PLUM ISLAND ECOSYSTEMS
LONG-TERM ECOLOGICAL RESEARCH

3-YR PROGRESS REPORT

Prepared for Fall 2001
National Science Foundation
Site Review Team Visit

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INTRODUCTION

Human activities in rivers and watersheds have altered enormously the timing, magnitude and nature of inputs of materials such as water, sediments, nutrients and organic matter to estuaries (Hopkinson and Vallino 1995). Despite an awareness of large scale, long-term changes in watersheds, we do not fully understand the consequences of activities such as damming of rivers, land use conversion, and removal of floodplains.

Climate variability and long-term patterns of climate change also can have immense effects on the timing, magnitude and nature of material inputs. Infrequent storms can accomplish in days what normally occurs over decades.

Variations and long-term increases in sea level affect estuaries from their seaward end. Tides and sea level have significant effects on water and marsh sediment salinity, plant community composition, primary production, access to marsh surface habitats by nekton and sediment accretion.

The interaction of organic matter and nutrient inputs from land and variations in the external forcings (climate, land use, river discharge, sea level) that regulate estuarine mixing and residence time will dictate the extent of nutrient and organic matter processing during estuarine transport and will determine the spatial patterns of productivity and trophic structure. The Plum Island Ecosystems LTER focuses on the following question and hypotheses:

How will trophic structure and primary and secondary productivity in estuaries be affected by changes in organic matter, nutrient and water fluxes caused by changing land cover, climate and sea level?

- **Hypothesis 1. The interaction of inorganic nutrients with the quantity and quality of organic carbon and organic nitrogen plays an important role in determining the trophic structure, production and efficiency of estuarine food webs.**
- **Hypothesis 2. The variability in land, ocean and atmospheric forcing is a key component determining the fate of allochthonous and autochthonous materials and the location and magnitude of primary and secondary production.**

We are testing these hypotheses through 1) short- and long-term measurements of the fluxes of dissolved and particulate organic carbon and organic nitrogen entering estuaries from land, marshes and the ocean, 2) short and long-term experiments to determine the effects of various nutrient and organic matter inputs and interactions on the flow of C and N through pelagic and benthic food webs, and 3) modeling the effects of land use change on food web transformations. The proposed research integrates estuarine biogeochemistry with studies of food webs and population biology of higher trophic levels.

Proposed Research - We focus our research around five primary research questions, each of which examines a different programmatic area. The scope of each question and linkages between programmatic areas are illustrated in our conceptual model (**Fig 1**).

- **Question 1-Watersheds: What is the magnitude and temporal pattern of organic carbon and nitrogen and inorganic N loading from watersheds to the estuary?**
- **Question 2-Marshes: How are tidal marsh processes and their connections to estuarine waters regulated by sea level, storms and water and material inputs from land and sea?**
- **Question 3-Water Column: How does planktonic community structure and production respond to changes in organic matter, nutrients and water fluxes?**
- **Question 4-Benthos: How does benthic use and recycling of nutrients and organic matter vary with changes in water fluxes and the quality and quantity of organic matter inputs?**
- **Question 5-Higher Trophic Levels: How does the structure and function of higher trophic levels respond to variations in organic matter, nutrients and water fluxes?**

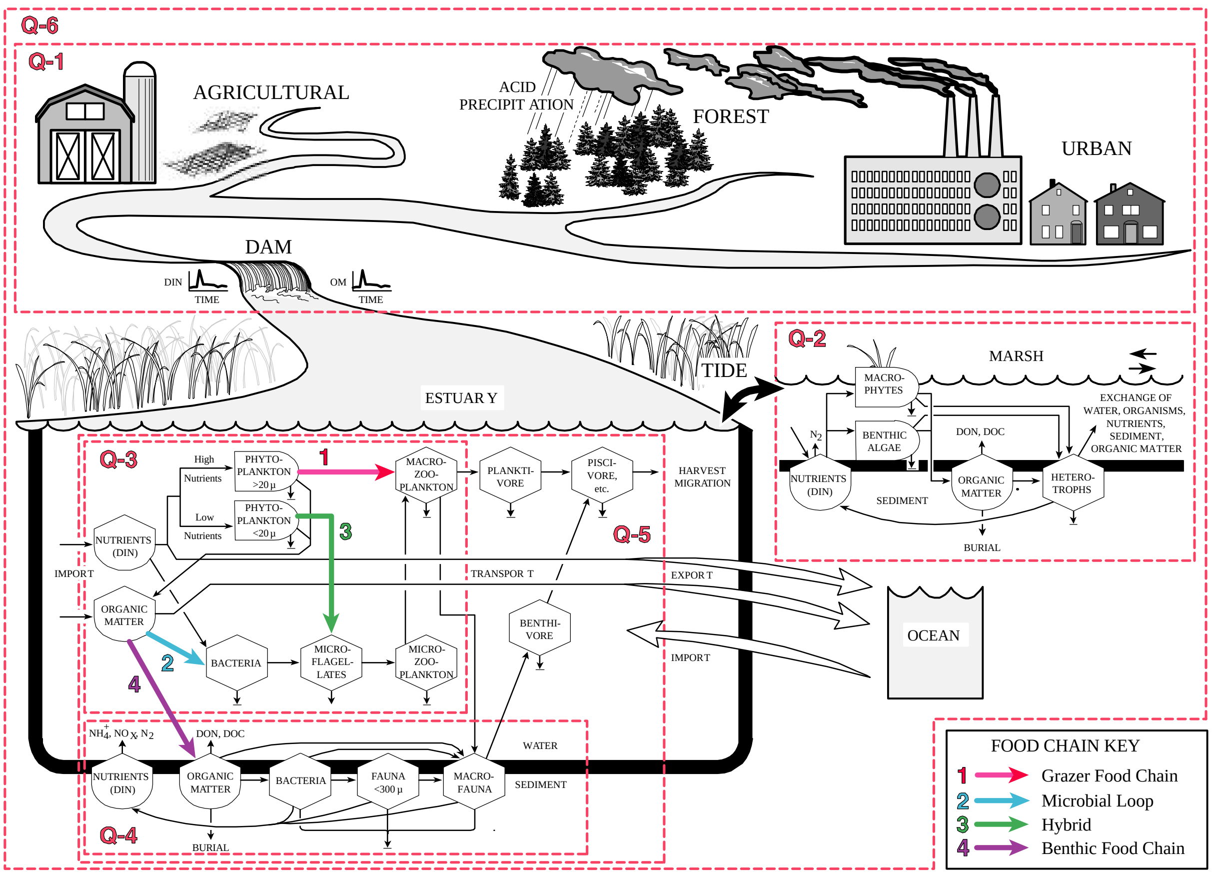

Fig 1. Conceptual diagram illustrating major ecosystem components to be addressed in each of the 5 programmatic areas as well as how the various landscape elements are linked.

Integration of the various programmatic areas is the 6th programmatic area, and is accomplished through simulation modeling, long-term experiments and a whole system ^{15}N addition experiment.

Research Approach and Schedule

Research in each of the programmatic areas consists of the following elements:

- Detailed, processed-based research focused in specific programmatic areas
- Long and short-term experiments designed to study mechanisms controlling processes
- Long-term field observations to detect trends in drivers and system response
- Comparative ecosystem research to assess generality of our understandings
- Modeling to test hypotheses, to guide research directions and to integrate within programmatic areas.

Over the 6-yr LTER funding cycle, we expect to devote roughly equivalent effort into each programmatic area. However, due to person-power and logistical constraints our strategy has been to shift research focus from one programmatic area to another over the 6-yrs.

Q1-Watersheds: mostly continuous effort over 6 years, but with additional focus in yrs 4-6.
Q2-Marshes: mostly continuous effort over 6 years, but with additional focus in yrs 1-3.
Q3-Water Column: effort focused in yrs 2 and 3.
Q4-Benthos: effort focused in yrs 1 and 6.
Q5-Higher Trophic Levels: effort focused in yrs 4 and 5.

Synthesis: mostly continuous effort over 6 years.

The LTER has enabled us to leverage substantial additional, non-LTER funds (**see Appendix I**). These additional funds have enabled us to significantly augment research beyond that proposed for the LTER. For instance, watersheds research was greatly augmented in yrs 1-3 and will continue for another 3 yrs. Marsh research will be greatly augmented in yrs 4-6. The water column and microbial research was augmented in yr 3 and will continue for another 4 yrs. Benthic research was augmented in yrs 1 and 2.

Description of the System and the Major Drivers

The Plum Island Ecosystems LTER lies at the interface of a thinly soiled, formerly glaciated New England land mass and the highly productive Gulf of Maine. The 629 km^2 site includes the largest salt marsh-dominated estuary in New England (**Fig 2)**, the Plum Island Sound estuary (60 km^2), and three watersheds that comprise the estuarine drainage basin: Parker (155 km^2), Rowley (26 km^2) and Ipswich (404 km^2). The system is within the Boston metropolitan region and "bedroom" communities continue to encroach.

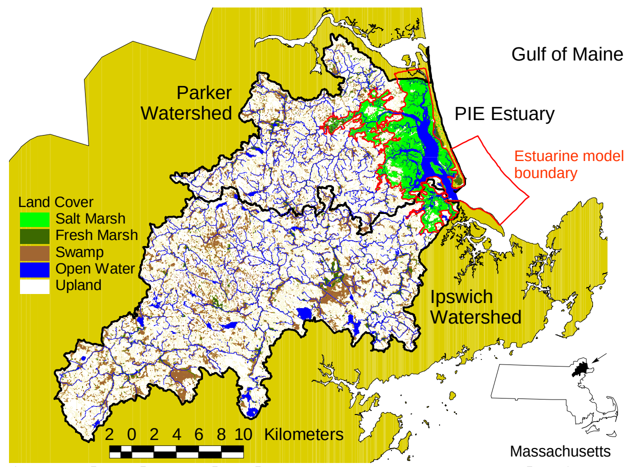

Fig. 2. The Plum Island Ecosystems LTER study site including watersheds and estuary.

There have been substantial long-term changes in several major ecosystem drivers of PIE, including climate, population, land use and sea level. We have documented significant increases in both precipitation and evapotranspiration in the Ipswich watershed over the past 60 years (see "Watersheds" research progress), which have altered the timing and magnitude of water discharge to the estuary.

Land-use in the basin has changed considerably over the past several hundred years. Beginning in about 1850, formerly extensive agricultural areas were abandoned and they reverted to forest. This pattern continued through 1960 at which time urbanization became the dominant land-use change (**Fig 3**). As of 1991, the basin was about 32% urban/suburban, 7% agriculture, 15% water and marsh, and 46% forest.

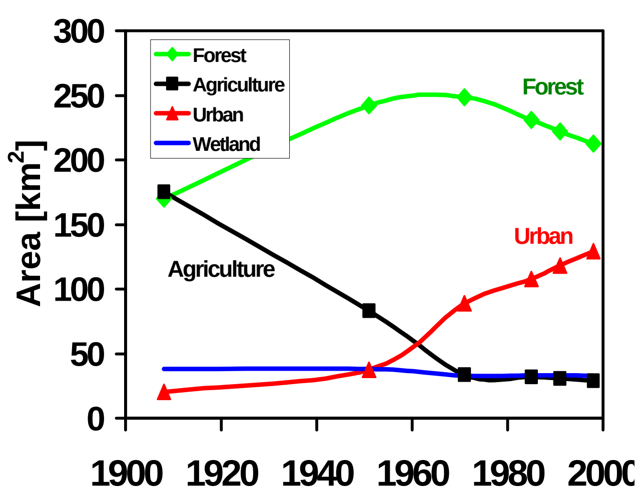

Fig 3. Land use change in the Ipswich watershed.

Population has increased continuously since the region was settled in the early 1600's, but especially during the 1950's and 1960's and again in the 1990's. The Ipswich watershed population is now in excess of 120,000, resulting in a population density of about 300 people km^{-2}. Population is even higher immediately adjacent to PIE, and municipal water withdrawals from the Ipswich River are having deleterious effects on river water levels and quality.

Changes are also occurring from the oceanic front. Since 1921 there has been in increase in mean annual sea level of 20 cm, which is equivalent to 2.42 mm yr^{-1}. As a result of continued anthropogenic increases in CO_2 emissions, air and water temperatures are predicted to increase worldwide, which will cause the rate of sea level rise to accelerate over the next century.

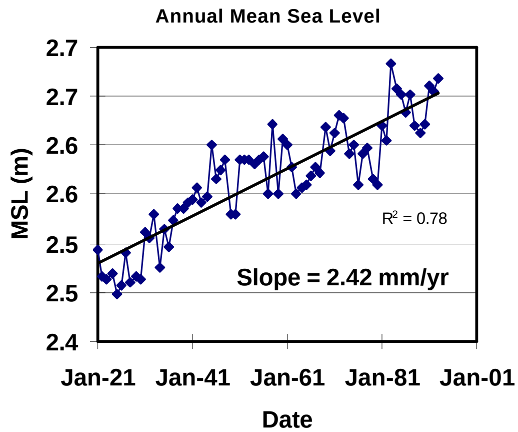

Fig 4. Long-term increase in mean sea level recorded at Boston.

These changes that are occurring in the PIE LTER system are occurring worldwide. Thus the PIE LTER system is a microcosm for studying and gaining an understanding of how coastal ecosystems will respond to these changes. These changes serve as the context for the PIE LTER research program.

In spite of the dramatic changes that have occurred in PIE watersheds, the estuary does not experience hypereutrophic conditions such as anoxia or hypoxia, toxic algal blooms, or fish kills. Along the 24 km length of the estuary, algal blooms only occur regularly in a short reach within the first 4 km of where the Parker River enters the estuary. This region, which represents less than 10% of the total estuarine area or volume, experiences chlorophyll concentrations between 40 and 100 ug l^{-1} during summer, when water residence time exceeds 1-2 weeks. In the vast majority of the estuary, flushing is rapid and chlorophyll concentrations are less than 10 ug l^{-1}. Another reason trophic levels are moderate is that N loading is relatively low compared to other US east coast estuaries that have experienced similar watershed changes. On the basis of riverine N loading and atmospheric N deposition, we estimate N loading to be 0.85 to 2.54 g N m^2 yr^{-1}, depending on how open water and marsh habitat areas are factored.

Research Report Outline

In the following sections we report on research progress for each of the programmatic areas plus integration and simulation modeling. Then we provide overviews of information management and technology, LTER network activities, outreach, and site management. Several appendices document LTER products, leveraged grants awarded and participants.

Q1-Watersheds: What is the magnitude and temporal pattern of organic carbon and nitrogen and inorganic N loading from watersheds to the estuary?

To develop a predictive understanding of material export from watersheds to the coastal zone, we examine both terrestrial and aquatic landscapes within the watersheds draining into Plum Island estuary. We ask two questions: **a) what is the temporal pattern of nutrient and dissolved and particulate organic matter output from catchments with different land covers? and b) to what extent do riparian and in-stream retention and processing affect the timing, magnitude and composition of organic matter and nutrient delivery to estuaries?** During the first 3 years we have made progress on both these questions focusing efforts on (i) development of appropriate geospatial data sets and land use change models, (ii) evaluation of long term changes in the hydrologic budget due to climate and land use change, (iii) routine monitoring of nutrient concentrations in streams draining catchments of varying land use and increasing stream order (including the entire watershed), (iv) experimental evaluation of in-stream nutrient processing, and (v) development of models to synthesize understanding of the controls on water and nutrient fluxes. In addition, outreach has been an important aspect of watershed activities. Additional funding was obtained by MBL and UNH through grants from NSF Water and Watersheds, NOAA CICEET, and EPA EMPACT programs.

(i) Geospatial data sets have been compiled for the Ipswich and Parker watersheds from data obtained from the Massachusetts GIS program. Data sets include high resolution (1:25,000 scale) land use in 1971, 1985, 1991, and 1999, DEM (3-m contours), aspect, slope, surface waters, wetlands (1:5,000), towns, and hazardous material sites. These data layers have been used to determine sample design of the various monitoring efforts described below, and are being used to parameterize models that predict land use change and nutrient fluxes to the estuary.

