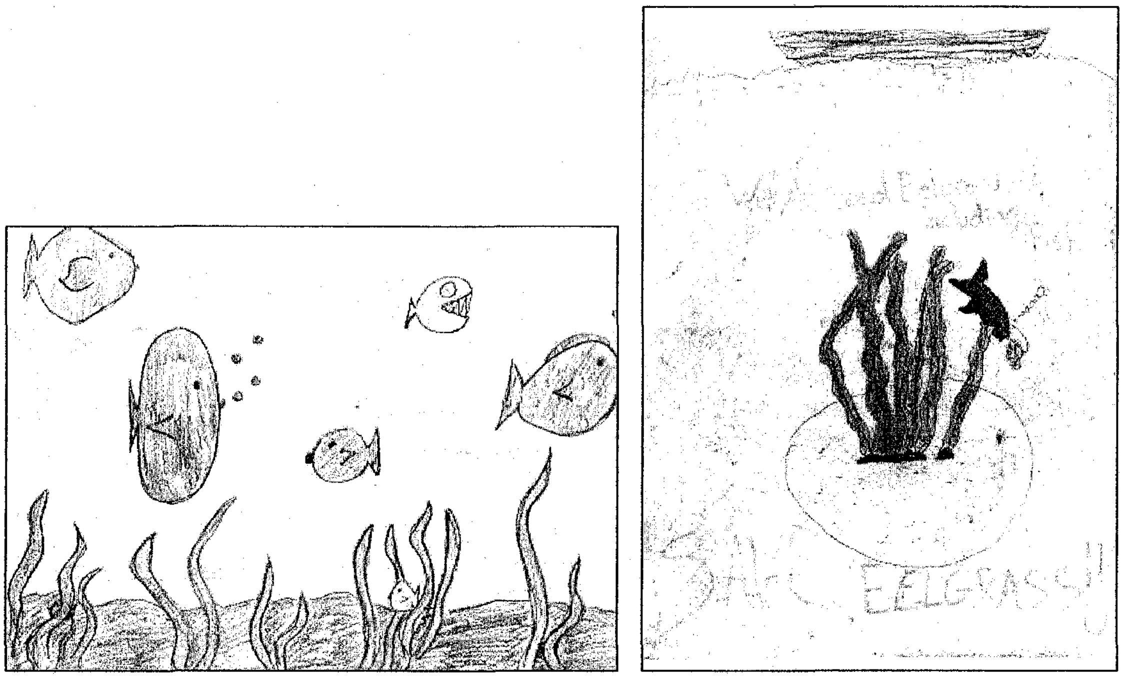


Figure 11. Student images depicting the role of eelgrass within the Great Bay Estuary.

Water quality testing of the GBE showed measurements within the ideal range for temperature and salinity, but not for clarity. Through further exploration of water quality during *Clean up the Bay!* (Appendix C), students identified fertilizer, soil erosion and septic/sewage inputs as the primary contributors to the reduced water clarity (Fig. 12). A handful of students mentioned pesticides as a potential stressor to eelgrass, given the rural landscape of some of the surrounding towns.

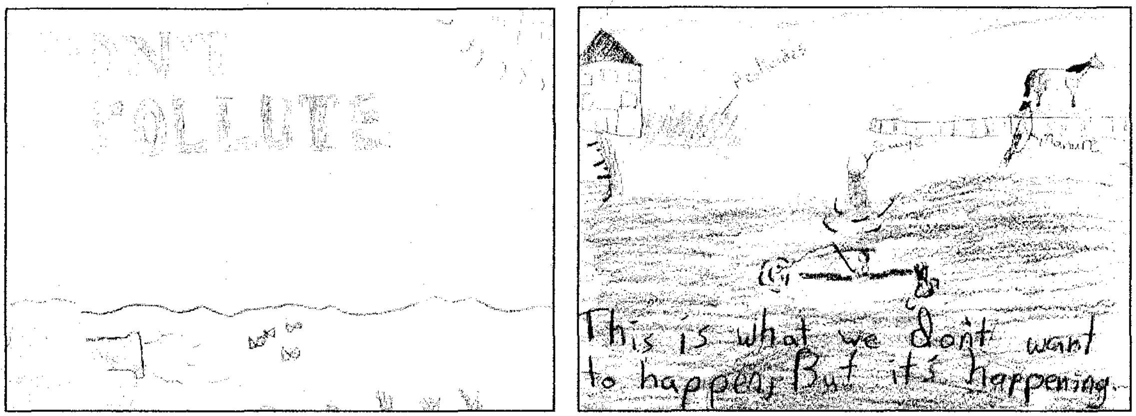


Figure 12. Student images depicting the primary contributors to eelgrass decline within the Great Bay Estuary.

Teacher Response

Conversations with the ORMS teachers following the outreach event yielded overwhelmingly positive feedback. The ORMS teachers and principal were excited to collaborate with another organization within the local community and to learn more about research in the GBE. None of the teachers were aware of the local eelgrass decline prior to the creation of the supplemental lesson plan, but were eager to incorporate real trends into their curriculum. The science teachers were conducting a unit on water quality at the time of the outreach event, and found that study of the recent eelgrass decline fit well, allowing students to conduct 'detective work' through water quality testing to link the effects of human activity on eelgrass. The ORMS teachers expressed a strong desire to incorporate the outreach event and trip to UNH's Jackson Estuarine Laboratory into the science curriculum as an annual event.

The teachers were particularly excited about the creation of the interpretive panels following the event. The teachers believed displaying the interpretive panels throughout the community would help instill a sense of pride and stewardship in the students. In addition, it would provide an opportunity for students to share the newly acquired information about the GBE with other members of the community.

Discussion

Creating an effective and relevant supplemental lesson plan required the involvement of the New Hampshire Science Literacy Curriculum Framework, ORMS teacher input, and an emphasis on experiential learning. The result was a 2.5 hour outreach event and the creation of interpretive panels displayed throughout the community. Investigation of the student responses revealed the nursery habitat role of eelgrass as the plant's most valued ecological function. However, the dominance of this response was likely a combination of the focus of the outreach and the prior knowledge base of students. The activities *Web of Life*, *Camouflage*, *Predator Snapshot*, and *Habitat Hopscotch* (Appendix C) all touched upon the connections between fish and eelgrass.

The emphasis on food webs and trophic interactions was guided by the objectives of the NH Science Framework for fifth grade (NHDOE 2006), and led to the overshadowing of other essential functions of eelgrass. The more complex functions of eelgrass, including water filtration and reduction of wave energy, may be more appropriate for high school science curriculum - a possibility for future outreach efforts.

The outreach event was intended to both get students interested in eelgrass and get them outside. The increasing rates of television and computer use by children, now up to almost 7 hours a day (Roberts et al. 1999), are leading to an obesity epidemic (Institute of Medicine 2005) and nature deficit disorder. "Nature-deficit disorder," a term coined by author Richard Louv, refers to a disconnect with the natural world driven by children (and adults) spending less time outside and more time in front of television and computers (Louv 2005). The trend has been connected with the rise in both obesity and behavioral problems in children. Experiential education may be an important part of the cure. Not only has experiential education been shown to improve standardized test scores (SEER 2000), it also increases children's attention capacity and ability to deal with stress (Wells 2000). The academic and health benefits of experiential education make it an attractive and important supplement to traditional classroom teaching.

The eelgrass lesson plan and outreach event brought the benefits of experiential education to ORMS, a school already committed to ecological awareness. The outreach event focused on familiarizing students with eelgrass and the local estuary while also adhering to the state science standards and fulfilling several of the overarching goals of the New Hampshire Science Literacy Curriculum Framework. The opportunity for students to learn using their local environment benefits not only their own academic achievement, but also the scientific and residential populations in the community.

APPENDICES

APPENDIX A

ORIGINAL DATA FOR CHAPTER I

Mean biomass (g m^{-1})and standard error for all NHPA sample sites

	OCC	SE OCC	T1	SE T1	T3	SE T3	R2	SE R2	DP	SE DP
2001	146.99	33.62	162.77	39.88	40.86	11.39	21.52	1.95		
2002	97.98	17.84	109.99	12.10	142.80	19.43	67.86	17.99		
2003	42.90	9.30	105.19	17.24	184.14	15.95	101.90	18.40	30.76	7.35
2004	56.43	19.84	82.91	18.14	156.46	26.17	79.91	18.13	45.55	9.47
2005	62.64	16.36	21.23	5.15	117.62	12.20	70.75	6.48	59.75	10.34
2006	5.85	1.27	7.07	1.75	44.52	13.44	28.74	4.41	18.11	4.83
2007	0.00	0.00	0.00	0.00	2.88	0.79	0.81	0.23	0.00	0.00

Mean density (shoots m^{-2}) and standard error for all NHPA sample sites

	OCC	SE OCC	T1	SE T1	T3	SE T3	R2	SE R2	DP	SE DP
2001	325.00	29.24	304.00	47.47	226.00	33.53	327.00	33.53		
2002	238.86	93.64	203.43	27.85	456.00	54.78	212.00	33.47		
2003	163.00	27.34	217.00	28.09	415.00	45.72	270.00	38.83	123.00	20.22
2004	162.00	39.82	178.00	28.32	257.00	54.06	130.00	18.44	117.00	17.69
2005	173.00	39.34	103.00	18.16	317.00	32.77	167.00	26.55	167.00	28.58
2006	71.00	12.14	49.00	12.27	183.00	34.95	118.00	18.62	65.00	13.73
2007	0.00	0.00	0.00	0.00	44.00	8.14	29.00	5.64	0.00	0.00

Mean canopy height (cm) and standard error for all NHPA sample sites

	OCC	SE OCC	T1	SE T1	T3	SE T3	R2	SE R2	DP	SE DP
2001	82.26	12.07	71.96	5.46	39.84	4.32	61.13	6.36		
2002	78.00	10.52	61.51	3.49	54.37	6.69	67.43	10.72		
2003	51.69	5.37	73.68	8.88	91.08	4.47	79.41	6.21	49.89	5.89
2004	50.90	6.54	76.36	9.21	112.75	2.41	75.85	7.06	52.16	4.02
2005	54.13	4.83	39.39	2.70	67.42	4.48	59.13	5.52	58.25	4.01
2006	19.20	1.34	25.57	1.92	38.82	3.14	45.86	2.02	41.61	2.00
2007	0.00	0.00	0.00	0.00	6.75	1.30	4.05	0.81	0.00	0.00

Mean leaf area (cm^{2} shoot^{-1}) and standard error for all NHPA sample sites

	OCC	SE OCC	T1	SE T1	T3	SE T3	R2	SE R2	DP	SE DP
2001	208.30	33.72	165.02	14.21	80.30	15.38	155.02	18.71		
2002	160.39	21.83	131.95	13.18	109.56	15.25	146.09	30.46		
2003	128.72	16.49	169.74	20.67	208.53	14.96	218.30	23.95	114.86	15.28
2004	115.10	14.18	139.75	21.86	229.08	7.88	182.13	24.30	123.13	15.67
2005	117.19	15.58	70.99	8.29	140.28	13.67	113.60	12.43	132.91	15.58
2006	25.12	2.90	36.68	3.50	55.20	9.42	74.95	6.34	82.50	7.51
2007	0.00	0.00	0.00	0.00	8.09	1.85	4.16	1.00	0.00	0.00