Land use changed dramatically over the past century. Agricultural abandonment and forest regrowth dominated the first fifty years, while urbanization, forest clearing and continued agricultural abandonment have dominated the past 50 years. Presently the watershed is comprised of forest (37%), urban (35%), water and wetland (21%) and agriculture (7%) land uses.

(ii) Land use change and associated socio-economic activities and climate change have had major impacts on watershed hydrology. Diversions of water from the watershed for municipal water supply and sewage disposal are equivalent to 20% of annual stream discharge. Land use change has resulted in decreased evapotranspiration, while climate change has resulted in increased evapotranspiration and precipitation. Unlike many systems experiencing urbanization, net water runoff has not increased in the Ipswich Basin (Claessens et al. submitted).

(iii) Nutrient exports from the Parker and Ipswich watersheds to the Plum Island Estuary have been monitored monthly since 1993. For the last 3 years, a number of additional spatially and temporally intensive biogeochemical data sets have been collected.

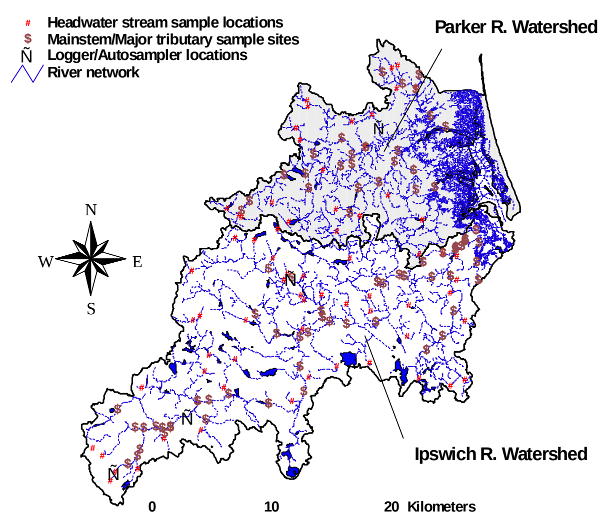

Fig 1. Location of catchment, tributary and mainstem sampling locations of the Plum Island watersheds.

Monitoring was coordinated by MBL and UNH in conjunction with the Ipswich River Watershed Association (IRWA) and the Parker River Clean Water Association (PRCWA). These efforts focused on determining loading rates from different land surfaces by sampling small catchments at different times of the year and sampling longitudinal concentration changes in the mainstem of the Ipswich and Parker Rivers (**Fig 1**). Since June 2000, event and cumulative based sampling of atmospheric deposition (wet and dry) also has been monitored. We have begun mounting data on the PIE-LTER and UNH-IPSWATCH (Ipswich/Parker Suburban Watershed Channel) web sites. Data sets collected by other groups working in the watersheds are currently being archived and will also be made available on the web site.

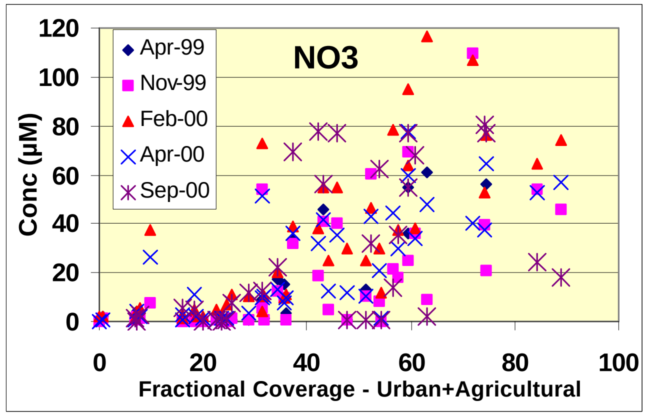

Fig 2. Runoff concentrations of NO_3^- are proportional to the relative area of urban and agricultural land uses within a catchment.

Monitoring of first-order catchments suggests that if urban areas expand, nutrient inputs to the aquatic system could increase considerably. Concentrations of Cl^-, SO_4^{2-}, NO_3^-, and base cations had significant, positive relationships with the percentage of urban and agricultural area in first-order catchments (e.g. NO_3^-, **Fig 2**), whereas DOC was significant and inverse. The relationships of DOC and DON are positively related to the % of wetland areas in these catchments.

In June 2001, YSI datalogging instruments, funded by the EPA-EMPACT program, were deployed in two headwater streams of contrasting land use: Sawmill Brook (urban) and Cart Creek (forest). The response of pH and conductivity following a storm runoff event differed significantly between the two watersheds (**Fig 3**) suggesting different flow paths dominated storm runoff. We hypothesize that water residence time in soils, groundwater, wetlands, or streams is an important determinant of nutrient export concentration from different watersheds across seasons.

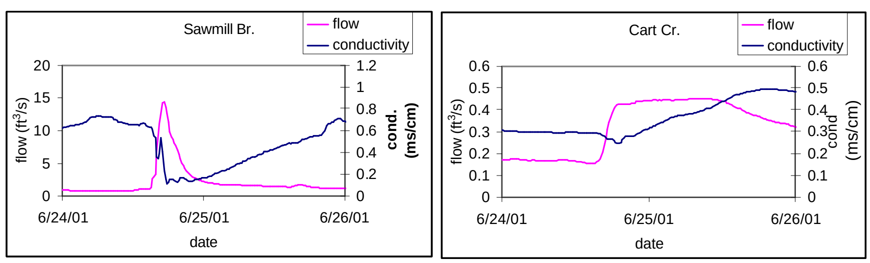

Fig 3. Water level and conductivity during a runoff event in urban (Sawmill) and forested headwater catchments. Conductivity declines rapidly initially before slowly returning to baseline in the urban stream, while it mostly increases above baseline in the foreste stream. Differences may indicate different flow paths of storm runoff.as stage increases

Whole system N budgets indicate that only 10-20% of total N inputs to the Ipswich watershed are exported to the estuary (**Fig 4**). While most retention is on land prior to entering streams (64-85%), there are also substantial instream N losses. While NO_3^- is the major form of N in 1st order streams, DON is the predominate form actually leaving the watershed. PIE scientist, Bruce Peterson, serves on the steering committee of a new LTER intersite activity that will compare whole watershed biogeochemical cycles at other LTER sites.

(iv) Much of the processing appears to be occurring in small 1st order streams (Peterson et al. 2001) and in slow moving, wetland reaches of the river mainstem. Nutrient processing within the aquatic network was evaluated using nutrient addition experiments in 1st order streams and observations of the changing Cl:NO_3^- ratios along the river mainstem. Negligible in-stream uptake of experimentally injected NO_3^- suggests that the observed ambient nitrate decline may be tied to convoluted flow paths more than in-stream processing. Significant processing occurs when the streams flow through marshlands (for example the Wenham Swamp – **Fig 5**). Using a chloride modification factor to partially remove the effect of dilution on nitrate concentrations indicates that marshlands are responsible for decreases in nitrate in both upland tributaries and the mainstem of the Ipswich River. NO_3^- concentrations in a marshy reach of Sawmill Brook can decrease from 80 uM to < 1 uM, suggesting substantial nitrate processing in this area. In contrast, NH_4 concentrations often increase from 2 to 5 µM, suggesting the potential importance of denitrification. However, tracer experiments of LiBr through this marshland indicate that the decrease in nitrate is due to some combination of dilution, long retention times that allow diffusion of NO_3^- into benthic substrates, and a complicated flow path that includes removal due to groundwater wells for public water supply.

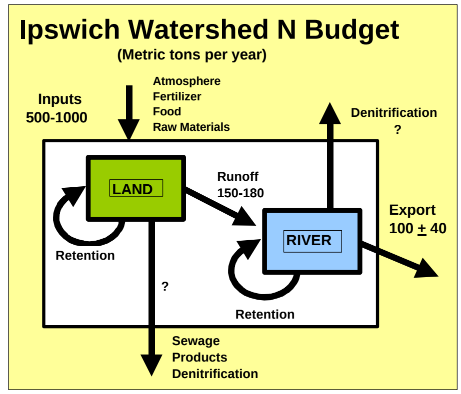

Fig 4. N budget for the Ipswich watershed (1993-98).

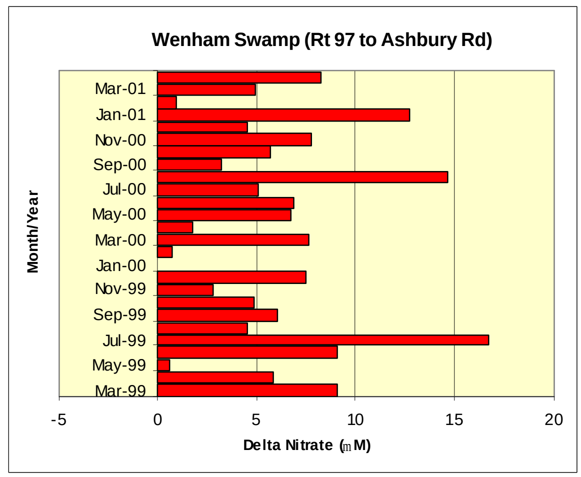

Fig 5. Differences in NO_3^- concentration as water flows through a major watershed wetland over the course of a year.

PIE scientist, Bruce Peterson, is a co-principal investigator of a recently funded intersite study of N cycling in "impacted" streams. The focus of the new NSF-funded LINX 2 (Lotic Intersite Nitrogen eXperiment) study is on nitrogen retention and denitrification in streams. The Ipswich watershed is one of the 8 regional sites in the US that will be studied.

(v) Modeling efforts included prediction of future land use change and its potential impact on nutrient exports from the Ipswich watershed, understanding where the hot spots of nutrient processing are within the Ipswich watershed (using HSPF) and developing a predictive model of nutrient export from whole watersheds that will eventually be applied across spatial scales (Nutrient Transport Model -NTM).

Geospatial data sets were used to parameterize a model to predict future land use change over the next 100 years under current legal constraints and past development patterns (Pontius 2000, Schneider and Pontius 2001, Pontius and Schneider 2001). Results indicate that if current trends continue, forest cover will be greatly reduced (**Fig 6**). This model is also being used to predict future changes in nutrient loading using the relationship between NO_3^- export concentration and land use.

The NTM developed thus far is a lumped parameter model coupling a water balance model with simple biogeochemical processing equations that control seasonal variation in the balance between uptake and net mineralization. Processing equations were based on results predicted from a more detailed biogeochemical model, PNET-CN. The model is being used as a synthesis tool for testing the patterns and timing of nutrient flux through various sub-basins of the larger watershed, in preparation for a distributed version of the model to simulate the entire Ipswich.

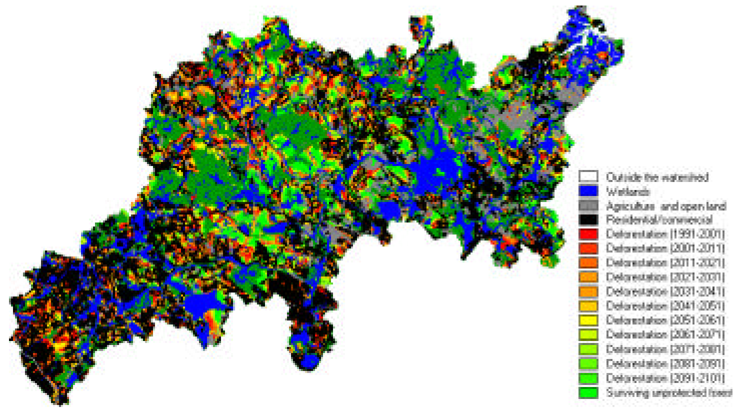

Fig 6. Predicted spatial pattern of urbanization in 10 yr increments through the century (Pontius et al. 2001).

Our preliminary version of the Nutrient Transport Model for the Ipswich and Parker Rivers yielded predicted export nitrate concentrations similar in magnitude and seasonal pattern compared to observed values (**Fig 7**). Seasonality of predicted nutrient fluxes also showed good agreement with observed fluxes because seasonal runoff was adequately modeled and often is the main factor controlling nutrient fluxes from watersheds. Absolute magnitudes will be improved with a geospatial version of the NTM taking into account land use specific nutrient loads.

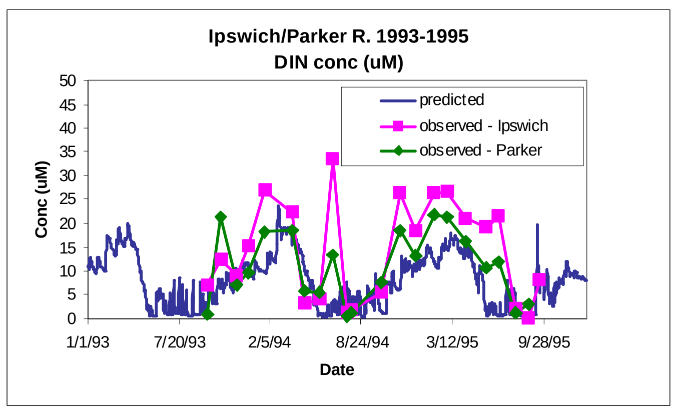

Fig 7. NTM-predicted and observed dissolved inorganic nitrogen export concentration in the Ipswich and Parker River. Model shows generally good correspondence but does not yet take into account increased loading due to land use change.

Outreach: Outreach activities have been an important aspect of the overall watershed effort and are detailed later in this report under OUTREACH. We have teamed with various local, state and federal government agencies, local citizens and watershed associations as well as corporations in monitoring, communication and advisory capacities.

Future Directions: Future directions involve continuing monitoring efforts to understand changes in nutrient exports due to land use and climate change. We plan to sustain the monitoring of flow and water quality using the YSI units, and making the results available on a web site in real time via telemetry. Sigma Inc. autosamplers in forested, urban, and agricultural headwater catchments, as well as at the mouth of the Ipswich and Parker Rivers will continue to be used to obtain frequent samples during storm events to obtain complete budgets of nutrient exports. Another objective is to conduct $^{15}N\text{-}NO_3$ tracer experiments to identify the predominant uptake mechanism(s) in streams. ^{15}N additions to urban, agricultural, and forest streams in the Ipswich and Parker watersheds are planned as part of a recently funded multi-biome intersite comparison of N cycling (Lotic Intersite Nitrogen Experiment (LINX) – II).

Brian Pellerin, PhD student at UNH, is investigating the role of riparian zones, wetland-river connectivity, and water residence time in controlling nutrient fluxes from the watersheds. The challenge is to quantify the role of wetlands, which are numerous and operate at small spatial scales, in controlling nutrient exports from whole watersheds. Wilfred Wollheim, another PhD student at UNH, will develop a spatially explicit, process model of nutrient fluxes to the coast. This model will consider differences in loading and processing in different land use categories (from our current site-specific work), as well as temporal and spatial variability in processing by the aquatic network. The monitoring program described above will provide information to parameterize and validate the model. The students plan to take advantage of the integrated modeling and field-monitoring program to help understand the control of nutrient fluxes to coastal areas and how these might change in the future.

The complex combination of land cover, soils, and human influences on nutrient loads in the upland watershed, together with in-stream processing will create an important challenge to our understanding of the major functional components of the ecosystem. We will take our NTM model, parameterized and tested on the series of more homogeneous catchments and convert it to a spatially-distributed model. Using the high resolution GIS data sets collected to date, we will test the model's behavior under a series of different spatial resolutions, from fine to coarse. One important test will be whether it is critical to preserve spatial topology across landscape units or if a simplification into lumped functional classes would preserve the fundamental dynamics. The scaling approach will be tested not only on the Parker/Ipswich but also in the much larger Kennebec/ Androscoggin Rivers in Maine as part of an allied effort by UNH .