Mean percent cover (%) and standard error for all NHPA sample sites

	OCC	SE OCC	T1	SE T1	T3	SE T3	R2	SE R2	DP	SE DP
2001										
2002	83.37	2.15	51.60	2.42	64.81	2.77	61.83	2.25		
2003	36.81	2.48	44.31	2.75	95.05	1.12	77.46	2.02	29.72	2.10
2004	49.13	2.59	65.32	1.91	90.75	1.29	53.29	2.58	37.98	2.32
2005	37.18	2.18	25.15	1.90	72.43	2.12	49.88	2.13	50.10	2.15
2006	13.90	0.88	21.18	1.38	48.18	2.22	55.48	1.95	34.85	2.17
2007	0.00	0.00	0.00	0.00	5.28	0.43	1.17	0.14	0.00	0.00

APPENDIX B

ORIGINAL DATA FOR CHAPTER II

Latitude and longitude coordinates for the GBE study sites sampled in August 2007

Site	**Latitude**	**Longitude**
G1	43° 06' 66"N	70° 69' 64"W
G2	43° 07' 44"N	70° 70' 02"W
G3	43° 07' 24"N	70° 71' 41"W
G4	43° 07' 68"N	70° 72' 47"W
G5	43° 07' 17"N	70° 73' 71"W
G6	43° 07' 50"N	70° 74' 15"W
G7	43° 07' 56"N	70° 74' 25"W
G8	43° 08' 65"N	70° 75' 82"W
G9	43° 11' 15"N	70° 80' 71"W
G9A	43° 11' 99"N	70° 80' 96"W
G10	43° 12' 50"N	70° 84' 33"W
G11	43° 12' 83"N	70° 86' 11"W
G12	43° 08' 97"N	70° 86' 93"W
G13	43° 08' 44"N	70° 86' 91"W
G14	43° 08' 42"N	70° 86' 92"W
G15	43° 08' 27"N	70° 87' 60"W
G16	43° 06' 34"N	70° 90' 15"W
G17	43° 07' 01"N	70° 87' 27"W
G18	43° 06' 88"N	70° 86' 19"W
G19	43° 06' 17"N	70° 86' 37"W
G20	43° 06' 64"N	70° 84' 96"W

Distance of study sites from coast (m) using the set point (43°05’12”N, 70°68’86”W) as a reference

Site Number	Distance from Coast
1	1830.49
2	2747.35
3	3403.73
4	4773.08
5	5282.53
6	5798.97
7	5904.20
8	8169.91
9	13025.71
9A	13753.05
10	16682.74
11	18210.75
12	22774.14
13	23362.76
14	23411.95
15	27147.03
16	27493.85
17	25084.24
18	25884.51
19	26144.65
20	26910.15

Mean Leaf Mass, %N, and NPI, including standard error, for study sites sampled August 2007

Site	Mean % N	SE	Leaf Mass (mg cm^{-2})	SE	NPI	SE
1	1.6825	0.0758	5.6321	0.4054	0.3125	0.0271
2	1.8336	0.0472	5.7576	0.5445	0.3377	0.0274
3	1.7557	0.0522	5.2725	0.2544	0.3413	0.0220
4	1.8100	0.0576	5.5796	0.5602	0.3499	0.0308
5	2.0793	0.0790	3.6047	0.3013	0.5973	0.0356
6	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
7	2.5792	0.1371	3.0610	0.1827	0.8734	0.0745
8	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
9	2.0492	0.1111	3.8250	0.4648	0.5642	0.0784
9A	1.7903	0.0895	3.7132	0.1771	0.4892	0.0244
10	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
11	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12	1.8103	0.1132	2.8664	0.1727	0.6622	0.0590
13	1.7915	0.1001	3.2507	0.1465	0.5703	0.0545
14	1.6456	0.0997	2.8952	0.2717	0.6050	0.0613
15	2.2675	0.1063	2.6299	0.1587	0.9005	0.0822
16	2.1049	0.0744	1.9756	0.0912	1.1020	0.0981
17	1.5077	0.0740	2.9855	0.1493	0.5206	0.0421
18	1.3806	0.1019	3.1233	0.1235	0.4558	0.0433
19	1.8780	0.1074	2.3724	0.0785	0.8077	0.0647
20	2.1247	0.0477	2.4642	0.1463	0.8934	0.0795

APPENDIX C

SUPPLEMENTAL EELGRASS LESSON PLAN

SEAGRASS OVERVIEW

Seagrasses are not true 'grasses,' but marine flowering plants that grow in intertidal and shallow subtidal portions of coastal waters. Seagrasses are also not seaweed. Seaweeds are not plants but protists (organisms with no tissue specialization), have no root system, and produce asexually (Fish and Wildlife Research Institute 2008). Seagrasses are considered vascular plants possessing nutrient transport systems, have roots and underground stems called rhizomes, and produce flowers and seeds. It is also important to note that seagrasses are not salt marsh plants. Plants growing in salt marshes, such as cordgrass (*Spartina alterniflora*) and salt hay (*Spartina patens*) are salt-tolerant terrestrial grasses even though they can become partially submerged during high tide.

There are nearly 60 species of seagrasses worldwide (den Hartog 1970, Green and Short 2003) and can be found off every continent except Antarctica. The bioregion with the highest species diversity, 24 species, is the tropical Indo-Pacific region, the waters between east Africa, south Asia, tropical Australia, and the eastern Pacific (Short et al. 2007). The northeast coastline of the United States has low species diversity, 2 species, and is dominated by the species eelgrass or *Zostera marina* (Short and Short 2003). Seagrasses fill an important niche in the world's oceans, creating a buffer at the land-water interface of the coast. The information presented below focuses on eelgrass, because it is the primary seagrass found in New Hampshire. Widgeon grass (*Ruppia maritima*) is also found in New Hampshire, and for a long time was not considered a seagrass, because of its ability to grow in fresh water (Green and Short 2003).

As mentioned before, the physical structure of seagrass is one of the major differences between it and seaweed, another marine primary producer. The structure of seagrass can be divided into above and belowground material (Fig. 1a). Seagrasses are the only submerged marine plants with root systems (Short et al. 2007), which help to stabilize sediment while anchoring the plant. The belowground material also includes rhizomes, or underground stems, that branch out below the sediment and sprout lateral shoots. The aboveground plant material consists of the leaves, which grow in bundles called shoots. New leaves are produced in the center of the bundle of leaves with the oldest growing on the exterior of the bundle (Fig 1a).

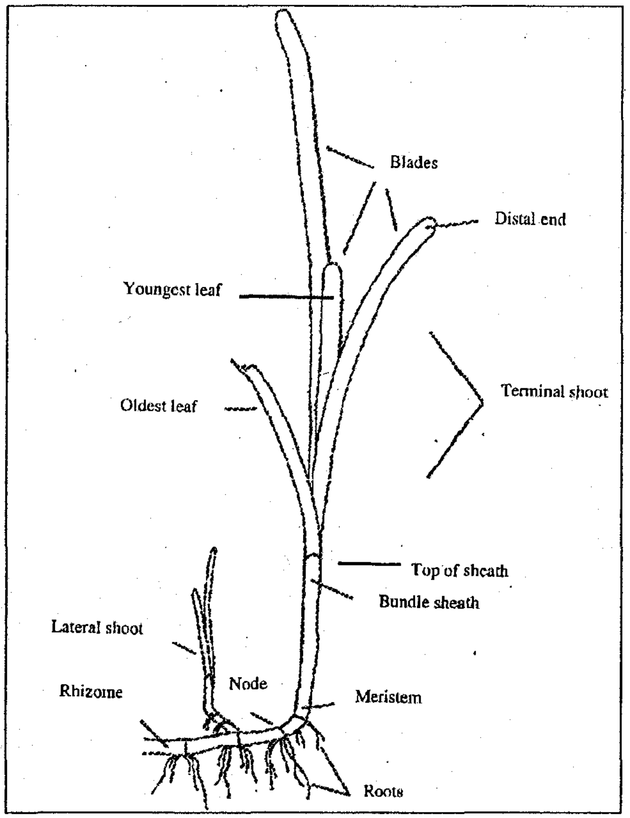


Figure 1a. Diagram of eelgrass plant structure. From Hoven (1992).

With the exception of some shallow intertidal beds, seagrass plants are always submerged, and thus do not possess a rigid leaf structure to support the plants. Out of the water, leaves are flaccid and lay on the surface of the substrate, illustrating their reliance on buoyancy to hold the plants upright.

Seagrasses reproduce sexually through the production of flowers, fruits and seeds. Once a shoot becomes reproductive and produces seeds, it dies. However, all seagrasses also have the ability to reproduce asexually, or clonally (Short et al. 2007). As mentioned before, rhizomes grow horizontally below the sediment and send up new lateral shoots, which possess the same genetic material as the parent plant. The ability to reproduce clonally as well as through seed production enables seagrasses to better deal with environmental disturbances; many species have come to rely heavily on lateral shoots for population growth (Rasheed 1999).

Water quality requirements for seagrasses vary among species. All seagrass species need light for photosynthesis, but the minimum requirement varies. Plants also have varying salinity and water temperature ranges. The ideal and survival ranges of eelgrass for water temperature, salinity, and water clarity are presented in Table 1.

Table 1a. Water quality requirements for eelgrass.

Water Temperature	
Survival range:	-6 to 34°C (21-93°F)
Ideal:	25°C (77°F)
Salinity	
Survival range:	5-60
Ideal:	15-25
Water Clarity	
Minimum:	22% of surface light

References for the water quality parameters are as follows: water temperature (Biebl and McRoy 1971); salinity (Short and Short 2003); water clarity (EPA 2003).

Seagrass ecosystems perform a number of ecologically important functions in coastal waters. The physical structure of the plants, both above and belowground, helps to stabilize sediment and filter particulate matter out of the water column (Short and Short 1984). The filtering of the water column by seagrass increases water clarity and light reaching the plants, increasing their capacity to photosynthesize. Aboveground seagrass material also reduces wave energy and slows water currents, allowing suspended material to collect within the seagrass bed (Fonseca et al. 1982; Koch 2001). The older leaves and poorly rooted plants are often uprooted by storm events, creating floating islands of 'wrack' in within an estuary. The dead plant material eventually washes up on shore, providing an important food source for detritivores such as amphipods. The decaying plants found on beaches are how most people in New England are familiar with eelgrass.

The dense patches of seagrass shoots are known as beds or meadows. The physical structure and camouflaging ability of the seagrass canopy offers protection to juvenile fish and invertebrates from predation. Because juvenile fauna are regularly found in seagrass beds, they are often referred to as 'nursery habitats.' In New England, the habitat created by eelgrass not only provides shelter, but also an important link between other estuarine habitats such as salt marshes, oyster reefs and mussel beds. Species such as mud snails that are found in both salt marshes and eelgrass beds often start their life as eggs on an eelgrass leaf to prevent desiccation (Coulombe 1984). Blue mussels also settle on eelgrass leaves in their early stages before settling on the substrate (Heck et al. 1995). Some species, such as lobster, burrow in the mud beneath the eelgrass beds (Heck and Orth 1980, Short et al. 2001). Other commercially important species, including flounder and bay scallops have also been shown to utilize eelgrass meadows as critical nursery habitat (Heck et al. 1995).

In addition to providing shelter, seagrass leaves and the detritus that collects in the root system provide important food sources. Turtles and manatees graze on seagrass in tropical climates. In New England, small invertebrates such as isopods feed on eelgrass leaves. Larger invertebrates and juvenile fish in turn feed upon the isopods. The dead leaves and other detritus that collects in the eelgrass root system also contribute greatly to the estuarine food web. Gastropods (eg. snails), grass shrimp, and polychetes (marine worms) all feed upon the detrital material in eelgrass beds, which can exceed the biomass of the living plant material (Adams and Angelovic 1970). The detritivores (organisms that eat decaying material) help convert nutrients in the plant material back into a usable form for the plants as well as provide another link in the estuarine food web.