Q2-Marshes: How are tidal marsh processes and their connections to estuarine waters regulated by sea level, storms and water and material inputs from land and sea?
To develop a predictive understanding of how terrestrial and oceanic forces affect intertidal marsh systems and how marshes interact with adjacent tidal waters, we examine the processes of primary production, organic matter and sediment storage, and nutrient cycling on marshes throughout the Plum Island Sound estuary. We ask the following two questions: a) h**ow are sediment accretion and primary production in tidal marshes altered by changes in freshwater discharge, material inputs and sea level? and b) how do indicators of organic matter and inorganic nutrient exchange between marshes and estuarine waters respond to variations in freshwater discharge and sea level?**

During the first three years we have made significant progress in addressing both questions. We are developing long-term primary data sets that include measurements of: i) a monthly plant census in *S. alterniflora* and *Typha* marshes (control and fertilized (NP factorial) plots); ii) monthly pore water chemistry in *S. alterniflora, S. patens,* and *Typha* sites, control and fertilized plots; and iii) monthly marsh surface elevations.

The first year of the project was dedicated to reconnaissance and site selection as very little basic information was known about the salt marshes around Plum Island Sound. Our primary data sets were started in the second year of the project. We have also started an extensive survey of marsh elevation with a goal of constructing a digital elevation model that we will couple with tidal and meteorological data to determine the frequency, duration and depth of flooding, as well as the spatial distribution of flood water, temperature and salinity. A series of SET (surface elevation table) platforms and marker horizons have been surveyed and are being monitored to determine the rate of change of the marsh surface. Coupled biogeochemical and hydrological models of the marsh and aquatic subsystems will be used to calculate import-export budgets of nutrients and sediments. Work on these objectives will be enhanced by an EPA grant that addresses geomorphological indicators of ecosystem condition.

(i) Primary Production - We have established permanent plots in 3 major marsh types where plant census and porewater nutrient data are collected monthly. Long-term experiments with monthly factorial N and P additions are being carried out to determine nutrient controls on primary production and sediment accretion. We plan to establish a large scale N and P addition experiment to determine nutrient control of species distribution and sediment accretion. We have also established an experiment that is designed to determine the optimal elevation for *Spartina alterniflora* and the relationship between primary production and relative marsh elevation. The generality of our findings is being tested by comparative research that is being done at North Inlet, SC (supported by an NSF LTREB grant) and in Wells, ME on primary production, pore water nutrient chemistry, and sediment accretion.

Sediment Accretion - We completed an initial survey of marsh elevation; we established SET platforms and feldspar marker horizons at 12 sites across 3 major marsh types. Comparative work on sediment accretion, supported by a grant from USGS, is being carried out at North Inlet.

(ii) Marsh-Estuary Linkage: We established a series of ground water level recorders in *S. alterniflora* and *Typha* marshes that are being used to monitor the dynamic response of subsurface water in relation to tidal and climatic forcing. We are gathering data on sediment structure, hydraulic conductivity, porosity and specific yield. We plan to install a wider array of pore-water wells to monitor pore water chemistry on a seasonal basis. Water level, coupled with hydraulic conductivity and other soil properties will enable us to estimate the quantity of water and nutrients leaving marsh sediments and entering tidal creeks on every tide. These fluxes will be compared with measures of estuarine metabolism conducted under the Water Column Programmatic Area (Q3).

Intersite Research:

We are conducting comparative studies at estuaries at Wells, ME and North Inlet, SC where there are strong contrasts in physical drivers such as climate and tidal range. The primary data sets being developed under **Q2a** are being duplicated at North Inlet, SC where we have 16 years of data on marsh primary production. Specifically, we are addressing the following questions through intersite research: 1) How do the temporal patterns in annual primary production correlate in salt marshes from different regions? 2) How do peat-dominated NE and mineral-dominated SE salt marshes differ in terms of sediment accretion, nutrients, decomposition? 3) How do the controls on primary production differ?

Research Result Highlights:

After only 2-yr of research at PIE we have learned that interannual variation in production of the salt marsh macrophyte *Spartina alterniflora*, which from earlier work was known to be high at North Inlet, SC is also high at PIE (**Fig 1**). This exciting result raises the possibility that regional scale variations in marsh productivity are synchronous. This would be the case if a common driver, such as sea level anomalies, are regional in scale. At North Inlet the variations in mean sea level (MSL) that are responsible for interannual variations in production are, in fact, regional in scale (Morris 2000). Note the variability in MSL in Boston Harbor during 1999 and 2000 (**Fig 2**). At North Inlet it is the change in sediment salinity that varies with MSL that is the proximate cause of the variability in primary production. We do not yet know if salinity is a proximate determinant of primary production at PIE.

The response of *Spartina alterniflora* to nutrient additions at PIE (**Fig 1**) is consistent with results at North Inlet and confirms that nitrogen is the primary limiting nutrient for *S. alterniflora* in salt marshes. *S. alterniflora* at PIE has responded to nitrogen additions, but not to phosphorus additions. Interestingly, preliminary data suggest that primary production of *Typha* in brackish water marshes at PIE is limited by phosphorus. If confirmed, then the nutrient controls on ecosystem function differ at opposite ends of the PIE estuary.

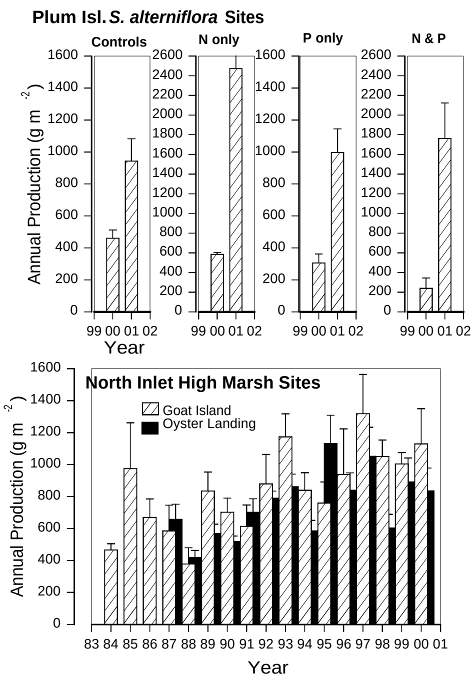

Fig 1. Top: annual aboveground production of S. alterniflora at PIE as a function of nutrient treatment. Bottom: production of S. alterniflora at two sites at North Inlet, SC.

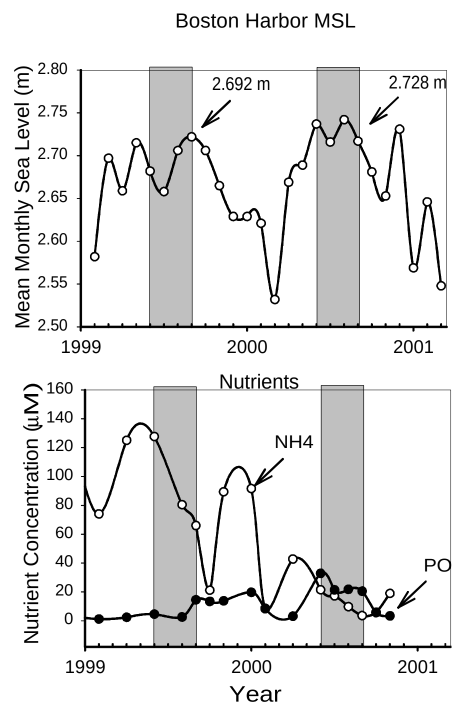

Fig 2. Top: mean monthly sea level (Boston Harbor). Bottom: mean monthly concentrations of pore water NH_4 and PO_4 in the S. alterniflora marsh, PIE. The shaded bars identify months of maximum growth.

There has been an inverse relationship between *S. alterniflora* primary production (**Fig 1**) at PIE and the concentration of dissolved ammonium in pore water (**Fig 2**), which suggests that the export of NH_4 from marshes is controlled by variations in marsh primary production during summer.

The entire range of pore water nutrient concentrations across an estuary can be depicted by a plot of NH_4 vs PO_4 (**Fig 3**). Based on large differences in nutrient concentrations that we have observed among a group of study sites (**Fig 3**), it can be concluded that nutrient exchanges between marshes and adjacent subsystems also differ. We see higher nutrient concentrations in general in the urbanized Cooper River estuary, and the lowest concentrations in our New England sites (Wells, ME and PIE; **Fig 3**). There are also differences within estuaries that are largely controlled by salinity. The urbanized Cooper R., SC displays a broad range of N and P concentrations with the highest concentrations at the saltwater end of the estuary and the lowest concentrations at the freshwater end. PIE displays a narrower range of nutrient concentrations.

The variation in pore water NH_4 in our southern salt marsh sites appears to follow the stochiometry of anaerobic decomposition by sulfate reduction or 14 mol of sulfides produced per mol of NH_4 generated (**Fig 4**). There appear to be differences in this pattern among estuaries, which suggests that there are differences in the dominant forms of microbial metabolism .

Future Directions: During the next three years U. South Carolina graduate students Robert Daoust and Diana Rodriquez will develop Ph.D. research proposals to conduct research in the Plum Island marshes. The large-scale marsh fertilization experiment will be initiated. We will also greatly expand research on relationships between marsh drainage network configuration (geomorphology) and marsh accretion and relationships between plant pigments and plant health in an attempt to develop indicators of marsh “vitality”. Work on marsh porewater exchange with adjacent tidal creeks will begin to incorporate nutrients and organic matter fluxes in addition to water.

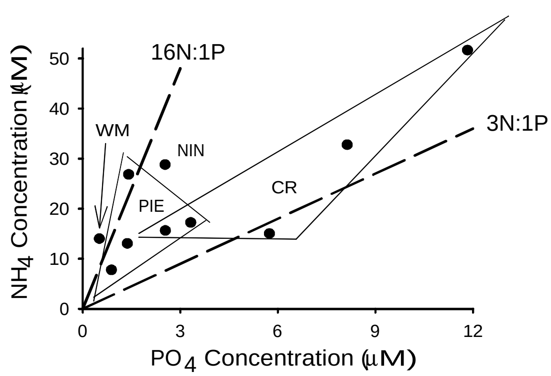

Fig 3. Geometric mean concentrations of NH4 as a function of PO4 concentration in pore water within different marsh habitats (tidal fresh to salt marsh) within different estuaries. PIE=Plum Island Estuary; CR= Cooper River, SC; NIN=North Inlet, SC; WM= Wells, ME.

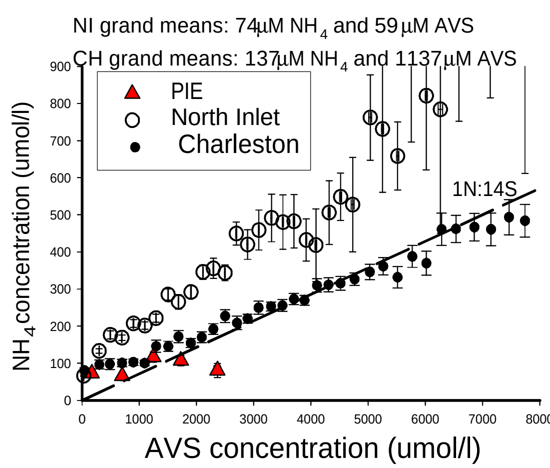

Figure 4. Mean pore NH4 concentration as a function of the concentration of acid volatile sulfide (AVS) concentration in pore water from PIE, North Inlet, and Charleston Harbor salt marshes.

Q3-Water Column: **How does planktonic community structure and production respond to changes in organic matter, nutrients and water fluxes?**

The water column programmatic area concerns the linkage between land and coastal water through the input of dissolved and particulate organic matter and the effect on this input of changes in land cover. Our research addresses three specific research questions: **a) what is the spatial and temporal variation in the source of dissolved and particulate organic matter (from land, oceans, macrophytes, and algae) supplied to and used by pelagic bacteria?, b) How does the quality and quantity of organic matter mediate competition between bacteria and phytoplankton for nutrients? and c) How does production of zooplankton and fish differ according to changes in water residence time, organic matter inputs, and nutrient supply?**

One approach to answering these questions is to sample along the estuarine transect from sea water to freshwater and to look for long-term changes in the plankton community and in the rates of processes**.** Transect collections and measurements are made from one to three times each year; nutrients, phytoplankton, primary productivity, respiration, and zooplankton are studied. During the first three years we have focused attention primarily on questions a and b through extensive field surveys and experimentation. We have concentrated on three areas: **(i)** the age and likely source of the dissolved (DOC) and particulate (POC) organic carbon that enters the estuary from the land and salt marsh; **(ii)** the metabolic response of the planktonic microbes and of the entire estuary to organic matter and nutrient inputs; and **(iii)** on changes in the taxonomic structure of the community of microbes in the plankton of the estuary.

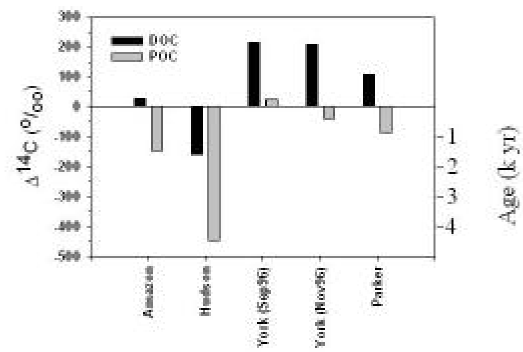

Figure 1. The age of dissolved (DOC) and particulate organic carbon (POC) in various rivers. The Parker River POC is ~1,000 years old.

(i) Spatial and temporal variation in the source and microbial utilization - The ^{14}C age of the DOC entering the estuary via freshwater transport from the land (Fig 1, from Raymond and Bauer in press) was first measured through collaboration with Jim Bauer and Peter Raymond at the Virginia Institute of Marine Science; Raymond has continued this work as a postdoctoral scientist on the PIE LTER project. The data indicate that the DOC is completely modern; its source is recent terrestrial primary production. The POC, in contrast, was ~1,000 years old indicating that most comes from old soil carbon.

Measurements of the d^{13}C in the DOC shows that there is an additional source of DOC within the estuary. If there were no source of DOC except the ocean (where the phytoplankton have a ^{13}C signal of -22 ppt) and land (where trees and shrubs have a ^{13}C signal of -28 ppt), then the line describing the values at various salinities in the estuary would follow the lower trajectory shown in Figure 2 (conservative mixing line). Instead, the values lie mostly above the conservative mixing line indicating that there is DOC from a third source

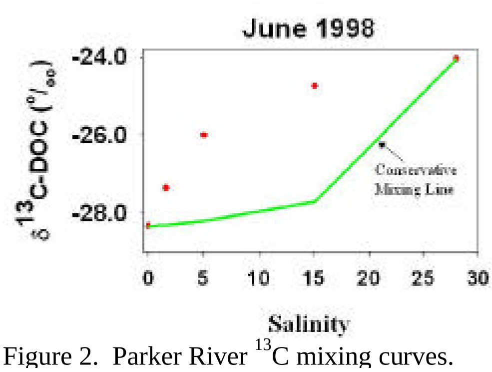

Figure 2. Parker River ^{13}C mixing curves.

entering the river. This is likely DOC from the salt and freshwater marshes.

A detailed study is underway to determine the flux of water and dissolved inorganic and organic carbon from the marsh to the estuary. To do this, perforated pipes equipped with pressure sensors are inserted into the marsh sediments to provide a transect of wells from the edge of the marsh to 20 m inland. With these wells we measure the depth of the water table (every 5 minutes) and concentrations of dissolved inorganic carbon, DOC, and colored dissolved organic matter. From these data, we can estimate water and carbon fluxes from the marsh to the estuary.

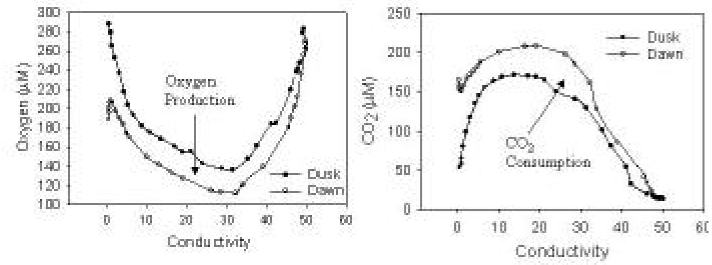

Figure 3. Oxygen and carbon dioxide concentrations in the Parker River estuary measured along a salinity transect at dawn and dusk.