SEAGRASS MEASUREMENTS

Measurements of seagrass parameters (eg. density, canopy height) provide useful information on the meadow's health and can be taken with little-to-no impact to the plants. Canopy height is defined as the height above the sediment of 80% of seagrass shoots. The measurement provides useful information about the ability of the bed to filter the water column and provide shelter for juvenile fish and invertebrates. To measure canopy height, bring together a handful of still-rooted plants (like a pony tail) and extend the leaves up through the water column to their full height, being careful not to uproot the plants. Ignoring the estimated tallest 20% of the leaves, place a meter stick at the surface of the sediment, and take a measurement of the highest of the other 80% of the plants (Duarte and Kirkman 2001). Removing the tallest 20% of plants from the measurement helps reduce the influence of very tall leaves on the overall measurement of the eelgrass bed; these tallest leaves do not contribute to the canopy structure of the bed.

Percent cover is an estimate of the percentage of estuarine bottom covered by eelgrass plants. The measurement gives a quick estimate of plant abundance, and although it is more subjective than measuring shoot density directly (see below), it has been shown in studies to be a very effective metric (Heidelbaugh and Nelson 1996). Placing a quadrat into the eelgrass bed, look straight down and estimate the percentage (0-100%) of bottom, or substrate, covered with eelgrass leaves (Duarte and Kirkman 2001). It is useful to have reference photos illustrating various percentages of eelgrass cover (downloadable from http://marine.unh.edu/jel/faculty/fred2/fredshort.htm).

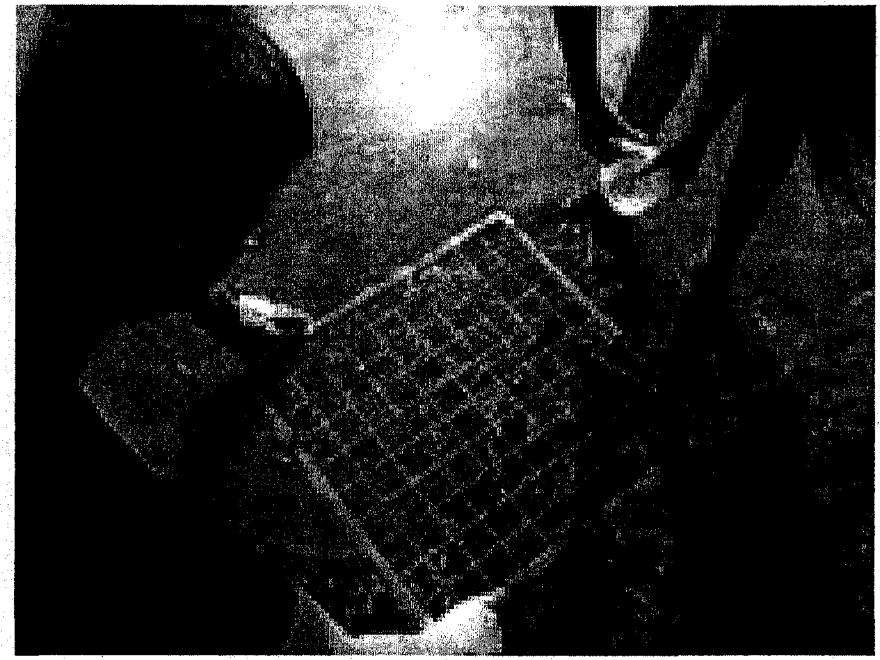


Figure 2a. Measuring eelgrass percent cover using a quadrat

In addition to percent cover, shoot density can be measured by counting the number of eelgrass shoots in a given area. To measure, place a quadrat of known size into an eelgrass bed and count all of the shoots within the area, being careful not to uproot any plants (Duarte and Kirkman 2001). The measurement can be difficult in areas of soft, fine sediment, since water easily clouds when disturbed. The shoot counts can later be converted into a standard measurement of shoots per meter^2 by multiplying the count by a given value, depending on the quadrat size. In the case of the 25x25cm quadrat, results can by multiplied by 16 to get shoots per meter^2. A measurement of shoot density can help determine the ability of the eelgrass bed to filter particles from the water column and to provide habitat for juvenile fish.

All of these measures, if done repeatedly over time, give a sense of trends in eelgrass health. Additionally, there are efforts to map and monitor eelgrass and seagrass populations over time to better understand large scale trends. SeagrassNet, a global monitoring program, is the largest of these efforts; the program measures various seagrass parameters on a quarterly basis, collecting data on both seasonal and long term trends in 27 countries worldwide (www.SeagrassNet.org).

NITROGEN AND EUTROPHICATION

In addition to salinity, temperature, and water clarity, seagrasses require certain nutrients to survive. Small increases in N can benefit eelgrass if the meadows are N-limited. A study of water column nitrogen enrichment found that fertilized plots of eelgrass exhibited significant increases in leaf length and biomass compared to controls (Orth 1977). A review of nitrogen addition experiments found increased eelgrass growth with low-to-moderate N additions (Burkholder et al. 2007). However, excess inputs of N have negative effects on seagrass in addition to increasing algal blooms. A mesocosm experiment found that N additions to eelgrass resulted in 75-95% shoot die-off compared with unenriched plants (Burkholder et al. 1992). Another study showed that, unrelated to light reduction, eelgrass growth is significantly diminished under excess N additions (van Katwijk et al. 1997).

In addition to the direct effects on eelgrass, N loading, the addition of excess amounts of nitrogen to a system, can lead to eutrophication. Eutrophication refers to increased plant growth caused by increased nutrient levels. While it can occur naturally, it is often associated with human inputs of N to a system, and is then referred to as cultural or anthropogenic eutrophication. In estuaries, eutrophication often leads to planktonic and macroalgal blooms (Orth and Moore 1983; Borum 1985; Kinney and Roman 1998). Algal blooms reduce the ability of surface light to reach the substrate, shading out seagrass. A study of N enrichment found excess nutrient loading significantly reduced eelgrass growth through competition with algae for light (Short et al. 1995). Eelgrass requires a minimum of 11% surface light (Duarte 1991) to survive, but needs much more light in order to thrive (Kautsky et al. 1986; Nielsen et al. 2002; Hauxwell et al. 2003). Percent surface light is a measure of the amount of light above the water reaching the substrate below. Eutrophication does not directly impede seagrass growth: excess nutrients are indirect stressors to the plants because of the algal blooms and associated light reductions they cause (Burkholder et al. 2007).

CONTRIBUTORS TO EELGRASS DECLINE

Seagrass decline has been documented both worldwide (Short and Wyllie-Echeverria 1996; Green and Short 2003; Orth et al. 2006), as well as locally in New

England (Short and Burdick 1996; Short et al. 1996; Deegan et al. 2002). Since 1960, Rhode Island's coastline has experienced a decline in eelgrass; in 2002 less than 40 hectares of eelgrass remained in Narragansett Bay (Save the Bay 2002). Aerial mapping of eelgrass in New Hampshire's Great Bay Estuary (GBE) showed a decline from 1,000 hectares down to 800 hectares over the past 14 years (Short 1992; NHEP 2006).

In the 1930s and again in the 1980s, the GBE in New Hampshire experienced drastic declines in the eelgrass population caused by wasting disease (Short et al. 1986; Short et al. 1987). Eelgrass populations were nearly eliminated in the GBE in the 1930s and did not reestablish healthy populations until the 1960s (Short et al. 1987). The wasting events were cause by the slime mold *Labyrinthula zosterae* (Short et al. 1986), which infects the cells of eelgrass leaves, causing dark lesions and eventual death of the plant (Short et al. 1987). While eelgrass rebounded after both these events, the plants now face new environmental stressors.

The recent decline in critical eelgrass habitat in New England has been attributed to nitrogen loading (Orth and Moore 1983; Short et al. 1995; Deegan et al. 2002), increased housing development (Short et al. 1996; Short and Burdick 1996), and grazing by Canada geese (Rivers and Short 2007). Shoreline development, characterized by impermeable ground cover such as asphalt and concrete, reduces an area's natural ability to absorb rain and runoff, promotes soil erosion, and leads to higher sediment and nutrient loads entering the estuary (Lee and Olsen 1985), both of which ultimately impact seagrass growth.

Sedimentation, the addition of particulate matter into an aquatic system, is another major factor in seagrass decline. Excess additions of sediment into an estuary cloud the water, increasing turbidity and reducing the amount of surface light reaching the substrate. Shoreline development and the creation of impervious surfaces increase the volume of sediment into a watershed (Steinke et al. 2007). In New Hampshire's Great Bay Estuary, sediment concentrations have increased 81% over the past 25 years (NHEP 2006).

In addition to declines caused by nutrient and sediment additions, seagrasses also experience direct physical damage from docks, boat moorings and propellers, and dredging. Boat docks reduce light levels, shading out plants and fragmenting eelgrass beds (Burdick and Short 1999). Dredging and dragging of the estuary bottom through moorings, channel widening, and harvesting of mussels, uproots plants and reduces water clarity from re-suspension of sediment in the water column (Neckles et al. 2005).

Habitat fragmentation in regard to seagrasses is the shift from large, continuous seagrass meadows to smaller, isolated seagrass beds. Fragmentation can be caused by a number of different factors ranging from physical damage from boating and construction to localized nutrient or sediment loading. Fragmenting seagrass beds increases their vulnerability to erosion and diminishes their ability to stabilize sediments (Uhrin and Holmquist 2003). Isolating beds makes it harder for fish and invertebrate species associated with seagrass to travel between beds without being exposed to predation.

SEAGRASS RESTORATION AND REGULATION

The worldwide decline in seagrass and local decline in eelgrass in the Great Bay Estuary have lead to the creation of restoration techniques. Transplanting, the transfer of seedlings from a donor bed to a restoration area, is the most common method of restoration. While there are many techniques for transplanting, including manually planting individual plants, recent restoration efforts in New England utilize the Transplanting Eelgrass Remotely with Frame Systems or TERFS methodology created by UNH's Dr. Fred Short. The method involves tying eelgrass shoots to wire mesh frames with biodegradable crepe paper and distributing the frames within the restoration area. The frames are retrieved several weeks later when the paper has degraded and the eelgrass shoots have taken root. To be successful, a restoration must be done in an area where the underlying issue (water quality, direct impacts) has been addressed.

Figure 3a. Tying eelgrass shoots to a TERFS frame before planting

In addition to restoration efforts, legal regulations are beginning to be created to address declining seagrass populations. In response to the declining redfish populations, Texas created the Redfish Bay State Scientific Area (RBSSA) along the state's Gulf Coast. The RBSSA, which became effective in May 2006, protects 32,000 acres of coastline, 14,000 acres of which are submerged seagrass beds (Texas Parks and Wildlife

1999). The protected area, popular with recreational fisherman, has made it a Class C misdemeanor and up to $500 fine to uproot seagrass plants (Texas Parks and Wildlife 1999). The installation of the RBSSA was based upon similar boating regulations in Florida to deal with damage to seagrass beds from propeller scars. Federally, seagrasses are protected under the National Estuary Program (NEP), a 1987 amendment to the Clean Water Act (EPA 2007). The NEP is a voluntary program designed to maintain the health of an estuary through federal, state, and non-profit cooperation. Currently there are 28 NEP partnerships nationally (EPA 2007). In addition to NEPs, Section 404(c) of the Clean Water Act states that any individual who takes part in activities that affect seagrasses must mitigate the results of their actions.

THE GREAT BAY ESTUARY, NEW HAMPSHIRE

The Great Bay Estuary (GBE) is located on the New Hampshire-Maine border and has a watershed, or drainage area, of 930 square miles (Short 1992). The GBE is subdivided into three parts; Great Bay proper, Little Bay/ Piscataqua River, and Portsmouth Harbor. The eelgrass beds within the Little Bay and Portsmouth Harbor portions of the bay are primarily subtidal, and remain submerged even at low tide. The eelgrass beds in Great Bay are largely intertidal; plant leaves lie on the surface of the water at mean low tide. Subtidal plants are more susceptible to declines in water clarity, since they are never exposed to direct surface light and rely on light filtering through the water column to photosynthesize. However, plants growing in intertidal and shallow areas are exposed to additional stresses, including grazing by Canada geese. A shallow intertidal eelgrass bed located near Fishing Island in Portsmouth Harbor was completely lost because of over-winter grazing by Canada geese (River and Short 2007).

The subsections of the GBE also experience differing dynamics from point and non-point sources of sediment and nutrient loading. Point source refers to an identifiable localized source like an effluent pipe, while non-point describes a diffuse source such as runoff. Seven main tributary rivers drain into the estuary, carrying with them sediment and nutrients from upstream. The largest carriers of N loads, the Salmon Falls and Cocheco Rivers, empty into Little Bay, along with the Oyster and Bellamy Rivers. The Great Bay portion of the estuary has the remaining three tributaries, the Lamprey, Winnicut, and Squamscott Rivers flowing into it. While nutrient loads in the upper portions of the GBE enter primarily through non-point tributaries, Portsmouth Harbor is additionally influenced by the presence of the city's wastewater treatment facility. Wastewater treatment facilities, such as the one located in Portsmouth, are the largest point source contributors to N loading in the GBE (NHEP 2006).

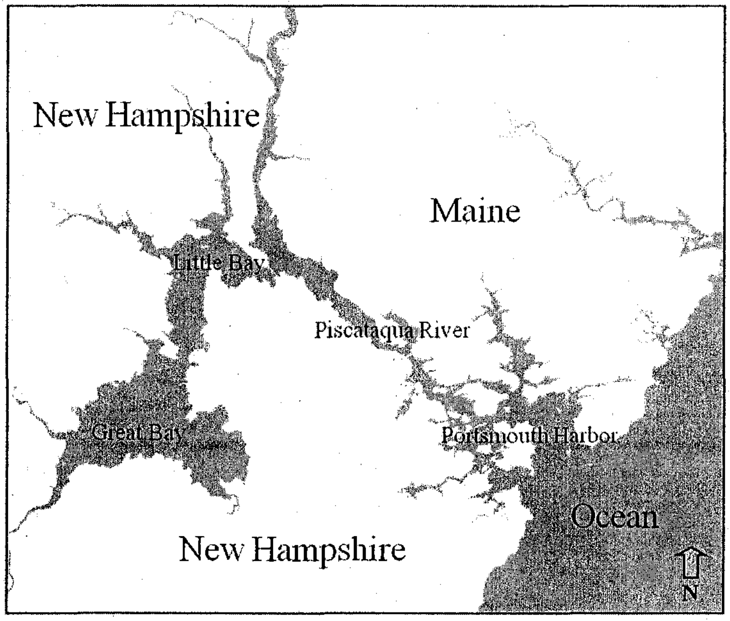


Figure 4a. Map of Great Bay Estuary, New Hampshire.

One of the state's most important natural resources, the GBE supports commercial fisheries, including lobster and flounder (Short et al. 2001; Evans and Short 2005). Unfortunately, the estuary has experienced a recent decline in annual catch for the majority of fish monitored (Trowbridge 2006b).

While over-fishing remains an issue, the loss of nursery habitat also plays a role in this decline. Between 1996 and 2004, eelgrass biomass within the estuary dropped from 1,600 metric tons down to less than 1,000 metric tons. During this same time period, eelgrass cover decreased 17 percent (NHEP 2006). The loss of eelgrass habitat and the subsequent loss of higher trophic levels are of great concern, especially since eelgrass is the most abundant primary producer in the GBE and the basis of the estuary's food web. Several ongoing field studies are monitoring eelgrass bed dynamics and addressing potential causes of the decline.

The New Hampshire Port Authority (NHPA) Mitigation Project was developed in 1993 to compensate for the loss of salt marsh, mudflat, and eelgrass habitat as well as loss of potential habitat resulting from the expansion of the New Hampshire State Port and associated dredging of the Piscataqua River. Approximately 2.5 hectares of eelgrass were transplanted in areas of the Piscataqua River upstream from the Port. The completed eelgrass transplanting effort is evaluated annually through a 15-year (1995 to 2010) monitoring program (Bosworth and Short 1993). By 2000, the eelgrass transplant sites had reached the functional level of nearby natural beds, indicating the transplant efforts were successful (Evans and Short 2005). However, data from 2001 to 2008 showed a significant decline in eelgrass measurements, especially biomass (Beem and Short 2008). Increases in impervious surfaces, suspended solids, and water column nitrogen have all contributed to the decline in GBE water quality, and are likely connected to the recent loss of eelgrass (NHEP 2006).

GREAT BAY ESTUARY FOOD WEB

In estuaries, as in many ecosystems, the energy from the sun fuels the photosynthetic process within primary producers. In the Great Bay, these are eelgrass, algae, and phytoplankton. Isopods, small arthropods, feed upon eelgrass leaves. In turn the isopods are fed upon by small fish, including sticklebacks, pipefish, and silversides. Sticklebacks and pipefish also seek shelter in eelgrass beds. These fish are fed on by larger fish, such as striped bass. Harbor seals also feed upon schooling fish like silversides in addition to crustaceans and squid (NEFSC 2007).

Organisms also rely upon the physical structure of eelgrass for survival. Mud snails lay their eggs on eelgrass blades to prevent desiccation (Coulombe 1984) and blue mussels settle on eelgrass leaves in their early stages before settling on the substrate (Heck et al. 1995, Grizzle et al. 1996). Some juvenile invertebrates, such as lobsters, burrow in the mud beneath eelgrass beds for protection against predation (Short et al. 2001). Horseshoe crabs forage in eelgrass beds looking for mollusks and marine worms (NYS DOS 2002). Green crabs also forage in eelgrass beds for soft shell clams and blue mussels. However, the foraging and burrowing by green crabs can be incredibly disruptive to the beds, as the crabs cut or tear eelgrass shoots during these pursuits (Davis et al. 1998). Even birds utilize eelgrass beds during low tide. Wading birds like blue herons search eelgrass beds for crabs and fish, while Canada geese graze directly on the leaves (Rivers and Short 2007). The trophic interactions mentioned highlight the importance of eelgrass as the basis for the Great Bay's food web.

SUPPLEMENTAL LESSON OVERVIEW

Below is the outline of an outreach event hosted at the University of New Hampshire's Jackson Estuarine Laboratory in June 2008. The outline was designed for an event that lasted 2 hours and 15 minutes, allocating time for a group introduction and 3 subsequent learning stations. The outline is intended as a guide; the described activities can be conducted during a single event or over an extended period of time, supplementing them into existing curriculum as appropriate.

OUTLINE FOR OUTREACH EVENT

Total Event Time: 2 hours and 15 minutes

I. Group Introduction – 20 minutes

1. Introduce myself and other instructors
2. Briefly highlight the objectives
3. Introduce trend of declining eelgrass in the Great Bay Estuary (GBE), highlight thinking about causes – will revisit at the end of the day
4. Introduce and play *Oh Eelgrass*

II. General Ecology Review (focus on primary producers) – 10 minutes

1. Split larger group of students into three smaller groups
2. Instructor introduction, student names
3. Create GBE *Web of Life*, manipulate different components to see effects

Rotating Stations (3) – 30 minutes each, 90 minutes total

(Each station will include 25 min of activities and 5 min for travel between stations)

III. Eelgrass Ecology – 25 minutes

1. Introduction to the parts/structure and growth of eelgrass plants
2. Understand the role of eelgrass as nursery habitat through *Predator Snapshot*
3. Reinforce protective role of eelgrass through *Camouflage*
4. Measure shoot density in tanks using $0.0625m^2$ (25cmX25cm) quadrats
5. Measure canopy height using meter sticks and rulers

IV. Water Quality Testing – 25 minutes

1. Outfit all participants with PFDs before heading to boat docks
2. Introduce the tools used to measure various parameters of water quality
3. Break students into 3 smaller groups, have each group test either salinity, temperature, or turbidity and then switch
4. Use YSI meter (adult) to test pH and compare with student results for other parameters

V. Human Impact – 25 minutes

1. Brainstorm potential human impact (good and bad) for GBE
2. Use *Habitat Hopscotch* to help explain habitat fragmentation
3. Review the cumulative effect of individual actions with *Clean up the Bay!*
4. Discuss possible solutions/mitigation efforts to preserve eelgrass habitat

VI. Group Wrap-Up – 15 minutes

1. Revisit/review results of the three stations
2. Brainstorm links between water quality, eelgrass ecology, and human impact
3. Reminder of after school poster project
4. Culminating activity – *Stressful Situation!*

ACTIVITIES

Oh Eelgrass

Oh Eelgrass, an activity that highlights the effects of limited or excess resources, is adapted from Project WILD's Oh Deer (1983a). The main objectives of this activity are:

- Understand the basic resources needs for eelgrass survival: proper sediment, sunlight, and nutrients
- Learn how excess or limit amounts of certain resources affect the populations
- Address one factor (resource abundance) influencing eelgrass populations

To prepare for this activity, you will need the following:

- 4 cones or other objects to mark boundaries

The activity works best with groups of 10 individuals or more. To begin, brainstorm the key resources for eelgrass survival. With help, students should be able to come up with sunlight, nutrients, and proper sediment. Next, split the group evenly in 2 and line the groups up facing one another on two parallel lines. One line will represent eelgrass plants and the other will represent the key resources eelgrass needs for survival. Each of the 3 resources will be designated by its own signal, which all participants must learn prior to beginning the activity. Potential signals include nutrients by hands on the stomach, light with hands forming goggles around the eyes, and sediment with hands on the feet. Once everyone learns the signals, the activity can proceed. For more in-depth assessments of the population patterns, instructors can record the results of each round for later discussion and even graphical representation. Each round will represent one year.

To begin, the two lines should face away from one another. Participants on the eelgrass side will individually decide which of the 3 resources they need for the year. On the resource line, each person will decide which resource to represent. Participants are not allowed to change hand signals until the next round. On the count of 3, participants on both sides will turn around to face one another, displaying their chosen hand signals. The eelgrass will then run over to the resource side, looking for what they need to survive. When an eelgrass finds a resource displaying the same hand signal, he or she will then bring the resource back to the eelgrass line and both will represent eelgrass in the following round. Resources cannot move unless an eelgrass has claimed him or her. If an eelgrass cannot find the needed resource, then he or she dies and moves to the resource line. Resources that are not claimed remain on the resource line.

Once the first round has finished, participants will again turn their backs to one another and decide on hand signals for the round. The activity should continue for as many rounds as it takes to illustrate a scarcity of resources followed by a die off of eelgrass. The activity can then continue to show the rebound of the surviving eelgrass into sustainable populations, followed by another population boom and resource shortage. The number of rounds will be dependent on group size and comprehension level. To address specific issues, instructors can silently assign the resources to all show the same signal, such as nutrients, or have no one signal a specific resource, such as light. Representing ecological stressors including eutrophication and sedimentation can help segue into human impact and our roles in the ecological landscape.