(ii)Metabolic response of the estuarine ecosystem - By measuring the oxygen and carbon dioxide concentrations at dawn and at dusk over the entire estuary, the production of oxygen and the consumption of carbon dioxide during the daylight hours can be calculated. In **Figure 3**, these values are the difference between the dawn and dusk concentrations. A conclusion from these studies is that the estuary is heterotrophic (i.e., more organic matter is consumed than is produced). This extra organic matter likely comes from the fresh and salt marshes surrounding the estuary.

One pathway for loss of CO_2 from the estuary is the transfer across the air—water interface. The transfer depends upon the diffusion gradient and the amount of turbulence in the uppermost waters. Usually, estimates are based upon a transfer coefficient (k) calculated from wind speed alone. However, in shallow estuaries "k" is also affected by turbulence caused by tidal flow of water. For this reason, we are we are collaborating with Wade McGillis of the Woods Hole Oceanographic Institution (WHOI) to study the small scale processes that control the "k" by measuring its variation at different values of tidal flow and wind. The first results from the study show that "k" increases strongly with tidal velocity on a day when there was little wind. A calculated CO_2 transfer based only on the wind velocity would have underestimated the flux from water to the atmosphere. This study is being continued by Peter Raymond who will be joining WHOI as a postdoctoral scientist.

As is typical of almost all aquatic systems, the bacteria are responsible for most of the water column respiration. Filtration through a 1 um pore-size filter reduced the respiration in flasks by only a few percent. The rates of bacterial production, measured by the incorporation of labeled leucine in short dark-bottle incubations, were high in the estuary and lower at the freshwater and ocean water ends of the salinity transect. In this study we are collaborating with Stefan Bertilsson, a postdoctoral fellow at the Massachusetts Institute of Technology, who is investigating the role of microbes in metabolizing organic matter derived from a bloom of planktonic algae.

(iii) Community Response of Planktonic Bacteria - The first step was to determine the distribution of bacterial communities in the estuary along the salinity gradient. Their distribution was investigated by extracting the DNA from water samples, performing a PCR amplification on 16S rRNA genes with bacteria-specific primers, and analyzing with denaturing gradient gel electrophoresis (DGGE). In the development of techniques for DGGE in estuarine waters, we have closely collaborated with the Microbial Observatory Project and its principal investigators

John Hobbie and Mitchell Sogin of the MBL and Andreas Teske and John Waterbury of WHOI. When the DGGE procedure was carried out on eight samples collected on single days in July and September we found almost no overlap between DGGE banding patterns from the river (0 ppt) and coastal ocean (34 ppt) sites. This suggests that different communities of bacteria inhabit the two ends of the estuary. However, the DGGE bands from the fresh and saltwater samples were also present in samples collected at sites with intermediate salinity levels, indicating a mixture of freshwater and marine communities. The DGGE patterns from these intermediate salinity samples also showed new bands, which suggests a third community or communities of microbes. We think that the organisms represented by these bands form an estuarine community adapted to the unique conditions created by the mixing of fresh and salt water. DNA sequencing revealed several freshwater forms previously described from temperate and arctic lakes.

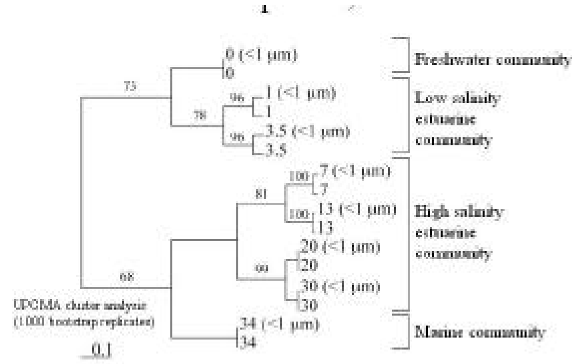

Fig 4. Parker River Estuary DGGE Patterns Sept. 28, 2000.

The banding patterns can be analyzed further by noting whether each band that has moved a particular distance on the gel is present or absent in a sample. A tree diagram can be constructed in which the lengths of the horizontal branches show how similar the banding patterns are from one sample to another (**Fig 4**). We conclude from this further analysis that the estuarine bacterial community has two parts, a low-salinity and a high-salinity segment.

Why are these two segments so different from each other? It is possible that certain species of bacteria are part of a community associated with the seasonal phytoplankton bloom, which is restricted to the lower-salinity regions of the estuary. Bacteria found in higher-salinity regions may be affected by the high levels of organic matter entering the estuary from adjoining salt marshes. Thus we have preliminary evidence that the composition of the bacterial communities in the estuary is influenced both by the salt content of the water and by the source of organic matter. Samples collected from the estuary in July, September and April will allow us to determine whether or not there is a seasonal shift in these distinct communities.

In conclusion, we found that the DGGE results fell into four clusters: a freshwater community, a low salinity community, a high salinity community, and a marine community. The next step will be to determine if the community at a given salinity changes in response to seasonal algal blooms or to seasonal changes in organic matter input from marshes.

Future Directions:

In the next three years of the project we will concentrate first on publishing the results of the intensive research of the past two years. We will also develop further the investigation of the transfer of organic matter and of metabolic products (inorganic carbon, oxygen) between the water column and the marshes. For this work, the continuously recording YSI Oxygen Meter will be used to look for correlations with the estimates of material exchanges calculated from the porewater-level recorders in the marsh sediments.

We will also begin to examine the role of nutrient limitation and the microbial community consortia on wetland organic matter decomposition. This effort will be partially supported by a new Biocomplexity development project. PIE investigators, Hobbie and Giblin, have a subcontract with Curtis Richardson at Duke University to participate in this intersite study. Hopkinson, Hobbie and Morris have been collaborating with Blum and Mills from VCR on a similar intersite study.

Q4-Benthos: How does benthic use and recycling of nutrients and organic matter vary with changes in water fluxes and the quality and quantity of organic matter inputs?

In addressing this overall question about estuarine benthic systems, we ask the following three questions: **a) how do benthic nutrient fluxes and metabolism in different regions of the estuary respond to variations in the quality and quantity of organic matter inputs?, b) what is the relative importance to higher trophic levels of carbon and nitrogen from organic matter of different qualities? and c) how variations in the salinity distribution in the estuary determine the magnitude and timing of the nutrient release from the water column?**

Each of our three sub-questions is currently being addressed in part, through our monitoring program. As part of our long term monitoring program we have been measuring the benthic fluxes of oxygen, CO_2 and nutrients at several stations in the estuary. To address **Q4a**, we are looking at seasonal and inter-annual changes in benthic fluxes to determine if factors such as the supply of organic matter from terrestrial, planktonic and pelagic sources, control year to year variability. We are also examining annual variability in the C/N ratio in the sediments and in the C/N ratio of what is mineralized. As part of **Q4b**, we are examining annual variations in the stable C,N and S isotopes of consumers including the bivalves *Mya* and *Geukensia*, to see if there are annual variations that relate to changes in discharge and sea level rise. For question **Q4c**, we have been focusing at several stations in the upper and mid-estuary which experience large changes in the salinity of the overlying water over the course of the season and measuring nutrient release in conjunction with our benthic flux measurements. Benthic fluxes, sediment data and isotope data collected each year are all archived in the database (Ben-PR-FLUX.htm, Ben-PR-Sediment.htm, HTL-PR-Isotopes.htm) on the web site.

As a result of our monitoring program we found that while rates of benthic respiration were well correlated with water temperature, both the seasonal and the inter-annual pattern of ammonium release at our upper estuary sites correlated better with salinity than with temperature. These sites experience salinities in the overlying water which range from near 0 psu in the spring to up to 20 psu in late summer. To further characterize how salinity affects nutrient release (**Q4c**), we carried out several years of intensive measurements and experiments at our upper estuary sites.

Over most summers, we observe high rates of ammonium release from sites in the upper estuary. We have also noted that this region of the upper estuary experiences blooms of phytoplankton during the mid-summer but not during the spring (**Fig 1**). During the spring, although nutrient loading from the watershed is high, the residence time is too short to allow phytoplankton to bloom. During summer, the residence time is much greater but the only source of nitrogen would have to be internal. We have speculated that the summer release of ammonium from the sediments may be partially responsible for supporting the mid-summer bloom.

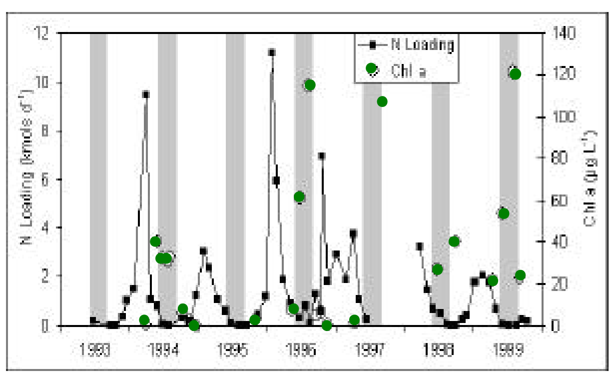

Fig 1. Temporal asynchrony of riverine N loading and occurrence of algal blooms in oligohaline region of estuary. Grey stripes indicate summer periods when flow is lowest but blooms most prevalent. Salinity-enhanced NH_4^+ flux is hypothesized to contribute to these summer blooms.

In 1999 we began several years of intensive process measurements to determine the effect of salinity on the adsorption and release of ammonium from sediments. While the chemical factors influencing the distribution of ammonium between dissolved, adsorbed, and fixed pools have been well characterized, the implication of daily and seasonal salinity changes in the overlying water on benthic nitrogen cycling in estuaries is not well understood. Our project has three goals: 1) assess how nitrogen storage and release from estuarine sediments changes in response to changes in the overlying water salinity; 2) determine the effect of porewater salinity on rates of sediment nitrification and denitrification and 3) model the implication of salinity control on benthic nutrient dynamics on temporal and spatial patterns of estuarine metabolism.

We found that salinity controlled the release of ammonium from sediments in two important ways. First, salinity directly affects ammonium release though ion exchange. At low salinities, more than 90% of the sediment ammonium pools are bound to exchange sites on particles. Over the spring, as metabolism increases, ammonium builds up on exchange sites. In summer, as salinity increases, this "trapped" ammonium is desorbed from particles and released into the porewater where it can diffuse to the overlying water (Weston et al. in prep., **Fig 2**). Second, salinity has a large effect on rates of coupled nitrification/denitrification (Giblin et al. in prep.). During summer, denitrification rates are lower than in the spring when the estuary is fresher, even though overall rates of sediment metabolism are greater in summer. This means that in summer a greater percentage of the mineralized ammonium reaches the overlying water (**Fig 3**). While we have made our most detailed measurements of the effect of salinity on ammonium fluxes at the upper estuary sites, we have characterized the seasonal changes in the pools of dissolved and exchangeable ammonium throughout the estuary. We found that there is a significant effect of salinity on ammonium pools throughout the entire upper half of the estuary.

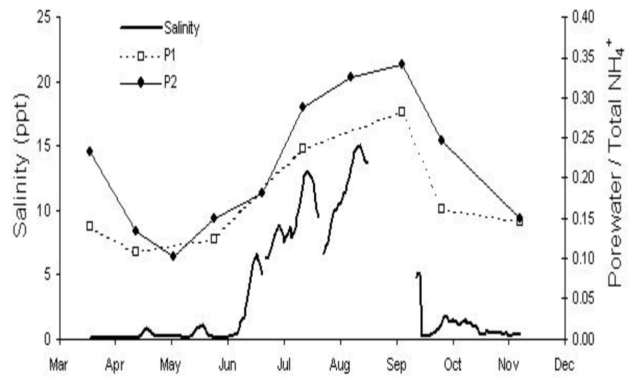

Fig 2. Annual pattern of overlying water salinity and the relative size of the exchangeable ammonium pool at 2 two stations in the upper estuary.

We have used the information on how ammonium production changes with temperature coupled with the data on changes in exchangeable pools and denitrification due to salinity to create a model of how benthic ammonium fluxes change over the season (Weston et al. in prep.). Using this model we have explored how changes in freshwater discharge can alter summer benthic ammonium fluxes (**Fig 4**).

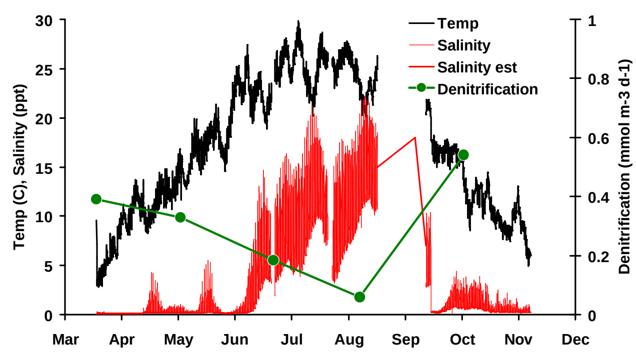

Fig 3. Annual pattern of denitrification in upper estuary sediments as influenced by changes in overlying water salinity.

Several mechanisms for the decrease in coupled nitrification/denitrification rates with increasing salinity have been proposed in the literature (Seitzinger et al. 1991, Joye and Hollibaugh, 1995). The lower exchangeable pool of ammonium or the higher sulfide levels in more saline sediments may inhibit nitrification, or direct physiological effects of salt may be important. To investigate how important physiological effects are, we measured nitrification rates in sediments at several salinities but directly after they were taken from the field and after they had been held at various salinities for 70 days. When sediments were taken directly from the field in spring, when in-situ salinities were near 0 psu, nitrification rates were highest in freshwater and decreased with increasing salinity (Mondrup 1999). When sediments were held in the lab their maximal rates of nitrification were at or close to the salinities at which they were held (**Fig. 5**, Mondrup 2001, Mondrup et al in prep.). This suggests that either nitrifiers can adapt to salinity changes, or that there are different populations of nitrifiers with different salinity tolerances.

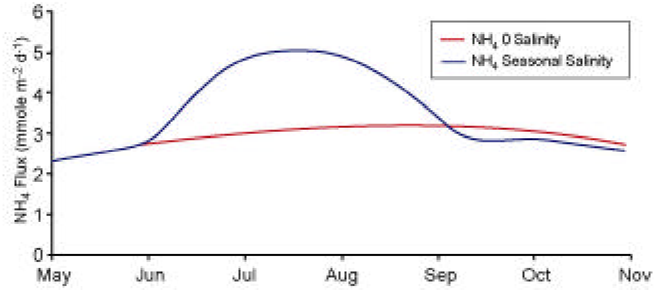

Fig 4. Simulated fluxes of NH_4^+ to overlying water under constant (0 psu) and seasonally varying salinity. The difference between blue and red lines is due to the "salinity effect".

We are currently following up on these findings by collaborating with investigators using microbial techniques to examine microbial populations at Plum Island funded through the NSF Microbial Observatories program. Ann Burnhard, a post-docotoral investigator working with David Stahl (Univ. Washington) is using molecular techniques to identify nitrifiers from sites where we are measuring nitrification and denitrification rates. At the same time John Waterbury (WHOI) is using traditional techniques to try to culture nitrifiers. This will be one of the first times that these two different approaches at looking at microbial community structure in sediments will have been compared to in-situ rate measurements.

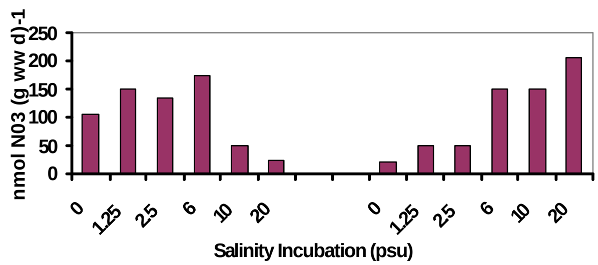

Fig 5. The effects of salinity on nitrification. Potential nitrification was measure on sediments held at 0 psu and preincubated for 70 days at 10 psu. (from Mondrup 2001).

Future Directions:

We are also planning further experiments to examine **Q4a**, and **Q4b** in the next 3 years. We will label organic matter from terrestrial sources, phytoplankton and the marsh (*Spartina*) with ^{14}C and add one type of each organic matter types to replicate cores in the lab. We will measure benthic fluxes from these cores to better understand how the quality of organic matter affects benthic respiration and fluxes (**Q4a**). At the same time we will add isopods to these cores and compare the growth, survival and ^{14}C content of isopods growing on the different sources.

Q5-Higher Trophic Levels: How does the structure and function of higher trophic levels respond to variations in organic matter, nutrients and water fluxes?

The overall goal of research on higher trophic levels is to understand how variation in environmental drivers affects animals and the role animals play in estuarine biogeochemical cycles. Estuarine biota are profoundly affected by changes to the spatial and temporal availability of habitat and food. The physicochemical environment (salinity, temperature, DO, water flux), food availability, competitive interactions and predators, influence nekton distribution, production, and habitat choice at both the microhabitat and whole-estuary scale. The functional roles of higher trophic levels may also change with variations in organic matter, nutrients and water flux. We ask the following three questions: **a) how does the production of higher trophic levels vary spatially and temporally with changes in organic matter, nutrients and water flux? b) how does the partitioning of production between benthic and pelagic fish change with variations in organic matter and nutrients? and c) what is the role of higher trophic levels in regulating trophic structure and in transporting carbon and nitrogen across estuarine interfaces?**

Our approach is to periodically monitor estuarine-wide nekton abundance to understand inter-annual variability in response to large-scale environmental drivers and to conduct experiments targeted at specific questions.

Temporal and Spatial Patterns in Production:

Our initial research documented a 10-fold increase in the abundance of *Fundulus heteroclitus* (mummichog) and *Menidia menidia* (Atlantic silversides) in 1993/1994 compared to 1964 (Table 1). We hypothesized that this increase is due to higher river discharge and sea level, lower salinity, and fewer predators because of long-term declines in striped bass. Determining which of these competing explanations is most important will require long-term monitoring of nekton abundance under a variety of naturally occurring environmental conditions. Replicate samples are taken on monthly intervals at ten stations distributed among habitats from the head of the estuary to the mouth. Our LTER strategy is to complete this broad-based survey of nekton every three years. Using a combination of LTER funding and supplemental funding from NMFS, we have completed 5 years of surveys (1993, 1994, 1997, 1998, 1999). We have measured fish abundance in a drought year roughly equivalent to the drought of the 1960's and under conditions of high discharge. We will continue to periodically survey the nekton populations and in the next few years we should see striped bass abundances roughly equal to those of the 1960's. We have used volunteers (usually about 15 per year) in cooperation with the

Table 1. Abundances of forage fish in two different decades, the 60's and 90's.

Common Name	Scientific Name	Annual Average Abundance (number $100m^{-2}$) 1965	1994
Mummichog	*Fundulus heteroclitus*	18	128
Atlantic silverside	*Menidia menidia*	6	110
Ninespine Stickleback	*Pungitius pungitius*	2	3
Sticklebacks	*Gasterosteus spp.*	1	1
River herring	*Alosa spp.*	1	4
Smelt	*Osmersu mordax*	0.4	0.1
	All others 8 & 9 species	0.5	0.5
	Total	**29**	**246**

Massachusetts Audubon Society to complete this effort. Because of this, the fish survey has also been an important part of our education and outreach efforts.

Marsh flooding and geomorphology is believed to be a major determinant of nekton productivity in this system. We have begun to examine this through examination of fish and crab abundance in 10 tidal creeks on the Rowley River. Mummichog abundance is positively related to the area of marsh flooded daily (**Fig 1**; Komarow 1999). The abundance of green crabs is among the highest measured (~ 5 adults m^{-2}) but is not related to marsh flooding (Young 1999). We have shown in large-scale experiments that mummichogs with access to the marsh for feeding have higher growth rates than those that feed only in pool environments (Javonillo 1997).

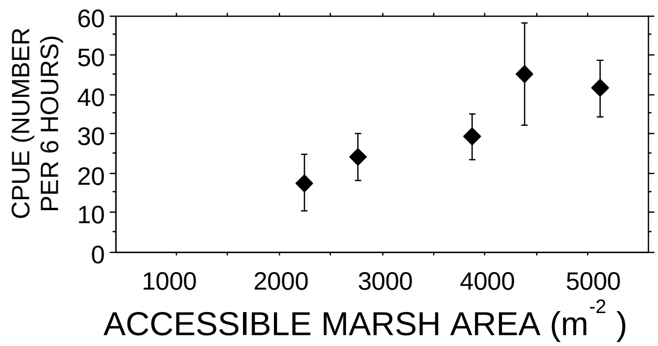

Fig 1. At the small watershed (~10ha) level, the abundance of mummichogs (*Fundulus heteroclitus*) is proportional to the area of marsh flooded on every tide.

A major future goal is to construct a spatially explicit model of fish production linking measures of habitat suitability to bioenergetic or individual based growth and survivorship models. Initially this model will be parameterized for mummichogs as they are the most abundant fish in saltmarshes and we know a lot about their life history and requirements. We will also determine the importance of the marsh configuration to whole system nekton production by determining depth of flooding requirements and the importance of geomorphology (esp. drainage density and edge) using flume nets. The model will allow us to integrate the interannual variability of environmental conditions that influence fish production within a single system. By applying this model to several different estuarine systems, such as Wells or North Inlet, we will be able to examine the influence of differing marsh geomorphology and tidal regimes on mummichog production.

Benthic and Pelagic Partitioning:

Understanding how various primary producers such as marsh grass, phytoplankton or benthic algae affect nekton is a fundamental question. We are using measurements of standing stocks and $\delta^{13}C$, $\delta^{15}N$ and $\delta^{34}S$ values of fish and invertebrates in experiments and sites within estuaries over time to address this topic. The large-scale, whole ecosystem experiments will contribute to this understanding by altering the primary producers at the base of the food webs. In the detritus removal (haying) experiment we have documented an increase in the biomass of marsh platform algae when detritus is removed and a concomitant shift in the stable isotope signal of some marsh platform invertebrates that indicates a stronger reliance on algal production (**Fig 2**). Haying of smooth cord grass (*Spartina patens*), which removes 80-90% of the above-ground grass biomass, has been conducted in New England salt marshes since colonial times. *Spartina* detritus is an important component of the salt marsh food web and the removal of the marsh grasses also increases the light reaching the marsh surface. This has the potential to alter the primary production that supports higher trophic levels. We have shown that chlorophyll *a* concentrations in four hayed and four reference marsh systems were higher on average (by approximately 5800 mg/m^3) in the hayed sites. This difference in chlorophyll content of surficial sediments indicates a larger benthic algal biomass in hayed areas in the early growing season. Carbon and nitrogen stable isotopes were used to examine the effects of haying on consumer diet by comparing the same species in hayed and reference marshes. Values of $\delta^{13}C$ were more depleted in *Melampus bidentatus* (by -2.8 $^{00}/_{0}$), *Orchestia grillus* (by -1.2 $^{00}/_{0}$), and *Ilyanassa obsoletus* (by -1.1 $^{00}/_{0}$) from hayed sites than those from reference sites This shift in ^{13}C isotopic content may indicate an increased algal component in diets of these organisms in the hayed areas. Several other organisms, *Fundulus heteroclitus*, *Menidia menidia*, *Palaemonetes* sp., *Nereis virens*, *Littorina* sp., and *Philoscia* sp., did not show this isotopic shift. This difference between species may be due to differences in trophic position, habitat in the marsh system, and feeding ecology.

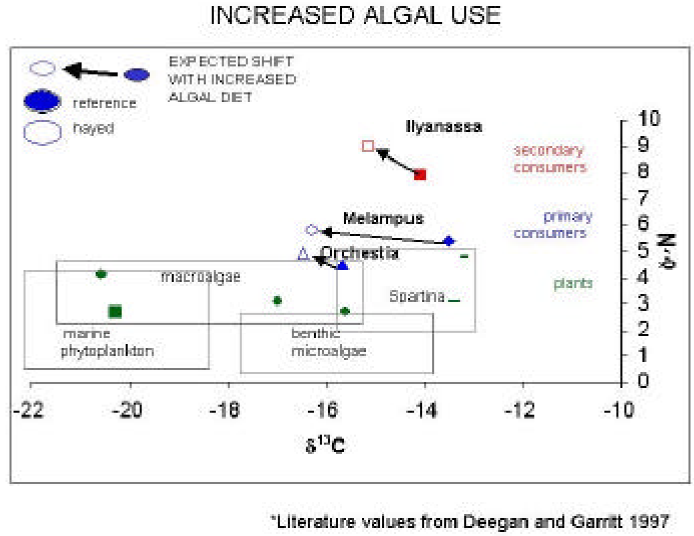

Fig 2. Effects of the removal of marsh aboveground vegetation on marsh fauna as evidenced by isotopic shifts in selected marsh organisms.

We are also monitoring some sentinel species (mummichogs, Atlantic silversides, mussels, *Crangon*, zooplankton and POM) in the open bay areas to examine the interannual differences in sources of primary production in estuarine food webs. We have made collections in 2000 and 2001.

The long-term marsh and creek fertilization experiments will also be used to address the importance of differing primary producers to estuarine food webs. By increasing nutrient availability, we should increase algal productivity and stimulate detrital decomposition. The combination of naturally occurring stable isotope composition and ^{15}N tracer additions before and after manipulation will provide information on which of these two sources of organic matter are more important to higher trophic levels in the food web.

Estuarine Interfaces:

Small forage fish, such as mummichogs or Atlantic silversides, have the potential to transport significant nutrients and energy across the marsh to open water, and the estuary to open ocean, boundary. These fish may provide a significant food source to other higher trophic levels such as striped bass, bluefish and birds. Under a separate grant from NOAA, National Marine Fisheries Service, we examined the potential export by Atlantic silversides (Boynton and Deegan 1999). Measurements of silversides population dynamics within the estuary indicated a net flux of fish biomass from the estuary to the near shore ecosystem. Stable isotopes indicated that at least 50% of this export was from a benthic food web that was substantially based on saltmarsh production. The dependence of Atlantic silversides on a benthic food web was surprising, as it was previously believed to be a pelagic zooplantivore. Gut contents of large offshore predators showed that Atlantic silversides were important food items during their fall offshore migration.

In conjunction with the University of Massachusetts Cooperative Fisheries unit, we have been examining the importance of marsh nekton in the diets of striped bass, a top carnivore and an important commercial and recreational species. We have observed striped bass feeding frenzies at the mouths of small tidal creeks during ebbing tides. Marsh dependent nekton such as mummichogs, Atlantic silversides and *Crangon* can comprise up to 50% of the diet of striped bass indicating an indirect connection between marsh production and striped bass. Currently, in conjunction with the Massachusetts Cooperative Fisheries Unit, we are parameterizing a bioenergetics model for Striped bass in New England estuaries.

In the future, we plan to use this model to identify areas within estuaries that are energetically favorable for the growth of striped bass and evaluate their importance as top consumers. Our hypothesis is that the confluence of tidal creeks in northern estuaries are ‘hot spots’ for striped bass growth because of the combination of warm temperatures and availability of food resources. We also suspect that striped bass operate as a top-down control on the abundance of mummichogs. The model will allow us predict consumption requirements of striped bass populations and compare these to mummichog and Atlantic silverside abundances. From this information we can determine if striped bass consume enough of these fish to exert top-down control.

INTEGRATION AND SIMULATION MODELING

A research program that involves as many disciplines and facets as the Plum Island Ecosystems LTER requires several approaches to insure effective integration across programmatic areas. Our overall research question is broad, involving i) human populations, ii) biogeochemical fluxes and transformations in the atmosphere, watersheds, estuaries and the ocean, and iii) food webs with a structure and function that reflects interaction with their environment. The flow diagram shown in **Fig 1** of the Introduction provides a conceptual framework that synthesizes our understanding of the effects of organic matter and nutrient inputs on trophic structure and function and it illustrates how the major research questions and programmatic areas in this proposal fit together. Other approaches we are using to integrate across programmatic areas include: 1) whole system ^{15}N additions, 2) long-term experiments aimed at changing the primary production resource base and 3) simulation modeling.

1) Whole System ^{15}N Addition:

The fate of nitrogen flowing from watersheds to estuaries is of great interest. A primary research goal of the LTER is to predict how changes in the relative loading of inorganic and organic N loading will affect the estuarine ecosystem structure and function. The state-of-the-art on this question has been the development of regression models relating inorganic N loading and flushing rate to sestonic chlorophyll concentrations. These regressions show very decisively that estuaries respond to inorganic N loading and that the response can be reduced by rapid flushing, but they don't show any detail about the cycling and retention of inorganic N in the estuary. To investigate the fate of inorganic N quantitatively, we have performed two Nitrogen ISOtope TRacer EXperiments (NISOTREX) at the Plum Island Sound.

The experiments were designed to trace nitrogen in one portion of the estuary with relatively slow flushing and in another portion of the estuary with rapid flushing. In the Parker River portion of the estuary the residence time of water during the summer experiment was 5 to 15 days whereas in the Rowley River portion the residence time was about 1 to 4 days. These differences had a great impact on the fate on nitrate entering the upper estuary. In the slowly flushed Parker a dense bloom of planktonic diatoms developed and assimilated all of the available nitrate. Very little nitrate was exported downstream but was instead carried to the bottom with the sinking diatom cells. Here it fueled a

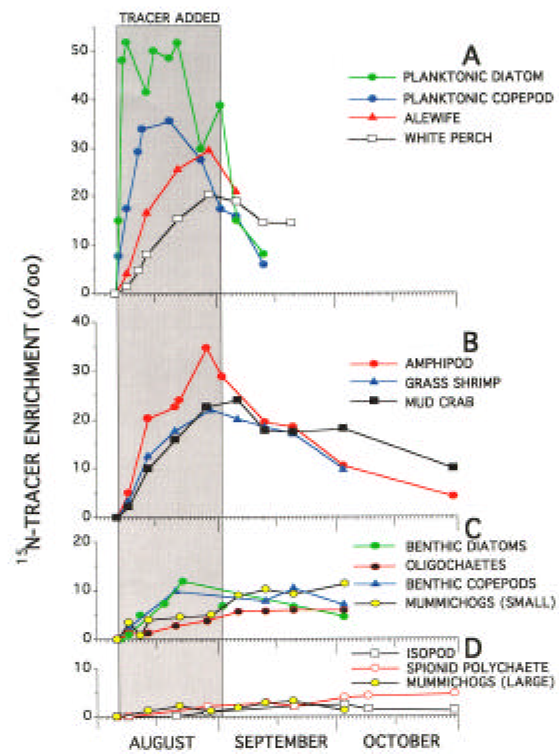

Fig 1. Time course of ^{15}N-tracer enrichments in biota. A. Planktonic food web showing the flow of nitrogen from nitrate to diatom, copepod, alewife, and white perch. B. Benthos illustrating a strong pelagic-benthic coupling via sedimentation of planktonic diatoms, including an amphipod, grass shrimp, and mud crab. C. Intermediately-labeled benthic food web based on benthic diatoms and detritus, which includes harpacticoid copepods and oligochaetes (mixed species), and small mummichogs. D. Species with little ^{15}N-tracer enrichment within a detritus- or marsh-dependent food web, including an anthurid isopod, spionid polychaete, and large mummichogs.

highly productive benthic community of amphipods, crabs and fishes (**Fig 1 –** Holmes et al. 2000, Hughes et al. 2000).

In the Rowley the story was very different. Here the rapid flushing inhibited the development of a planktonic algal population. The nitrate in the water was directly taken up by benthic diatoms and attached algae. In the Rowley benthic invertebrates became labeled by feeding on benthic diatoms rather than on a rain of planktonic diatoms. Because of the rapid flushing and the lack of planktonic nitrate assimilation, much of the nitrate was transported downstream to the Plum Island Sound and coastal ocean.

These synthetic experiments allowed us to study the interactions of hydrology, nitrogen biogeochemistry and estuarine food web structure all at the same time and at the natural estuarine scale. The experiments cut across all programmatic areas from the watershed to higher trophic levels and the marsh. The information from these experiments is being synthesized in a simulation model of the N cycle of estuaries.