Web of Life (Great Bay Estuary)

There are many variations on Web of Life activities. Project Learning Tree (1993) describes a passive Web of Life activity which has been adapted to be more interactive (Shutsky et al. 2006a). The following description focuses specifically on the Great Bay Estuary of New Hampshire, but can easily be changed to illustrate any local system. The main objectives of the activity are:

- Understand the basic resources needed for different trophic levels
- Describe food chain for local natural system
- Learn about the direct and indirect interactions between trophic levels
- See the cascading effects of certain human activities

To prepare for this activity, you will need the following:

- Web of Life role card for each participant (see examples below)
- Ball of yarn

Creating a human Web of Life works best with groups of 8 to 15 people. Larger groups can be split into sub groups and work with different ecosystems. Role cards can either be made up beforehand or written out on the spot according to participant responses. To begin, participants should stand facing one another in a circular formation. Together the group should brainstorm the driving force of life - the sun. From here subsequent organisms named should be directly connected or in the same trophic level as the one before (sun to primary producers to herbivores to carnivores). Beginning with the sun, an individual should take on the role of each component named (with nametag) until everyone has been dubbed with a Great Bay alter ego.

Once everyone has been given a role, give a ball of yarn to the individual representing the sun and have him or her hold on to one end. Instruct the sun to hand the ball of yarn to someone in the circle they are directly connected to. The yarn recipient should continue this connection until everyone in the circle is holding a piece of yarn. (Note, in handing out nametags, it is helpful to disperse members of the same trophic level around the circle so they are not concentrated in a single area). The group has now created a Great Bay Web of Life. The strands of yarn represent direct connections between organisms. Have the participants comment on the how they think organisms might interact with one another if they do not share a direct connection. To illustrate different situations try removing certain individuals from the Great Bay Estuary by having him or her drop the yarn. Then determine the effects this would have on the organisms directly connected. If this would be negative, have them also drop the yarn, following the effect throughout the group until there are no more negative direct connection. Discuss the newly identified indirect interaction. Have the participants pick the yarn back up, restoring a healthy web of life. Try manipulating the loss of eelgrass and compare with the loss of an animal, such as striped bass to illustrate the effects of water quality decline as well as overfishing.

Possible role cards for the Great Bay Estuary include:

Sun
Blue Mussel
Horseshoe Crab
Harbor Seal
Eelgrass
Canada Goose
Phytoplankton
Silverside
Algae
Pipefish
Isopod
Striped Bass
Mud Snail
Lobster
Blue Heron
Green Crab

Predator Snapshot

The activity Predator Snapshot focuses on the protective role of eelgrass for juvenile and small organisms. The purpose of Snapshot is to compare the camouflaging ability of vegetated and bare sediment through an areal view of the habitats. The several second 'snapshot' of the areas is based upon the activity Camera described by Joseph Cornell (1989). The primary objectives of the adapted activity are:

- Compare the protective capability of vegetated and bare sediment
- Understand the importance of eelgrass as a 'nursery' habitat
- Assess one's own predatory ability

To prepare for this activity, you will need the following:

- Containers planted with eelgrass or something to simulate an eelgrass bed
- Fish cutouts of varying size tied down with weighted monofilament line
- Blindfolds

The activity outlined below takes advantage of the meter^3 fiberglass mesocosm tanks at UNH's Jackson Estuarine Laboratory. However, Snapshot could easily be adapted to be run on a smaller scale using plastic storage bins or even baking dishes. While it requires the most preparation of all the activities, it is a useful and interactive way to address the structural role of eelgrass in an estuary. To prepare, you will need at least two tanks, although for larger groups more tanks increase the effectiveness. Half the tanks should be planted with eelgrass at a relatively high density – at least 100 shoots per square meter. The other tanks should be left with bare sediment. Place plastic or foam cut-outs of fish and invertebrates in both tanks at varying heights – surface, mid-water column, substrate. Placement can be achieved by tying different lengths of monofilament and sinkers to the cut outs. For additional assessment, try varying the color of the fish.

Once the tanks have been prepared, blindfold participants and line them up around the vegetated tanks. Explain that on your command they are to remove the blind folds and study the scene in front of them until you give the cue to close their eyes again. Participants are transformed into one of the aviary estuary predators, such as blue herons. During this time their assignment is to silently count all the animals they can see in the tank. Their viewing time will only last 3 to 5 seconds. Once the participants have done this, lead them to the set of bare tanks and have them do the same thing.

If the group is large and there are not enough tanks or space for everyone to go at once, have the participants view in shift. However, explain that animal counts must be kept to oneself until the very end. After all participants have seen a 'snapshot' of each tank, allow individuals to share how many animals they were able to see in each tank. Which tank was easier to spot prey in? Which colors were easier to see? After participants have discussed their findings, take them back over to the tanks for longer viewing. During the revisit to the tanks discuss how this activity translates into a real situation in the Great Bay. Eelgrass beds provide critical habitat for juvenile fish and invertebrate species through protective camouflage, helping to ensure healthy future populations. What if there were no more eelgrass beds? Connect this habitat comparison back to the Web of Life activity and the cascading consequences.

Camouflage

The activity Camouflage facilitates the comparison of different habitats and their concealing capacity. The activity, adapted from Project WILD (1983b), can be executed at a designated time or as a surprise amidst other activities. The key objectives of Camouflage are:

- Compare the concealing ability of vegetated and bare sediment
- Understand the importance of eelgrass as a 'nursery' habitat
- Assess the concealment quality of varying sizes and colors

No materials are needed for the preparation of this activity.

Whether you choose to deploy this activity as a surprise or not, it is necessary to first explain the rules. Camouflage can be used to effectively compare any number of habitats. The instructor will act as a large predator – in the case of the Great Bay Estuary, a striped bass or blue heron. The rest of the participants will take on the role of the prey – juvenile and small fish. The activity begins when the predator yells 'camouflage,' or any other agreed upon phrase, closes his or her eyes and counts aloud to 10. During those ten seconds, the prey must run and find a protective hiding spot where they can see the predator with at least one eye. It is important to explain that hiding prey *must* be able to see the predator – in a real life situation, prey would want to be able to see a predator to determine whether they have been spotted and need to run or hasn't and can stay where they are. Once the predator reaches the count of 10, he or she will open their eyes and begin looking for prey. However, the predator is not allowed to leave his or her standing spot – only rotate for a 360 degree view.

When the predator spots prey, the predator can either call out the prey's name (if prey is identifiable) or describe their location and attire until the prey emerges, at which point the spotted prey comes out of hiding and stand quietly next to the predator. The predator will continue to call out prey until he or she can no longer spot prey. At this point the predator calls for the remaining prey to step out from behind their hiding spots. The prey closest to the predator that wasn't spotted is deemed the 'winner' for having the best camouflage while expending the least amount of energy.

Camouflage works best when played in several different habitats: forest, field, beach, parking lot. Doing so allows participants to compare the camouflaging ability of different habitats. Playing in both a field and a forested area works well for the analogy of eelgrass meadows and bare sediment. While the Predator Snapshot activity provides similar comparison using actual eelgrass, Camouflage helps to secure participant understanding of eelgrass' protective canopy while getting to role play as members of the Great Bay Estuary.

Habitat Hopscotch

Habitat Hopscotch is adapted from Migration Headache (Project WILD Aquatic 2001) and Wetlands Hopscotch (Shutsky et al. 2006b). Both activities focus on bird migration. However, I have adapted the activity to highlight fragmentation of eelgrass habitat in the Great Bay Estuary. The primary objectives of Habitat Hopscotch are:

- Understand the implication of habitat fragmentation on higher trophic levels
- Learn potential causes of habitat loss in the Great Bay Estuary
- Identify possible solutions and mitigation efforts for habitat loss

To prepare for this activity, you will need the following:

- 10-15 carpet squares or other non-slip placemats to represent eelgrass beds
- 8-10 'fate cards' for activity occurring in the GBE (see examples below)

Start the activity by lining the 'eelgrass patches' (carpet squares) into a hopscotch-like formation. Explain to the participants that they have been transformed into small fish within the Great Bay Estuary. Their mission is to successfully travel from one end of the estuary to the other without getting eaten by larger predators. To do this, the fish must remain within eelgrass habitat at all times. Start by letting each fish hop easily from eelgrass patch to patch until they reach the end of the estuary. Then have the one of the participants pick a fate card from the bag and read it aloud. Apply the fate to the eelgrass and have the fish travel through the estuary again.

If a fish is not able to make it from one end of the estuary to the other, then they are eliminated from the round. At the end of each round determine by a show of hands how many fish survived. For future or graphical analysis, the instructor can record the number of eelgrass patches and surviving fish. Play through several rounds with the fate cards until the students can no longer travel the entire estuary or understand the implications of habitat fragmentation. Afterwards, discuss with the participants what potential actions could be taken to reduce or restore eelgrass habitat.

Possible Fate Cards:

- Eliot builds a golf course on the waterfront – remove 1 square
- Newington develops a water park next to the river – remove 1 square
- Wagon Hill Park purchases abutting land for more trails – remove no squares
- Newmarket installs a new sewage treatment facility – remove 1 square
- Summer houses build on Nanny Island – remove 2 squares
- Newington power plant shut down – remove no squares
- Restoration effort replants grass – add 1 square
- ORMS students urge conservation commission to re-vegetate park below Oyster River dam – remove no squares
- Clear cutting for new housing development – remove 1 square

Clean up the Bay!

The activity Clean up the Bay focuses on the complexities involved in cleaning up polluted waters. The activity is adapted from Ferry Beach Ecology School's Dirty Water and builds upon Build a Watershed, which shows participants how individual actions contribute to watershed dynamics (Shutsky et al. 2006c). The primary objectives of Clean up the Bay are:

- Distinguish between effective and ineffective and clean up techniques
- Understand how individual actions add up on a watershed-wide scale
- Identify ways to mitigate individual contributions to watershed pollution

To prepare for this activity, you will need the following for each group:

- 1 clear or white container – 1 to 5 gallons
- 6 'pollutants' from readily available household materials (ie: food coloring for nutrient additions, coffee grounds for sediment, vegetable oil for motor oil)
- 4-6 tools for 'cleaning' the water – strainers, slotted spoons, plankton nets, etc.

Divide the participants into smaller subgroups of approximately 6 people. Give each group a container of clean water and set of film canisters filled with the pollutants; set aside the second containers of clean water for later. Allow each student to add a pollutant into the water until all canisters are empty. When all of the pollutants have been discharged into the container, provide each group with an assortment of tools to clean the water. Have each group pick what item they think will be most useful and justify their reasoning. Continue having the groups choose the next best tool until they have exhausted their options.

Looking at the containers, have the group successfully cleaned their water? Provide the groups with the second container of clean water for comparison. What were they able to remove and what weren't they? What tools ended up being most useful and why? Take a minute to brainstorm with the participants how the remaining pollutants might be removed. Offer the students the clean water as a way of treating the polluted water. Does this help? In real life, is adding more clean water a feasible solution for improving the water quality of the Great Bay? (Remind participants of the May flooding in recent years as why this would not work). While adding more water isn't a real option, what would have the same effect? If less of the pollutants were added to the watershed in the first place, then they wouldn't accumulate so much in the Great Bay Estuary. Brainstorm with participants ways to reduce pollution additions. Have each person think of an example specific to the pollutant he or she added to the clean water earlier in the activity. Which actions would be easy to accomplish and which would not?

Stressful Situation!