2) Long-Term Experimental Manipulations of Primary Production Resource Base

One of the two overall hypotheses of the PIE LTER deals with the relative importance of inorganic N vs organic N inputs to a system. Systems driven by allochthonous, usually low quality organic matter inputs are likely to have a very different trophic structure and food web efficiency than ones driven by autochthonous algal production. The water column programmatic area focuses heavily on these issues. We are developing 3 long-term experiments that should produce large differences in the relative inputs of high and low quality organic matter: detrital removal (haying), detrital production (marsh fertilization) and algal production (tidal creek N fertilization).

During the first three years we worked on the structure of these experiments and began to choose study sites. For the detrital removal experiment, we will use extensive areas of the marsh that are hayed on a regular 1 or 2-year cycle. We have established the haying history of the region and established a working relation with one of the major remaining hayers in the country (Dan McHugh). For the marsh fertilization experiment, we chose a site that is large enough to potentially influence higher trophic levels, such as mummichogs, and which is at the head of a small tidal creek. We have identified 5 tidal creeks that we can use as long-term experimental sites. We are also collaborating with the town of Ipswich, which discharges secondary treated sewage into a small tidal creek. We may decide to use this tidal creek as our experimental site, as it is already receiving high N loads.

At all these sites we have conducted baseline high precision GPS elevation surveys, mapped plant species composition and to some extent biomass, and porewater nutrients. In the tidal creek sites we have also surveyed water column nutrient levels and forage fish and shellfish populations.

3) Simulation Modeling

Simulation modeling and data analysis are being used to integrate programmatic area research that is conducted at a variety of temporal and spatial scales. Simulation modeling (1) ties together field observations and experiments across space and time permitting a whole systems perspective, (2) allows us to test hypotheses and understanding of mechanisms governing ecosystem processes, and (3) provides whole system prognostic capabilities. Below we highlight the major synthetic and simulation accomplishments to date.

<u>Estuarine Food Web Development</u>

Data Assimilation: Work has been completed on developing data assimilation (DA) techniques that facilitate food web model development and testing using observed data (Vallino 2000). The DA techniques were tested with mesocosm data (**Fig 2**). The DA approach not only determines the model parameter set that best explains the observations, but also can be used to identify structural uncertainties in the model, which should facilitate the development of more robust food web models.

Stable Isotope Modeling: In order to utilize data obtained from the ^{15}N-addition field experiments, the ability to track stable isotopes has been incorporated into our 1D estuarine food web-biogeochemistry model (Hopkinson and Vallino 1995, Vallino and Hopkinson 1998). Using our DA techniques, this model has been initially calibrated using the field observations along the Parker River (**Fig 3**) during the first ^{15}N labeling experiment. Data from benthic flux chambers and marsh porewater chemistry have also been used for calibration. Although the model shows good agreement to standard observations (**Fig 3A vs 3C**), a discrepancy has been observed when the ^{15}N predictions are compared to observations (**Fig 3D vs 3D**), which indicates model structural errors. Note, the model discrepancies would have gone undetected if only standard observations were relied upon for model testing. We are currently improving the model to obtain better agreement between all observations and model predictions.

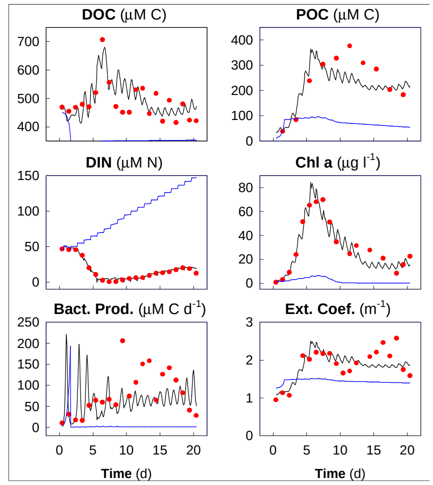

Fig 2. Model simulation before (blue line) and after (black line) assimilation of mesocosm data (red symbols).

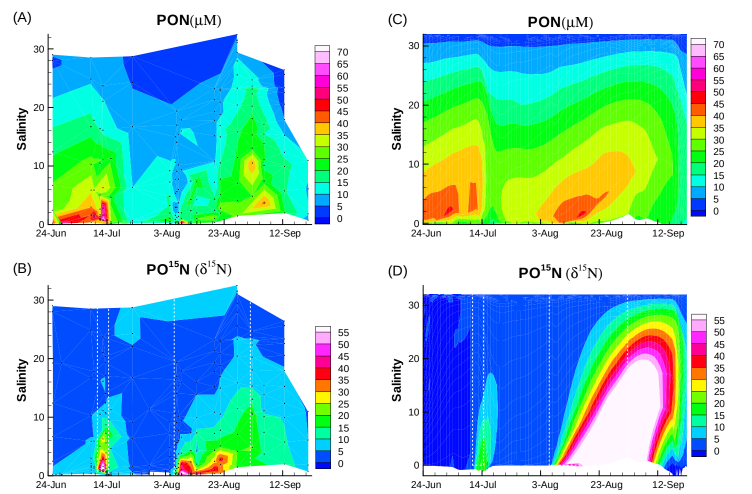

Fig 3. Observed (A and B) and simulation (C and D) concentrations of PON (A and C) and PO^{15}N (B and D) along Parker River during NISOTREX experiment (1996). Hurricane struck the area on July 13th, causing bloom washout. Dotted lines (B and D) show periods of ^{15}N addition.

Optimized Metabolic Ecosystem Network (OMEN) model: In order to develop more robust food web-biogeochemistry models, we have extended our work on modeling ecosystems as optimized metabolic networks to whole systems (Vallino *et al.* 1996). In this approach, state variables that represent organisms (such as phytoplankton, zooplankton and bacteria) are replaced by the concentration of enzymes that catalyze ecosystem biogeochemistry, such as photosynthesis, denitrification, sulfate reduction, etc. Allocation of system resources (mostly protein) is governed by an optimization procedure in which a chosen objective criterion is maximized. To date, we have mostly focused on optimizing the production rate of whole system biomass **(Fig 4)**, but other objective functions are possible and under investigation. Ultimately, we believe this approach will lead to more robust food web-biogeochemical models that can be applied to vastly differing systems without requiring extensive reparameterization. Collaboration has also been established with Roseanne Ford at the University of Virginia via a Biocomplexity Incubation Activity to test this modeling approach in groundwater systems.

Estuarine Transport Modeling

1-D, intratidal Model: To study processes occurring over short time scales (< 1 month), we have begun development of a branched, 1D, intratidal transport model. Often, observations and field experiments are conducted on short time scales, such as occurred in the ^{15}N labeling experiment. In these cases, it is difficult to compare observations with predictions from intertidal (i.e., tidally averaged) models since the averaging can mask processes, such as those associated with flooding and drying the marsh platform. Consequently, we are combining the USGS branched, 1D, shallow water transport model FEQ with the EPA constitutive transport model WASP5 to facilitate development of process models associated with marsh flooding and drying.

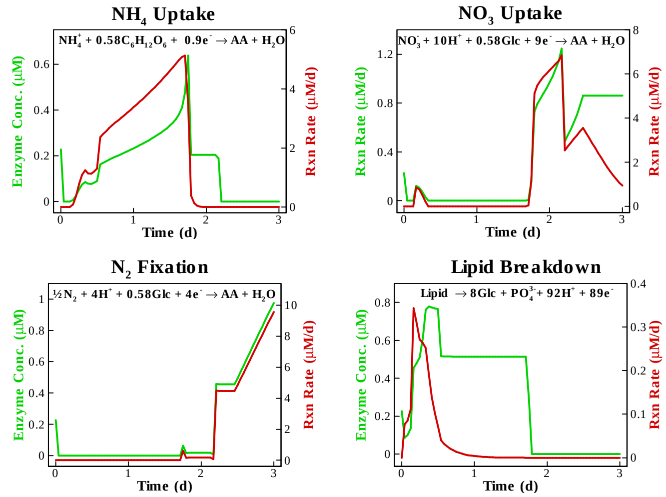

Fig 4. Simulated reaction rates (red) and allocation of protein (green) to a subset of four biogeochemical reactions associated with a phytoplankton ecosystem model.

2-D, intratidal Model: A 2D (depth averaged), finite element (FE), intratidal, hydrodynamic model has been developed for the Plum Island Estuary that employs a diffusive wave approximation (Ip *et al.* 1998) to allow for flooding and drying of the marsh platform (**Fig 5**), output from which drives a 2D FE constitutive transport model. A high resolution, tidal creek resolving FE mesh (**Fig 5**) is used to represent marsh topography and channel bathymetry (also see http://eco37.mbl.edu/kinematic). The modeling approach also incorporates a 2D groundwater model. Surveys of marsh hydraulics provide calibration. Although the 2D model more accurately represents the true spatial characteristics of PIE, the model currently has a high computational overhead, which makes rapid testing of food web-biogeochemical models problematic. Consequently, we currently use our 1D model for testing food web-biogeochemiical models, which we then port to the 2D model.

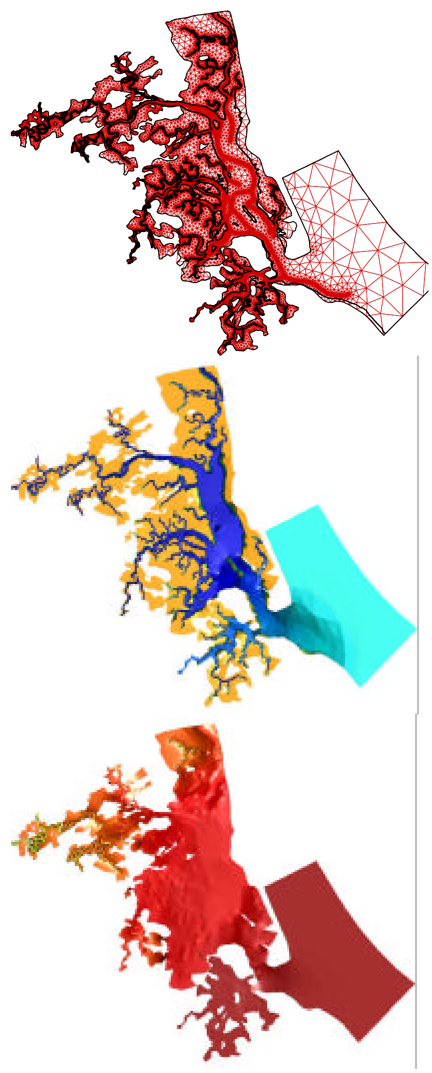

Fig 5. Creek resolving finite element grid (top) used in 2D PIE estuarine circulation-biogeochemistry model. Simulated water elevation at low tide (middle) and high tide (lower).

Marsh topography and channel bathymetry: In collaboration with the VCR LTER, we have established a high resolution GPS network at PIE that allows us to survey marsh topography to cm accuracy. Kinematic marsh surveys are being used to build a high-resolution marsh topography map that is required by the 2D transport model. We have also combined the kinematic GPS with a depth sounder that allows us to generate high-resolution bathymetry maps, required by all transport models.

Whole system metabolism model: Our 1D, intertidal model for oxygen transport has been combined with a nonlinear inverse technique that allows estimation of gross production, community respiration and net production given observations on dawn-dusk longitudinal oxygen concentrations in PIE (**Fig 6**) (Vallino *et al.* 1999). The model also incorporates data on oxygen gas transfer velocities that have been obtained from SF_6 experiments (Carini *et al.* 1996).

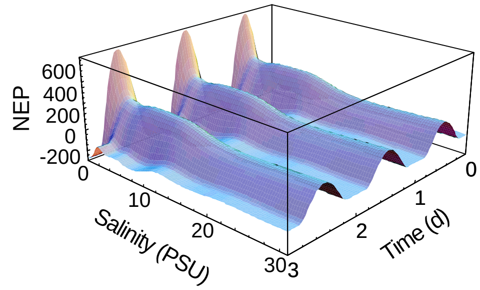

Fig 6. Estimated net ecosystem productivity ($\mu M\ O_2\ d^{-1}$) along Parker River over 3 day sampling period.

Watershed Hydrology and Biogeochemistry Model

HSPF Model: In combination with an EPA Water and Watersheds Project, and in collaboration with USGS, we have implemented and initially calibrated EPA's Hydrologic Simulation Program, Fortran (HSPF) for the Ipswich watershed (**Fig 7**) (Kirkby *et al.* 2000). While the model accurately simulates river hydrology, stream biogeochemistry still requires more development (**Fig 8**). The model is being used to study alterations in river hydrology and biogeochemistry as changes in land use occur. A land use change model (see Watersheds Section) developed and initially calibrated by team member Gil Pontius (Clark University) is based on economics and legal development constraints, and generates most likely land use changes based on historical trends (Pontius Jr *et al.* 2000). By combining HSPF with the land use change model, we are able to examine how stream hydrology and biogeochemistry may change in the future.

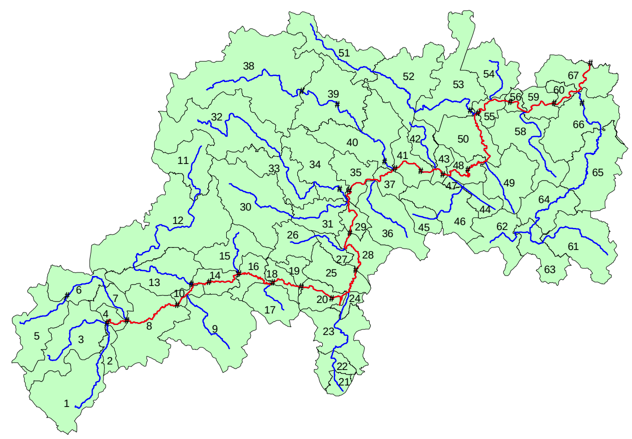

Fig 7. Representation of Ipswich watershed in HSPF illustrating sub-basins (black lines with numbers), main stem of Ipswich River (red line) and major tributaries (blue lines), and monthly sampling stations (black symbols).

Future Directions:

Data Assimilation: To take advantage of our near real-time water quality and weather observations network (see http://www.pielter.org/), we plan to extend our data assimilation techniques to our 1D and 2D estuarine food web-biogeochemistry models so that this real-time data can continuously update a running, spatially explicit model.

Stable Isotope Modeling: We are beginning to test our stable isotope estuarine model using data from the ^{15}N labeling experiment in which the Rowley River was labeled with enriched $^{15}NO_3$ during high flow conditions.

OMEN Model: We will continue developing this model using both mesocosm and field observations. A primary objective is to determine if ecosystem biogeochemistry can be explained by simple objective functions, such as maximizing biomass production rate, or energy throughput.

2D, intratidal Biogeochemistry Model: We are currently working on porting this model to a parallel Beowulf architecture. The Beowulf cluster is current being assembled as part of a NASA funded terrestrial ecosystem modeling (TEM) project, which we will have access to.

Watershed HSPF model: In addition to finishing calibration of this model, we plan to begin integration of the HSPF output with both our 1D and 2D estuarine models which will allow us to examine how changes in land use will affect estuarine biogeochemistry.

Spatial scaling in watershed modeling: as described under the Watersheds review section, we are interested in how best to apply models across a variety of scales. How do we apply models developed for relatively small data-rich systems like the Ipswich to other systems that are data poor or to larger watersheds? Likewise, how do we apply continental scale models to much smaller regions such as the Gulf of Maine or even the Ipswich and Parker River basins?