The activity Stressful Situation! emphasizes the impact of 'stressors' on eelgrass productivity. The term stressor is used to describe any factor (cloudy water, excess nutrients) that inhibits the functional ability of eelgrass. The stressor/s can be as broad or specific as the instructor needs to emphasize particular inputs of the system. Stressful Situation! is loosely based upon Project WET's activity, Macroinvertebrate Mayhem (1995). The primary objectives of Stressful Situation! are:

- Observe the effects of environmental stressors on overall eelgrass function
- Monitor the functional ability of 'stressed' plants
- Identify possible mitigation efforts to improve eelgrass function

To prepare for this activity, you will need the following:

- 4 cones or other objects to mark boundaries

To prepare for the activity, start by clearly marking out two parallel lines 25-30 feet apart. Line all of the participants up along one side to explain the rules. One member of the group will start as an environmental stressor, such as turbid water, and the rest will be eelgrass plants. On the designated signal, the eelgrass will run to the opposite line. It is important to explain that the movement back and forth does not represent eelgrass uprooting itself and running along the floor of the Great Bay. The motion of the individuals is illustrating the productivity of different processes within a plant (photosynthesis, root growth, leaf growth).

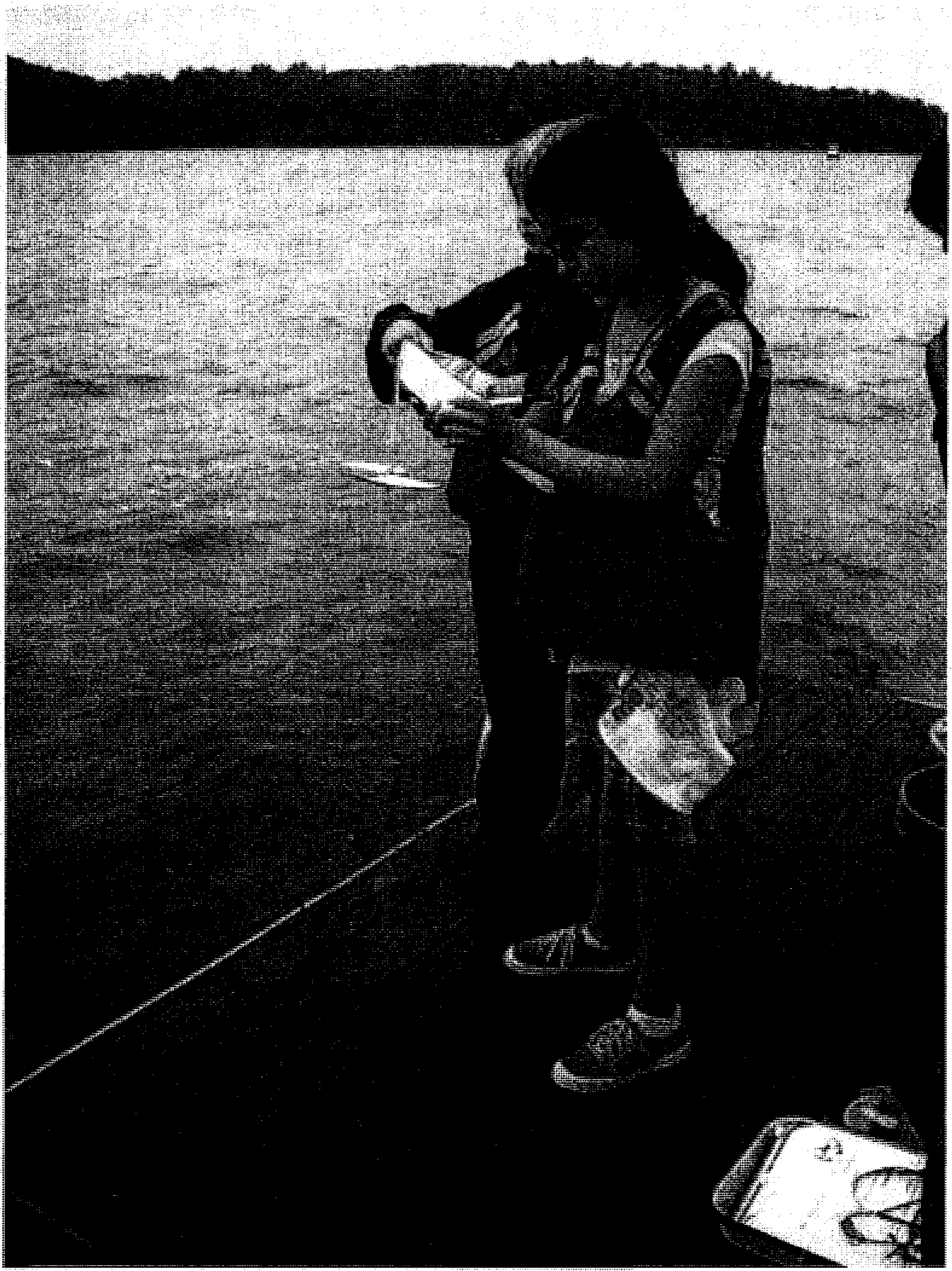
When the eelgrass is passing from one side to another, the role of the environmental stressor is to tag as many individuals as possible. Once plants cross the line, they are off limits for the stressor. When all of the participants are standing on the opposite line, ask for a show of hands from individuals who were affected (tagged) by the stressor. Plants that were affected have a lower functional ability than the healthy plants. To represent this, the plants affected by the stressor will have to cross the playing field on one leg in the next round. In the second round, plants will again travel to the far line with the stressor trying to tag as many as possible. Healthy (untagged) plants have use of both legs, while stressed (tagged) plants will have to hop on one leg. Once all of the plants have crossed for a second time, ask the participants how many healthy plants were affected by the stressor. These individuals will lose the use of one leg in the next round. Then ask how many stressed plants were again affected by the stressor. These doubly stressed plants will be reduced to crawling in the next round. If in subsequent rounds the highly stressed (crawling) eelgrasses get tagged by the stressor, they will be considered dead and can sit out the remainder of the activity. Depending on the instructor's intended effect, an alternative for dead eelgrass individuals is to become additional stressors in the system.

Depending on the group size and intended emphasis on environmental stressor(s), the number of tagging stressors can be manipulated. After several rounds, take the time to discuss the implications of the different stress levels with the participants. How did the stressor affect healthy plants? How did the stressor affect the already stressed plants? What might these stressors be? How could we reduce their effect?

IMAGES OF STUDENTS PARTICIPATING IN THE ACTIVITIES

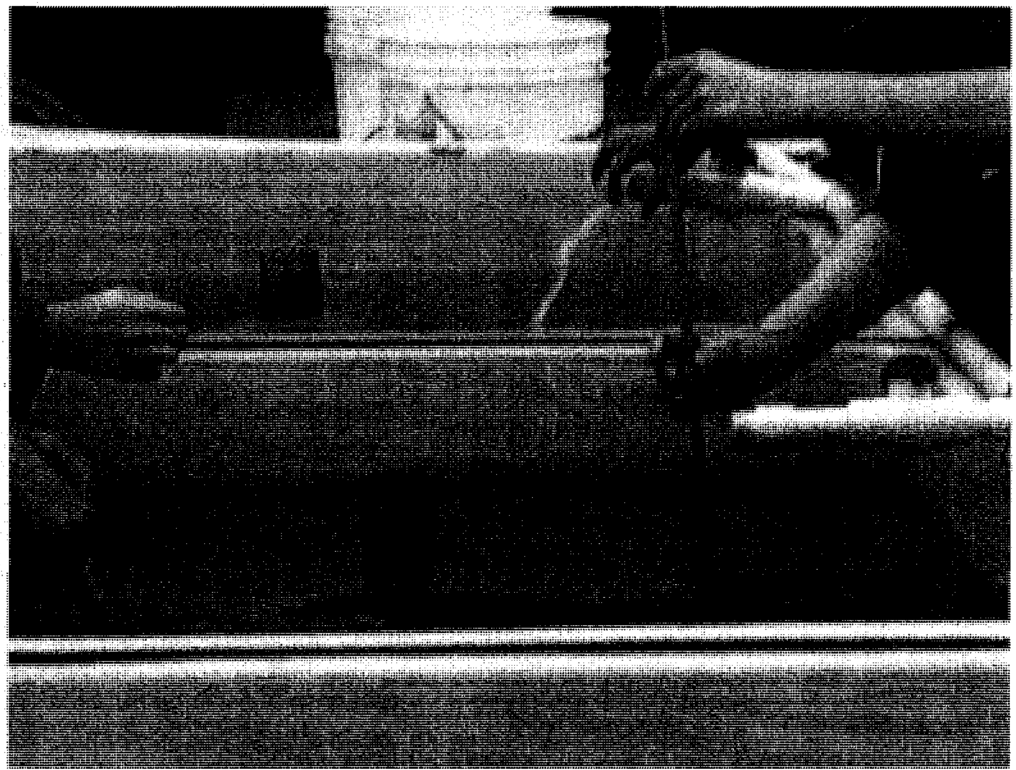
The images presented below were taken during the Oyster River Middle School outreach event held at the University of New Hampshire's Jackson Estuarine Laboratory. The images are meant to help visualize how particular activities were conducted as well as how some of the measurements were taken.

An instructor showing middle school students how to use an YSI meter for data collection on the dock at the Jackson Estuarine Laboratory, Great Bay, New Hampshire.

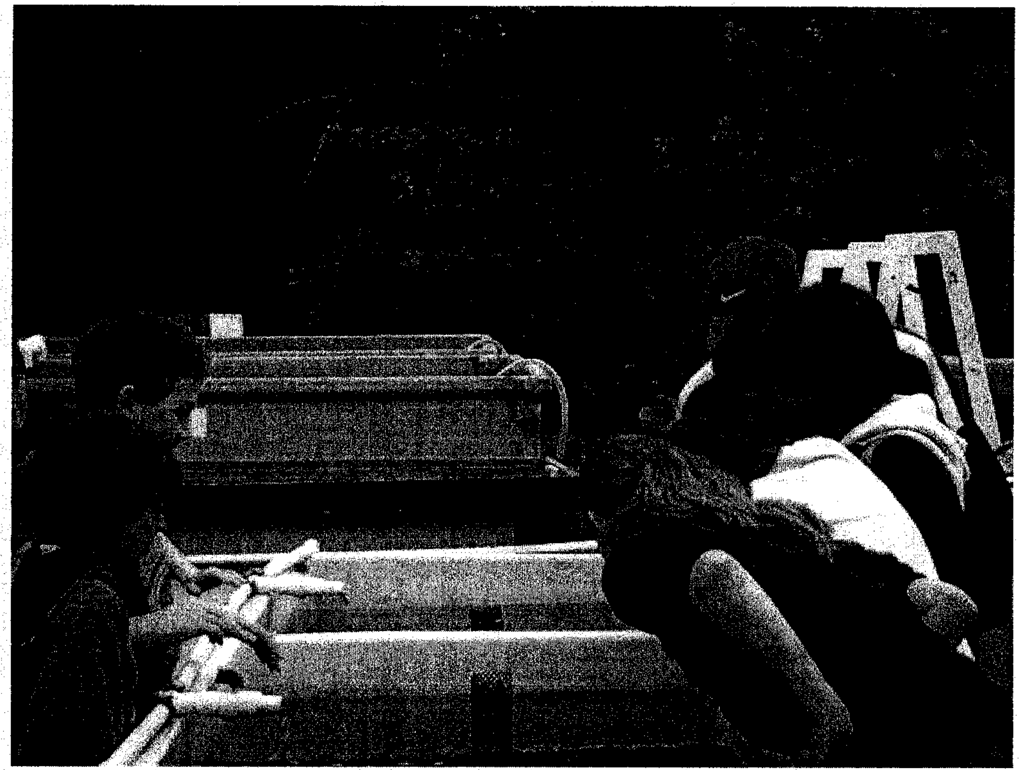


Middle school students using a Secchi disk to measure water clarity.

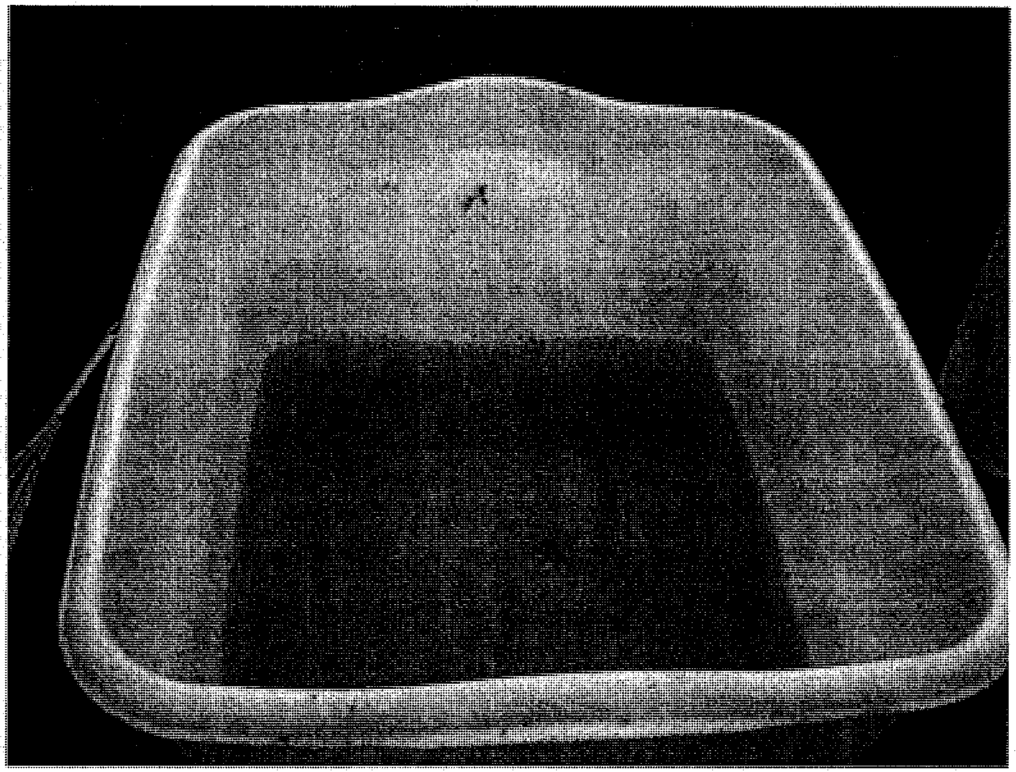
Students using a hydrometer to measure water salinity.



Students measuring eelgrass canopy height in outside mesocosm tanks.


Students counting fake fish suspended in the mesocosm tanks during *Predator Snapshot.*


Students learning about habitat fragmentation during *Habitat Hopscotch.*



The 'bay' after students tried to clean out pollutants during *Clean up the Bay.*

Students taking on the role of eelgrass during the activity *Stressful Situation!*.

APPENDIX D

IRB APPROVAL LETTER

University *of* New Hampshire

Research Conduct and Compliance Services, Office of Sponsored Research
Service Building, 51 College Road, Durham, NH 03824-3585
Fax: 603-862-3564

02-Apr-2008

Beem, Nora
Natural Resources, James Hall 215
5 Willey Road
Durham, NH 03824

IRB #: 4258
Study: Eelgrass in the Great Bay: Field Research and Educational Outreach
Approval Date: 31-Mar-2008

The Institutional Review Board for the Protection of Human Subjects in Research (IRB) has reviewed and approved the protocol for your study as Expedited as described in Title 45, Code of Federal Regulations (CFR), Part 46, Subsection 110 with the following comment(s):

If the school agrees to waiving parental consent, the IRB will agree to that process. This would require a letter from the school principal that recognizes parental consent requirements will be waived.

Approval is granted to conduct your study as described in your protocol for one year from the approval date above. At the end of the approval date you will be asked to submit a report with regard to the involvement of human subjects in this study. If your study is still active, you may request an extension of IRB approval.

Researchers who conduct studies involving human subjects have responsibilities as outlined in the attached document, *Responsibilities of Directors of Research Studies Involving Human Subjects.* (This document is also available at http://www.unh.edu/osr/compliance/irb.html.) Please read this document carefully before commencing your work involving human subjects.

If you have questions or concerns about your study or this approval, please feel free to contact me at 603-862-2003 or Julie.simpson@unh.edu. Please refer to the IRB # above in all correspondence related to this study. The IRB wishes you success with your research.

For the IRB,

Julie Simpson

Julie F. Simpson
Manager

cc: File
Short, Frederick

LIST OF REFERENCES

Adams, S.M. and J.W. Angelovic. 1970. Assimilation of detritus and its associated bacteria by three species of estuarine animals. *Chesapeake Science* 11:249-254.

Beem, N.T. and F.T. Short. 2008. Subtidal eelgrass declines in the Great Bay Estuary, New Hampshire and Maine, USA. *Estuaries and Coasts.*

Biebl, R. and C.P. McRoy. 1971. Plasmatic resistance and rate of respiration and photosynthesis of *Zostera marina* at different salinities and temperatures. *Marine Biology* 8: 48-56.

Borum, J. 1985. Development of epiphytic communities on eelgrass (*Zostera marina*) along a nutrient gradient in a Danish estuary. *Marine Biology* 87: 211-218

Bosworth, W. and F.T. Short. 1993. Port of New Hampshire Mitigation Plan. For the New Hampshire Commercial Marine Terminal Development Project in Portsmouth, New Hampshire. Submitted to US Army Corps of Engineers, March 10, 1993: 98p.

Burdick, D.M. and F.T. Short. 1999. The effects of boat docks on eelgrass beds in coastal waters of Massachusetts. *Environmental Management* 23: 231-240.

Burkholder, J.M., K.M. Mason, and H.B. Glasgow Jr. 1992. Water-column nitrate enrichment promotes the decline of eelgrass (*Zostera marina* L.): evidence from seasonal mesocosm experiments. *Marine Ecology Progress Series* 81: 163-178.

Burkholder, J.M., D.A. Tomasko, and B.W. Touchette. 2007. Seagrasses and eutrophication. *Journal of Experimental Marine Biology and Ecology* 350: 46-72.

Cornell, J. 1989. “Nature Activities: Stage Three” in *Sharing the Joy of Nature: Nature Activities for All Ages.* Dawn Publications; Nevada City, CA: 85-107.

Correll, D.L. 1998. The role of phosphorus in the eutrophication of receiving waters: a review. *Journal of Environmental Quality* 27: 261-266.

Coulombe, D.A. 1984. *The Seaside Naturalist.* Simon and Schuster, New York: 246p.

Davis, R.C. and F.T. Short. 1997. Restoring eelgrass, *Zostera marina* L., habitat using a new transplanting technique: the horizontal rhizome method. *Aquatic Botany* 59: 1-15.

Davis, R.C., F.T. Short, and D.M. Burdick. 1998. Quantifying the effects of green crab damage to eelgrass transplants. *Restoration Ecology* 6: 297-302.

Deegan, L.A., A. Wright, S.G. Ayvanian, J.T. Finn, H. Golden, R.R. Merson, and J. Harrison. 2002. Nitrogen loading alters seagrass ecosystem structure and support of higher tropic levels. *Aquatic Conservation: Marine and Freshwater Ecosystems* 12: 193-212.

den Hartog, C. 1970. The Sea-Grasses of the World. North-Holland Publication Co., Amsterdam.

Driscoll, C.T., D. Whitall, J.D. Aber, E.W. Boyer, C.S. Cronan, C.L. Goodale, P. Groffman, C. Hopkinson, K.F. Lambert, and G.B. Lawrence. 2003. Nitrogen pollution in the Northeastern United States: sources, effects, and management options. *BioScience* 53: 357-374.

Duarte, C.M. 1991. Seagrass depth limits. *Aquatic Botany* 40: 363-377.

Duarte, C.M. and H. Kirkman. 2001. Methods for the measurement of seagrass abundance and depth distribution. In: F.T. Short and R.G. Coles (eds), *Global Seagrass Research Methods*, Elsevier Science: 141-153.

Environmental Protection Agency. 2003. *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for Chesapeake Bay and its Tidal Tributaries.* EPA 903-R-03-002. U.S. Environmental Protection Agency, Chesapeake Bay Program Office.

Environmental Protection Agency. 2007. *The National Estuary Program: a Network Protecting and Restoring Coastal Ecosystems.* United States Environmental Protection Agency: Washington D.C.: 8p.

Evans, T.N. and F.T. Short. 2005. Functional trajectory models for assessment of transplanted eelgrass, *Zostera marina* L., in the Great Bay Estuary, New Hampshire. *Estuaries* 28: 936-947.

Fish and Wildlife Research Institute. 2008. *Seagrass versus seaweed.* Florida Fish and Wildlife Conservation Commission; St. Petersburg, FL.

Fonseca, M.S., J.S. Fisher, J.C. Zieman, and G.W. Thayer. 1982. Influence of the seagrass, *Zostera marina* L., on current flow. *Estuarine, Coastal and Shelf Science* 15: 351-364.

Gotceitas, V., S. Fraser, and J.A. Brown. 1997. Use of eelgrass beds (*Zostera marina*) by juvenile Atlantic cod (*Gadus morhua*). *Canadian Journal of Fisheries and Aquatic Sciences* 54: 1306-1319.

Green, E.P. and F.T. Short (eds.). 2003. *World Atlas of Seagrasses.* University of California Press, Berkley.

Grizzle, R.E., F.T. Short, C.R. Newell, H. Hoven, L. Kindblom. 1996. Hydrodynamically induced synchronous waving of seagrasses: 'monami' and its possible effects on larval mussel settlement. *Journal of Experimental Marine Biology and Ecology* 206: 165-177.

Hauxwell, J., J. Cebrian, and I. Valiela. 2003. Eelgrass *Zostera marina* loss in temperate estuaries: relationship to land-derived nitrogen loads and effect of light limitation imposed by algae. *Marine Ecology Progress Series* 247: 59-73.

Heck, K.L., K.W. Able, C.T. Roman, and M.P. Fahay. 1995. Composition, abundance, biomass, and production of macrofauna in a New England Estuary: Comparisons among eelgrass meadows and other nursery habitats. *Estuaries* 18: 379-389.

Heck, K.L. and R.J. Orth. 1980. Seagrass habitats: the role of habitat complexity, competition and predation in structuring associated fish and motile macroinvertebrate assemblages. 449-464. In V.A. Kennedy (ed.), *Estuarine Perspectives*. Academic Press, New York.

Heidelbaugh, W.S. and W.G. Nelson. 1996. A power analysis of methods for assessment of change in seagrass cover. *Aquatic Botany* 53: 227-233.

Hemminga, M. and C.M. Duarte. 2000. *Seagrass Ecology*. Cambridge University Press, Cambridge, Massachusetts.

Hoven, H.M. 1992. *Eelgrass (*Zostera marina L.*) as a substratum for larval blue mussels (*Mytilus edulis L.*) in Mount Desert Narrows, Maine*. Master of Science Thesis, University of New Hampshire.

Institute of Medicine. 2005. *Preventing Childhood Obesity: Health in the Balance*. Institute of Medicine of the National Academies, Washington DC.

Jaworski, N.A., R.W. Howarth, and L.J. Hetling. 1997. Atmospheric deposition of nitrogen oxides onto the landscape contributes to coastal eutrophication in the northeastern United States. *Environmental Science and Technology* 31: 1995-2004.