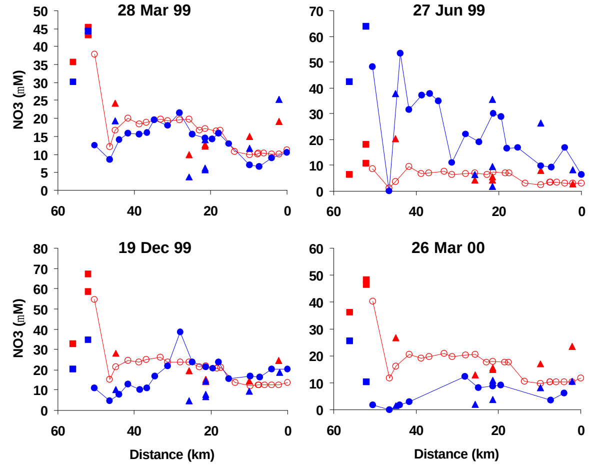

Fig 8. Selected simulated (in red) and observed (in blue) nitrate concentrations along main stem of Ipswich River (symbols connected by line) and major tributaries (symbols alone) over a 15-month period.

DESCRIPTION OF DATA AND INFORMATION MANAGEMENT

Information Management

The objective of the Plum Island Ecosystems Long-Term Ecological Research (PIE-LTER) data and information system is to provide a centralized network of information and data related to the Plum Island Sound Estuarine Ecosystem and its watersheds. This centralized network provides researchers associated with PIE-LTER access to common information and data in addition to centralized long-term storage. Researchers associated with PIE-LTER are committed to the integrity of the information and databases resulting from the research.

PIE-LTER information and databases are stored on a NT network server, which is backed up on 4 mm tape nightly. Public access to PIE-LTER data and information for the scientific community at large is provided through the PIE-LTER World Wide Web home page on the Internet at the following URL: http://ecosystems.mbl.edu/PIE. The PIE-LTER home page has been active since late 1998 and consists of a variety of information including personnel, data and published and unpublished papers and reports. The data section is broken down into four sections consisting of Major Research Themes, Education, Physical Characteristics and Database Links. The home page is updated annually and when a particular database update affects data already on the web.

Data Management and Coordination of Research Projects

Individual researchers are responsible for each of the six core programmatic areas outlined in the PIE-LTER (Watersheds, Marshes, Planktonic Food Web, Benthos, Higher Trophic Levels and Integration). Information management is based upon a team of principal investigators and research assistants who have the knowledge and technical expertise for creating and maintaining the PIE LTER research information. Several meetings each year provide each researcher the opportunity to communicate with the PIE information management team regarding the design of the specific research project and subsequent incorporation of data and information into the PIE-LTER database. Robert Garritt, a senior research assistant with The Ecosystems Center, MBL, has been database manager for the PIE-LTER and has the responsibility for overseeing the overall integrity of the data and information system for PIE-LTER.

Contributions of Data to Database

Researchers on the PIE-LTER are expected to follow the guidelines as defined in the LTER Guidelines for Site Data Management (Porter and Callahan 1994). The current PIE-LTER and North Inlet, SC databases follow the LTER guidelines and we plan on developing similar database management with Wells Bay, ME in the future. Research conducted using the facilities of the PIE-LTER will be expected to comply with the following policy: All researchers will provide digital copies of data to the data manager. Data files will include accompanying documentation files that will completely describe the data. Individual researchers will be responsible for quality assurance, quality control, data entry, validation and analysis for their respective projects. An electronic link will be established between remote site databases (North Inlet-NERR, Wells Bay-NERR) and PIE-LTER for accessibility of long-term data sets.

Data Accessibility and Timelines

Researchers on the PIE-LTER have been and will continue to be encouraged to both publish and contribute data to the PIE-LTER database. It is recognized that investigators on PIE-LTER have first opportunity for use of data in publications but there is also the realization for timely submittal of data sets for incorporation into the PIE-LTER database. Four categories of

data are recognized as outlined in the LTER Guidelines for Site Data Management (Porter and Callahan 1994). PIE-LTER's specific policy for data sharing is as follows:
Type 1: Published data and meta-data are available upon request without review.
Type 2: Collective data of PIE-LTER (routine measurements) are available for specific scientific purposes within one year after generation.
Type 3: Original measurements by individual researchers (experimental data) are available for scientific purposes two years after generation.
Type 4: Unusual long-term data collected by individual researchers are available with permission of the researcher.

Future Objectives

Data sets are currently in spreadsheet and text format, which has been adequate in the past due to the relatively small size of the data sets. We anticipate the need for converting data sets of routinely measured parameters to spatially referenced databases, which will allow compatibility of format for use in Geographic Information Systems (GIS). We also plan to incorporate a query feature for seeking out subsets of the databases.

LTER NETWORK ACTIVITIES

We have rapidly established linkages with other LTER sites and the LTER network. We have held network-wide meetings, initiated new network-wide intercomparison projects, hosted LTER executive and coordinating committee meetings, organized science symposiums and served on steering committees for other intersite activities.

One of our first activities was to organize and host a network-wide workshop for aquatic sciences. Hobbie and Hopkinson held a workshop in Feb 2000 in Salt Lake City that was attended by representatives from 21 sites and the network office. Three purposes of the meeting were to 1) communicate the range of aquatic research that is conducted at the various LTERs, 2) to introduce the 4 new "coastal" sites to other aquatic scientists within the network and to LTER as a whole, and 3) to develop by consensus four intersite symposia or workshop topics for the summer 2000 All Scientists Meeting at Snowbird, Utah.

A follow-up project was initiated at the Salt Lake City workshop to study organic matter preservation in soils and sediments. PIE scientists, Jim Morris and Chuck Hopkinson, have taken the lead in developing this intersite, comparative study into the controls on organic matter storage in soils and flooded sediments. We were successful in obtaining network office funds to expand these activities over the next couple of years. To date we have organized three meetings to develop comparative research questions, to build a common database of organic matter and site characteristics and to plan a manuscript summarizing our present knowledge about organic matter preservation. The goals of our most recent workshop (July 2001) were 1) to explore relationships between soil organic matter content and edaphic factors using existing data sets, 2) to plan for a pilot reciprocal peat transplant intercomparison experiment, and 3) to discuss the development of a proposal for an inter-site, collaborative study of organic matter preservation exposed to a variety of natural environmental conditions. To date meetings have been held in August 2000 at Snowbird, Utah, Feb 2001 at Albuquerque, New Mexico and July 2001 at the Virginia Institute of Marine Sciences in Va (**Fig 1**).

Plum Island scientist, Bruce Peterson, is a co-principal investigator of a recently funded intersite study of N cycling in "impacted" streams. The focus of the new NSF-funded LINX 2 (Lotic Intersite Nitrogen eXperiment) study is on nitrogen retention and denitrification in streams. The Plum Island Sound watershed is one of 8 regional sites in the US chosen for intensive experimentation. The experiment will involve the use of ^{15}N tracers to determine nitrate uptake and denitrification in forested, agricultural and urban streams in the Ipswich and Parker River watersheds. The goal is to improve our ability to predict the extent of nitrogen processing in streams and it's relationship to land use patterns in the watershed.

Fig 1. Jim Morris (PIE) with Chris Craft (GCE) and Curt Richardson (Duke) at the OM preservation workshop - VIMS July 2001.

PIE scientists, John Hobbie, Jim Morris and Chuck Hopkinson, are partners with Linda Blum and Aaron Mills, in their NSF supported intersite study of microbial community dynamics on decaying litter in estuarine marshes. This is a reciprocal transfer study of marsh grass decomposition across multiple sites.

PIE scientist, Bruce Peterson, serves on the steering committee of a new LTER intersite activity that is exploring the topics most appropriate for comparing biogeochemical cycles at different LTER sites. This activity was initiated at the last LTER all-hands meeting and a second meeting was held at the ESA annual meeting in Madison last August. Thus far the committee, under the leadership of Larry Baker (Phoenix LTER site investigator), has formulated, sent out and compiled responses on an extensive questionnaire summarizing data availability at different sites. The next steps will be selection of topics for in-depth discussion by investigators from multiple sites with the goal of producing one or more cross-site proposals.

Gil Pontius and Chuck Hopkinson serve on the steering committee of another new LTER intersite activity that is focusing on the incorporation of social science in LTER. This activity began in fall 1999 at the LTER Coordinating Committee Science Meeting on Social Science studies in LTER. We will participate in the November LTER Workshop on Ecosystem Function being organized by CAP. The anticipated goals of the 2 ½ day workshop are to 1) establish a framework for conducting long-term and cross-site evaluation of ecosystems function within and among LTER and other large-scale projects, and 2) plan for formal proposals to NSF's Biocomplexity program for cross-disciplinary study of ecosystem function.

PIE scientist, Chuck Hopkinson, serves on the steering committee of another new LTER intersite activity that is exploring ways to study subsurface water flow and to link biogeochemical study with groundwater flow. An intercomparison proposal was submitted and recommended for funding. To date, there has been exchange of people, ideas, and measurements between the Georgia Coastal, Virginia Coastal and PIE systems. Each of these sites is very interested in various land-water linkages in estuaries – terrestrial to tidal waters flow and intertidal marsh to tidal water flow.

PIE scientists Giblin and Hobbie are co-PIs on a Biocomplexity Incubation project that will test whether primary producers and microbial heterotrophs in low nutrient environments, terrestrial and aquatic, often are limited by different nutrients. The environments to be studied are freshwater wetlands, salt marshes, tundra, lakes, and upland forests. Giblin and Hobbie along with scientists from various long-term sites, including the North Inlet Estuary (SC), Plum Island Estuary (MA), Everglades (FL), Duke Forest FACE (NC), and Alaskan Arctic, will design experiments and further develop a model to test this idea.

PIE scientist Joe Vallino is trying to develop more robust food web-biogeochemical models that can be applied to vastly differing systems without requiring extensive reparameterization. In his collaboration with Roseanne Ford at the University of Virginia via a Biocomplexity Incubation Activity he will test this modeling approach in groundwater systems.

Finally PIE is hosting the Executive Committee and Coordinating Committee Meetings this fall. The meetings will be held both in Woods Hole and the University of New Hampshire. In conjunction with the CC meeting, there will be a science symposium. The overall theme for the meeting will be land – water linkages. The full day symposium will be devoted to the discussion of water and materials transport across the watershed landscape and into the coastal zone. Invited presentations will focus on the mechanisms controlling materials transport and on synthesis and modeling at a variety of spatial and temporal scales. Discussion of watershed biogeochemical cycles will include responses to climate change, human development and other influences. A goal of the symposium will be to describe the state-of-the-science of our knowledge about watershed hydrology and biogeochemistry. Individual presentations will not be case studies, but synthetic talks that seek generalities. Presentations will synthesize research on the specific topic, describe major advances and our current understanding, present the major current questions and assess the major obstacles to progress. Steve Carpenter, *Ecosystems* co-editor, has offered to dedicate a single issue of the journal to manuscripts resulting from the symposium. Additionally, we plan a synthetic review paper that will include aspects of each of the 12 symposium presentations. The paper will cover the various aspects of watershed and land-water linkages including recent progress, current pressing questions and major obstacles to the advancement of the science. The paper will be a jointly authored, synthetic paper that summarizes the major issues in watershed hydrology and biogeochemistry. The article will be a summary paper that describes the state-of-the-art of subject with respect to novel approaches, recent advances, challenging frontiers and modeling. Bioscience will be the 1st choice target journal for the review article.

OUTREACH

The Plum Island Ecosystems LTER is situated in the Boston metropolitan region. Boston bedroom communities are continuingly encroaching on the Ipswich and Parker River watersheds. Reestablishment of the Boston to Newburyport rail line is causing accelerating rates of urbanization. Present population density is on the order of 300 people per km^2. This urban/suburban setting provides the PIE LTER with unique opportunities and challenges to develop links with local citizens, teachers and students, conservation groups and local, state and federal government agencies.

Education

K-12: The Plum Island Long Term Ecological Research Project seeks to develop partnerships between the LTER and local schools in and around the Ipswich and Parker River watersheds. For the past several years, the LTER has received supplemental funding from the NSF to involve teachers and students with LTER research. We have been supporting a collaboration with Governor Dummer Academy since 1999. Academy (GDA) high school students have interned with LTER scientists studying the effects of marsh haying on salt marsh productivity and community structure and they have conducted independent research projects, the results of which will be incorporated into the LTER long-term database. In conjunction with their high school teacher, Susan Oleszko, they developed a long-term project on the distribution of ribbed mussels and snails in tidal creeks off the Rowley River. Dr. Oleszko has also involved her Marine Science class in a study of plant diversity and biomass in tidal marshes. A series of six transects were established across the marsh. The project will continue each fall with this class, and the records of shifting populations will stay as part of the GDA record, and will also be incorporated into the LTER long-term database for the system.

Beginning in the summer of 2001, the LTER is supporting the Massachusetts Audubon Society's (MAS) Salt Marsh Science Project. Funds are used to involve middle and high school students in long-term monitoring of salt marshes for vegetation, invasive species (e.g., *Phragmites australis*), salinity levels, and salt marsh fish. Teachers are trained by LTER scientists and Massachusetts Audubon educators in various sampling methodologies so that their students can participate in collecting long-term data useful to the LTER and to their own education. This fits in very well with inquiry-based learning stressed in new Massachusetts's education standards. We anticipate working with 4-5 schools, 10 teachers, and 350 students. The MAS education coordinator and assistants will offer professional development as well as field and classroom support.

Undergraduates and REU's: Each summer the LTER and associated projects support from 2 to 6 students in the NSF Research Experience for Undergraduates program. Each student works closely with a principal investigator and either post-doc or research assistant. Students typically help out with the various field activities that are occurring at Plum Island (thereby gaining a broad research experience), plus they conduct their own independent research projects. Each student is required to prepare a poster and short manuscript describing their research project. Students participate in the Marine Biological Laboratory Annual Scientific Meeting and present their research reports. We encourage students to submit their papers to the Biological Bulletin for publication. We have been very successful in having the vast majority of these manuscripts accepted for publication. See Appendix II for list of students and titles of accepted papers.

MBL offers an undergraduate Semester in Ecosystems Science (full 15 credits) annually. Over the past 4 years, PIE investigators have supervised 4 students with independent projects in the Ipswich watershed, where the effects of urbanization on ecosystems processes were of interest (see Appendix II).

Graduate Students, Post-docs and Research Interns: Perhaps our most effective means of education is through graduate student training, post-doctoral fellowships and research assistant internships. Over the past 3 years PIE has supported 3 grad students at the University of New Hampshire, 6 graduate students at Clark University and 2 at the University of South Carolina. We have supported 7 Post-docs at the Marine Biological Laboratory and collaborated with 2 others from MIT. We typically offer 2 research assistant fellowships (RAF) to recent college graduates prior to beginning graduate school. In the past 3 years we have supported 4 RAFs, two of whom have gone on to graduate school in ECOSYSTEM science (Nat Weston - UGA and Greg Peterson - Stanford).

Science Writers: Each summer the Marine Biological Laboratory supports a course for professional science writers (TV, newspaper, journal, etc). These people play a critical role in our society, as they try to inform the public of the excitement and concepts that scientists work on. An informed public is the cornerstone of a democratic society. Public support for science depends on effective channels of communication between science and the general public. Over the past several years, we have hosted 2 groups of science writers on a 2-day intensive field and laboratory experience at the Plum Island estuary. Writers were forced to think about land-water connections and the potential effects of urban and watershed activities on estuarine processes. See appendix II for a list of participants.

Public/Media/Management Agencies:

Outreach activities have been an important aspect of the overall estuarine and watershed efforts. We have teamed with various local, state and federal government agencies, local citizens and watershed associations as well as corporations in monitoring, communication and advisory capacities. During the summer of 2001, we began collaborating with the Plum Island National Wildlife Refuge personnel in their marsh restoration project. We conducted a preliminary, high precision GPS elevation survey of diked freshwater marshes that FWS hopes to restore to intertidal saltwater marsh in the next couple of years.

The Town of Ipswich currently disposes of their secondarily-treated sewage in a small tidal creek in the Plum Island marshes. The town is under EPA control on effluent concentrations; their discharge limits will be reevaluated in 2 years. We have begun collaborating with the town in assessing the impacts of nutrient rich wastewater on food web structure and productivity. We may consider using their effluent tidal creek as a long-term experimental site to study the effects of changing the quality of autochthonous organic matter.