Kautsky, N, H., Kautsky, I. Kautsky, and M. Waern. 1986. Decreased depth penetration of *Fucus vesiculosus* (L.) since the 1940's indicates eutrophication in the Baltic Sea. *Marine Ecology Progress Series* 28: 1-8.

Kennish, M.J., S.B. Bricker, W.C. Dennison, P.M. Glibert, R.J. Livingston, K.A. Moore, R.T Noble, H.W. Paerl, J.M. Ramstack, S. Seitzinger, D.A. Tomasko, and I. Valiela. 2007. Barnegat Bay-Little Egg Harbor Estuary: Case study of highly eutrophic coastal bay system. *Ecological Applications* 17: S3-S16 Suppl.

Kinney, E.H. and C.T. Roman. 1998. Response of primary producers to nutrient enrichment in a shallow estuary. *Marine Ecology Progress Series* 163: 89-98.

Koch, E.M. 2001. Beyond light: Physical, geological, and geochemical parameters as possible submersed aquatic vegetation habitat requirements. *Estuaries* 24: 1-17.

Lee, K.S., F.T. Short, and D.M. Burdick. 2004. Development of a nutrient pollution indicator using the seagrass, *Zostera marina*, along nutrient gradients in three New England estuaries. *Aquatic Botany* 78: 197-216.

Lee, V. and S. Olsen. 1985. Eutrophication and management of initiatives for the control of nutrient inputs to Rhode Island coastal lagoons. *Estuaries* 8: 191-202.

Louv, R. 2005. The New Relationship Between Children and nature. In *Last Child in the Woods: Saving Our Children from Nature-Deficit Disorder*. Algonquin Books of Chapel Hill; Chapel Hill, NC: 7-35.

Neckles, H.A., F.T. Short, S. Baker, and B.S. Kopp. 2005. Disturbance of eelgrass *Zostera marina* by commercial mussel *Mytilus edulis* harvesting in Maine: dragging impacts and habitat recovery. *Marine Ecology Progress Series* 285: 57-73.

NEFSC. 2007. *Seal FAQs*. Northeast Science Fisheries Center: Woods Hole Science Aquarium; Woods Hole, MA: 2p.

NHDOE. 2006. *K-12 Science Literacy New Hampshire Curriculum Framework*. New Hampshire Department of Education; Concord, NH: 123p.

NHEP. 2006. *State of the Estuaries 2006*. New Hampshire Estuaries Project. Durham, NH: 32p.

Nielsen, S.L., K. Sand-Jensen, J. Borum, and O. Geertz-Hansen. 2002. Depth colonization of eelgrass (*Zostera marina*) and macro-algae as determined by water transparency in Danish coastal waters. *Estuaries* 17: 1025-1032.

NWREL. 1997. *Inquiry Strategies for Science and Mathematics Learning: It's Just Good Teaching*. Northwest Regional Educational Laboratory; Portland, Oregon: 37p.

NYS DOS. 2002. *New York State Significant Coastal Fish and Wildlife Habitat Narrative*. New York State Department of State Division of Coastal Resources; Albany, NY: 4p.

Olsen, B. and K. Sand-Jensen. 1993. Seasonal acclimatization of eelgrass *Zostera marina* growth to light. *Marine Ecology Progress Series* 94: 91-99.

Orth, R.J. 1977. Effect of nutrient enrichment on growth of the eelgrass *Zostera marina* in the Chesapeake Bay, Virginia, USA. *Marine Biology* 44: 187-194.

Orth, R.J., T.J.B. Carruthers, W.C Dennison, C.M. Duarte, J.W. Fourqurean, K.L. Heck, A.R. Hughes, G.A. Kendrick, W.J. Kenworthy, S. Olyarnik, F.T. Short, M. Waycott, and S.L. Williams. 2006. A Global crisis for seagrass ecosystems. *Bioscience* 56: 987-996.

Orth, R.J. and K.A. Moore. 1983. Chesapeake Bay: an unprecedented decline in submerged aquatic vegetation. *Science* 222: 51-53.

Oviatt, C., P. Doering, B. Nowicki, L. Reed, J. Cole, and J. Frithsen. 1995. An ecosystem level experiment on nutrient limitation in temperate coastal marine environments. *Marine Ecology Progress Series* 116: 171-179.

Paul, M.J. and J.L. Meyer. 2001. Streams in the urban landscape. *Annual Review of Ecology and Systematics* 32: 333-336.

PerkinElmer. 2005. Organic elemental analysis: 2400 Series II CHNS/O Elemental Analyzer. PerkinElmer Life and Analytical Sciences: Shelton, CT: 10p.

Project Learning Tree. 1993. Systems in *Project Learning Tree: Environmental Education Pre K-8 Activity Guide.* American Forest Foundation; Washington, D.C.: 135-214.

Project WET. 1995. Water Resources are Managed in *Project WET: K-12 Curriculum and Activity Guide.* The Watercourse and the Council for Environmental Education; Bozeman, MT: 287-364.

Project WILD. 1983a. Ecological Knowledge: Wildlife Populations in *Project WILD: K-12 Curriculum and Activity Guide.* Council for Environmental Education; Houston, TX: 2-48.

Project WILD. 1983b. Ecological Knowledge: Changes and Adaptations in *Project WILD: K-12 Curriculum and Activity Guide.* Council for Environmental Education; Houston, TX: 114-143.

Project WILD Aquatic. 2001. Ecological Knowledge: Wildlife Populations in *Project WILD Aquatic: K-12 Curriculum and Activity Guide.* Council for Environmental Education; Houston, TX: 2-18.

Rasheed, A.M. 1999. Recovery of experimentally created gaps within a tropical *Zostera capercorni* (Aschers.) seagrass meadow, Queensland, Australia. *Journal of Experimental Marine Biology and Ecology* 235: 183-200.

Rivers, D.O. and F.T. Short. 2007. Effect of grazing Canada geese *Branta canadensis* on an intertidal *Zostera marina* meadow. *Marine Ecology Progress Series* 333: 271-279.

Roberts, D.F., U.G. Foehr, V.J. Rideout, and M. Brodie. 1999. *Kids and Media at the New Millennium: A Comprehensive National Analysis of Children's Media Use.* The Henry J Kaiser Family Foundation; Menlo Park, CA: 96p.

Roman, C.T., N.A. Jaworski, F.T. Short, S. Findlay, and R.S. Warren. 2000. Estuaries of the Northeastern United States: Habitat and land use signatures. *Estuaries* 23: 743-764.

Save the Bay. 2002. *Restoration Projects throughout the Narragansett Bay Watershed.* Save the Bay Inc., Providence, RI.

SEER. 2000. *California Student Assessment Project: The Effects of Environment-based Education on Student Achievement.* State Education and Environment Roundtable (SEER); San Diego, CA: 112p.

Short, F.T. 1992. The ecology of the Great Bay Estuary, New Hampshire and Maine: an estuarine profile and bibliography. NOAA – Coastal Ocean Program Publishing: 222p.

Short, F.T. and D.M. Burdick. 1996. Quantifying eelgrass habitat loss in relation to housing development and nitrogen loading in Waquoit Bay, Massachusetts. *Estuaries* 19: 730-739.

Short, F.T., D.M. Burdick, S. Granger, and S.W. Nixon. 1996. Long-term decline in eelgrass, *Zostera marina* L., linked to increased housing development. Seagrass Biology: Proceedings of an International Workshop: 291-298.

Short, F.T., D.M. Burdick, and J.E. Kaldy. 1995. Mesocosm experiments quantify the effects of eutrophication on eelgrass, *Zostera marina. Limnology and Oceanography* 40: 740-749.

Short, F.T., T.J.B. Carruthers, W. Dennison, and M. Waycott. 2007. Global seagrass distribution and diversity: A bioregional model. *Journal of Experimental Marine Biology and Ecology* 350: 3-20.

Short, F.T., A.C. Mathieson, and J.I. Nelson. 1986. Recurrence of the eelgrass wasting disease at the border of New Hampshire and Maine, USA. *Marine Ecology Progress Series* 29: 89-92.

Short, F.T., K. Matso, H.M. Hoven, J. Whitten, D.M. Burdick, and C.A. Short. 2001. Lobster use of eelgrass habitat in the Piscataqua River on the New Hampshire/Maine border, USA. *Estuaries* 24: 277-284.

Short, F.T., L.K. Muehlstein, and D. Porter. 1987. Eelgrass wasting disease: cause and recurrence of a marine epidemic. *Biological Bulletin* 173: 557-562.

Short, F.T. and C.A. Short. 1984. The seagrass filter: purification of estuarine and coastal waters. In: V.C. Kennedy (ed.), *The Estuary as a Filter*, Academic Press: 395-413.

Short, F.T. and C.A. Short. 2003. Seagrasses of the western North Atlantic. pp. 225-233. In: Green, E.P. and F.T. Short (eds.). *World Atlas of Seagrasses*. University of California Press, Berkley, California.

Short, F.T. and S. Wyllie-Echeverria. 1996. Natural and human-induced disturbance of seagrasses. *Environmental Conservation* 23: 17-27.

Shutsky, K., S. Kaufman, and S. Signell. 2006a. ABCs of Ecology in *The ABCs of Ecology: an Educators Guide to Learning Outside*. Ecology Education, Inc.; Saco, ME: 13-56.

Shutsky, K., S. Kaufman, and S. Signell. 2006b. Watersheds: Where the River Meets the Sea in *The ABCs of Ecology: an Educators Guide to Learning Outside*. Ecology Education, Inc.; Saco, ME: 197-204.

Shutsky, K., S. Kaufman, and S. Signell. 2006c. Watersheds: What is a Watershed in *The ABCs of Ecology: an Educators Guide to Learning Outside*. Ecology Education, Inc.; Saco, ME: 188-191.

Steinke, K., J.C. Stier, W.R. Kussow, and A. Thompson. 2007. Prairie and turf buffer strips for controlling runoff from paved surfaces. *Journal of Environmental Quality* 36: 426-439.

Texas Parks and Wildlife. 1999. *Seagrass Conservation Plan for Texas*. Texas Parks and Wildlife: Austin, TX: 79p.

Tomasko, D.A., C.J. Dawes, and M.O. Hall. 1996. The effects of anthropogenic nutrient enrichment on turtle grass (*Thalassia testudinum*) in Sarasota Bay, Florida. *Estuaries* 19: 448-456.

Trowbridge, P. 2006a. *Environmental Indicator Report: Water Quality*. New Hampshire Estuaries Project: Durham, NH: 85p.

Trowbridge, P. 2006b. *Environmental Indicator Report: Critical Habitats and Species*. New Hampshire Estuaries Project: Durham, NH: 52p.

Uhrin, A.V. and J.G. Holmquist. 2003. Effects of propeller scarring on macrofaunal use of the seagrass *Thalassia testudinum*. *Marine Ecology Progress Series* 250: 61-70.

van Katwijk, M.M., L.H.T. Vergeer, G.H.W. Schmitz, and J.G.M. Roelofs. 1997. Ammonium toxicity in eelgrass *Zostera marina*. *Marine Ecology Progress Series* 157: 159-173.

Wazniak, C.E., M.R. Hall, T.J.B. Carruthers, B. Sturgis, W.C. Dennison, and R.J. Orth. 2007. Linking water quality to living resources in a Mid-Atlantic lagoon system, USA. *Ecological Applications* 17: S64-S78.

Wells, N.M. 2000. At home with nature: effects of "greenness" on children's cognitive functioning. *Environment and Behavior* 32: 775-795.