EMPACT: For the past 3 years PIE scientists have been monitoring stream water nutrient concentrations in conjunction with the Ipswich River Watershed Association (IRWA) and the Parker River Clean Water Association (PRCWA). This requires close contact with volunteers to explain why the sampling is being conducted and to ensure quality control. Through an EMPACT grant from EPA, PIE scientists from UNH and MBL have been working with the Town of Ipswich to develop a web site geared towards the lay public (see www.ipswatch.sr.unh.edu for preliminary version). The web site represents a collaboration between the PIE-LTER, UNH, MBL, the Town of Ipswich, IRWA, PRCWA, Massachusetts Executive Office of Environmental Affairs (EOEA), USGS, and YSI Inc. The goal of this effort is to make key environmental data available in real time so that interested citizens and managers can monitor changes in watershed conditions as they occur. A major goal is to present the monitoring information in a way that is clear, educational, and relevant to people living in the two watersheds. Other actions include consulting with the watershed associations, and Massachusetts EOEA with regard to various water quality issues in the Ipswich and Parker watersheds.

Ipswich River Taskforce: The Ipswich River taskforce is a group of private citizens, scientists and people from government agencies organized by the Mass Executive Office of Environmental Affairs (EOEA). The taskforce meets regularly to discuss environmental issues in the Ipswich and Parker River. Hopkinson has been a member of that taskforce for the past 3 years. Hopkinson also sits on the Ipswich River Watershed Management Council and is a member of the Water Quality Subcommittee. PIE scientists are also collaborating in the Communities Connected by Water Project (CCBW) that is funded by Mass EOEA and administered by the IRWA. This project is largely interested in water quality and water levels in the Ipswich River. PIE scientists collaborated with the USGS in applying the HSPF model to the Ipswich River to study the effects of water withdrawals and sewage discharge.

Falmouth in the Fall Seminar Series: To celebrate the 25th anniversary of the Ecosystems Center at MBL, Ecosystems scientists offered a series of lectures to the general public in Falmouth, Woods Hole and Cape Cod. Hopkinson presented a lecture on the effects of watershed activities on estuarine health. The lecture was broadcast on the local TV station several times during winter 2000-2001.

Other “coastal” presentations to communities include that of PIE scientist Bruce Peterson. Bruce reviewed the use of stable isotopes in tracing organic matter inputs in coastal systems. His lecture was in Cavoeiro, Portugal in Feb 1998.

Estuarine Synthesis: PIE investigator John Hobbie recently organized a symposium and book on Estuarine Synthesis (Hobbie 2001). With support from the US Scientific Committee for Problems of the Environment (SCOPE), NSF and NOAA, a workshop on estuarine synthesis was held to show the capabilities of synthetic methods of research. The meeting featured twelve plenary talks that documented a variety of successful approaches to synthesis. Five working groups identified important areas for synthesis in the next decade, along with specific ideas about the kinds of process studies or models that will be needed. This book is likely to guide estuarine synthesis activities for the next decade.

Dissemination of Research Results:

PIE LTER participants have presented numerous posters and presentations to local, regional and national lay, student and scientific audiences. Scientific articles that have been printed or accepted for publication are listed in Appendix III.

SITE MANAGEMENT

Considerable effort goes into maintaining open channels of communication and maximizing the input of all participants in the Plum Island Ecosystems LTER. Charles Hopkinson provides overall direction, management and coordination. Hopkinson continues in this role from the previous LMER project. Research direction, strategic scheduling of major initiatives and budgetary matters are discussed collegially amongst all PIs and decisions reached by consensus.

The Ecosystems Center at the Marine Biological Laboratory is the "home" of the PIE LTER. Six of the 9 funded PIs work at the Ecosystems Center. PIs and other staff at MBL meet once or twice a month (except during the summer field season) for presentation of results, information discussion and planning sessions. Summaries of these meetings are distributed by e-mail to all personnel. We hold an intensive 2-day workshop of all researchers each spring to synthesize results across programmatic areas and to plan research for the coming season. Communication within PIE LTER is very high and pretty much assured as 6 of the 9 funded PIs have offices within 10 m of each other and Vörösmarty and Buchsbaum regularly visit MBL. All the post-docs and research assistants supported on the LTER are housed in the same building. Hopkinson is jointly funded with Vörösmarty and Morris on separate projects related to the LTER and this further brings these individuals together, which contributes to LTER cohesiveness.

Research in each programmatic area is directed by one of the principal investigators.

Programmatic Area	Director
1) Watersheds	Vörösmarty
2) Marshes	Morris
3) Planktonic	Hobbie
4) Benthic	Giblin
5) Higher Trophic Levels	Deegan
6) Synthesis & Modeling	Vallino

Each programmatic area typically consists of 2 to 5 other principal investigators, plus post-docs, research assistants, and graduate students. These groups get together at regular intervals that vary from year to year as research focus is moved from one programmatic area to another. It is within these groups that most collaboration with non-LTER scientists occurs. We have also established working groups for discussing meteorological/atmospheric deposition issues, Data and Information Management, and Long-Term Experiments.

REFERENCES

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Carini, S., Weston, N., Hopkinson, C., Tucker, J., Giblin, A. E., and Vallino, J. 1996. Gas exchange in the Parker River estuary, Massachusetts. Biol. Bull. 191: 334-335

Chiaravalle, K., J. Hughes, R. Javonillo, and L. Deegan. 1997. Tidal river riffle habitats support high diversity and abundance of Gammaridean amphipods. Biol. Bull. 192:283-285.

Claessens, L., E. Rastetter, C. Hopkinson, J. Vallino, S. Canfield and R. Pontius. 2001. Evaluating the effect of historical changes in land-use and climate on the waterbudget of the Ipswich River Basin, Ma. USA. Water Res. Res. Submitted.

Giblin, A.E., N. Weston, G. Banta, C.S. Hopkinson, J. Tucker. The effect of salinity on nitrogen dynamics in estuarine sediments.

Hobbie, J. E. 2001. Estuarine Science, A synthetic approach to research and practice. Island Press, Washington, D.C. 539 p.

Holmes, R.M., Peterson, B.J., Deegan, L.A., Hughes, J.E., and B. Fry. 2000. Nitrogen biogeochemistry in the oligohaline zone of a New England Estuary. Ecology. 81:2, 416-432

Hopkinson, Jr. C. S. and Vallino, J. J. 1995. The relationships among man's activities in watersheds and estuaries: A model of runoff effects on patterns of estuarine community metabolism. Estuaries 18: 598-621

Hughes, J.E., Deegan, L.A., Peterson, B.J., Holmes, R.M., and B. Fry. 2000. Nitrogen flow through the food web in the oligohaline zone of a New England Estuary. Ecology. 81:2, 433-452.

Ip, J. T. C., Lynch, D.R., and Friedrichs, C.T. 1998. Simulation of estuarine flooding and dewatering with application to Great Bay, New Hampshire. Estuarine, Coastal Shelf Sci. 47: 119-141, (http://www-nml.dartmouth.edu/~justin/GtBay/gtbay.html).

Javonillo, R., L. Deegan, K. Chiarvalle, and J. Hughes. 1998. The importance of access to salt-marsh surface to short-term growth of *Fundulus heteroclitus* in a New England salt marsh. Biol. Bull. 193:288-289.

Joye, S. B. and Hollibaugh, J. T., 1995. Influence of sulfide inhibition of nitrification on nitrogen regeneration in sediments. Science 270: 623-625.

Kirkby, R., Claessens, L., Hopkinson, Jr. C., Rastetter, E., and Vallino, J. 2000. Modeling the effects of land-use change on nitrogen biogeochemistry in the Ipswich watershed, Massachusetts. Biol. Bull. 199: 218-219

Komarow, S., T. Young, L. Deegan, and R. Garritt. 1999. Influence of marsh flooding on the abundance and growth of *Fundulus heteroclitus* in salt marsh creeks. Biological Bulletin 197:299-300.

Mondrup, T. 1999. Salinity effects on nitrogen dynamics in estuarine sediments investigated by the plug-flux method. Biol. Bull. 197: 287-288

Mondrup, T. 2000. Salinity effects and tolerance and adaptation of estuarine nitrifying bacteria investigated by a plug-flux method. M.S. Thesis, University of Roskilde, Denmark. 47 pp.

Mondrup, T., G. Banta, and A.E. Giblin. Salinity effects and tolerance and adaptation of estuarine nitrifying bacteria investigated by a plug-flux method.

Morris, J. T. 2000. Effects of sea level anomalies on estuarine processes. Pp. 107-127. In: J. Hobbie (ed.), Estuarine Science: A Synthetic Approach to Research and Practice. Island Press. 539 pp.

Peterson, B., W. Wollheim, P. Mulholland, J. Webster, J. Meyer, J. Tank, E. Marti, W. Bowden, M. Valett, A. Hershey, W. McDowell, W. Dodds, S. Hamilton, S. Gregory and D. Morrall. 2001. Control of Nitrogen Export from watersheds by headwater streams. Science 292: 86-90.

Pontius, Jr., R. G., Claessens, L., Hopkinson Jr., C., Marzouk, A., Rastetter, E. B., Schneider, L. C., and Vallino, J. 2000. Scenarios of land-use change and nitrogen release in the Ipswich watershed, Massachusetts, USA. In: *Proceedings of the 4th international conference on integrating geographic information systems and environmental modeling: problems, prospects, and needs for research*, Edited by Parks, B. O., Clarke, K. M., and Crane, M. P., Boulder, University of Colorado, Cooperative Institute for Research in Environmental Science.

Pontius, R. G. Jr. and L. Schneider. 2001. Land-use change model validation by a ROC method for the Ipswich watershed, Massachusetts, USA. Agriculture, Ecosystems & Environment 85: 239-248.

Pontius, R. G. Jr. 2000. Quantification error versus location error in comparison of categorical maps. Photogrammetric Engineering & Remote Sensing 66: 1011-1016.

Porter, J. H. and J. T. Callahan. 1994. Circumventing a dilemma: historical approaches to data sharing in ecological research, pages 193-203. In- W.K. Michener, S. Stafford and J.W. Brunt (eds.). "Environmental Information Management," Taylor and Francis, Bristol, PA.

Schneider, L. and R G Pontius Jr. 2001. Modeling land-use change in the Ipswich watershed, Massachusetts, USA. Agriculture, Ecosystems & Environment 85: 83-94.

Seitzinger, S. P., Gardner, W. S. and Spratt, A. K., 1991. The effect of salinity on ammonium sorption in aquatic sediments: implications for benthic nutrient cycling. Estuaries 14: 167-174.

Vallino, J. J., Hopkinson, C. S., Garritt, R., and Tucker, J. 1999. A non-linear inverse technique to estimate estuarine ecosystem metabolism from whole system oxygen measurements. 3rd International Symposium on Ecohydraulics. Salt Lake City, Utah State University Extension. CD ROM, http://extension.usu.edu/confer/ecohydra/.

Vallino, J. J. 2000. Improving marine ecosystem models: use of data assimilation and mesocosm experiments. J. Mar. Res. 58: 117-164, (http://eco25.mbl.edu/DataAssim.html).

Vallino, J . J. and Hopkinson, C. S. 1998. Estimation of dispersion and characteristic mixing times in Plum Island Sound estuary. Estuarine, Coastal Shelf Sci. 46: 333-350

Vallino, J. J., Hopkinson, C. S., and Hobbie, J. E. 1996. Modeling bacterial utilization of dissolved organic matter: Optimization replaces Monod growth kinetics. Limnol.Oceanogr. 41: 1591-1609

Weston, N., A. E. Giblin, G. Banta, C. S. Hopkinson, J. Tucker. The effects of varying salinity on the ammonium exchange and ammonium losses of estuarine sediments.

Young, T., S. Komarow, L. Deegan, and R. Garritt. 1999. Population size and summer home range of the green crab, *Carcinus maenas*, in salt marsh tidal creeks. Biological Bulletin 197:297-299.

APPENDIX I

APPENDIX II

EDUCATION

A list of High School Students, Undergraduates, Research Assistant Interns, Graduate Students, Post-Doctoral Associates, and Science Writers that have participated in LTER research at PIE. Publications, presentations, or posters that came as a result of research projects are listed here for reference.

HIGH SCHOOL STUDENTS:

The following students are from the Governor Dummer Academy (South Byfield, MA). The period of each student's participation is listed in parentheses.

Lipman, Gabe (2001)
McDonnell, Marc (1999)
Murch, Marienna (2000)
Mayo, Scott (2000)
Noblitt, Carl (2001)

- Williams, L., C. Noblitt, and R. Buchsbaum. 2001. The effect of salt marsh haying on benthic algal biomass. Abstr. 2001 MBL General Scientific Meetings.

Oxton, Michael (2001)
Panall, Simon (1998, 1999, 2000)
Scheintaub, Madeline (2000)
Sergeant, Kara
Tsao, Nate (1999, 2000)
Turner, Sarah (1998)

UNDERGRADUATES

Research Experience for Undergraduates (REU):

Aldrich, Stephen (Clark University, 2001)

- Aldrich, S., and G. Pontius. The influence of Land Use on Nitrate Loading in the Ipswich River Watershed, Massachusetts MA.. In prep for Biol. Bull. and poster presentation.

Balsis, Brian (Dartmouth College, 1995)

- Balsis, B., D. Alderman, I.D. Buffam, R.H. Garritt, C.S. Hopkinson and J.J. Vallino. 1995. Total system metabolism in the Plum Island Sound estuary. Biol. Bull. 189:252-254.

Buchalski, Mike (Michigan State University, 1996)

Canfield, Susannah (Bates College, 1999)

- Canfield, S., L. Claessens, C. Hopkinson Jr., E. Rastetter, and J. Vallino. 1999. Long-term Effect of Municipal Water Use on the Water Budget of the Ipswich River Basin. Biol. Bull. 197(2): 295.

Carini, Stephen (University of Colorado at Boulder, 1996)

- Weston, N.B., S.S. Carini, A.E. Giblin, G.T. Banta, C.S. Hopkinson and J. Tucker. 1996. Estimating denitrification in sediments of the Parker River estuary, Massachusetts. Biol. Bull. 191:334-335.

Chiaravalle, Katina (Coastal Carolina University, 1997)

- Javonillo, R., L. Deegan, K. Chiarvalle, and J. Hughes. 1997. The importance of access to salt-marsh surface to short-term growth of Fundulus heteroclitus in a New England salt marsh. Biol. Bull. 193:288-289.

Distler, Matt (Amherst College, 1996)

Govignon-Berry, Ayora (University of Massachusetts at Boston, 2001)

Greenbaum, Adena (Wellesley College, 2000-2001)

- Greenbaum, A.H. 2001. Long-term fate of heavy metals in sediments of a Massachusetts salt marsh. Honors Thesis, Wellesley College.
- Greenbaum, A. and A. Giblin. 2000. Differences in properties of salt marsh sediment betweened hayed and reference sites. Biol. Bull. 225-226.

Haines, Jamie (Connecticut College, 2000)

- Haines, J., M. Cieri, and L. Deegan. 2000. Food Choice Convergence of Benthic and Pelagic Fishes Along an Estuarine Geomorphological Gradient. Presentation at the 2000 MBL General Scientific Meeting.

Javonillo, Robert (Boston University Marine Program, 1997)

- Javonillo, R., L. Deegan, K. Chiarvalle, and J. Hughes. 1997. The importance of access to salt-marsh surface to short-term growth of Fundulus heteroclitus in a New England salt marsh. Biol. Bull. 193:288-289.

Kilham, Nina (University of California at Berkeley, 1998)

Kirkby, Ryan (Harvey Mudd College, 2000)

- Kirkby, R., L. Claessens, C. Hopkinson Jr., E. Rastetter, and J. Vallino. 2000. Modeling the effects of land-use change on nitrogen biogeochemistry in the Ipswich watershed, Massachusetts. Biol. Bull. 199(2): 218-219.
- Presentation at 2000 MBL General Scientific Meeting.

Komarow, Sharon (Stanford University, 1999)

- Komarow, S., T. Young, L. Deegan and R. Garritt. 1999. Influence of marsh flooding on the abundance and growth of *Fundulus heteroclitus* in salt marsh creeks. Biol. Bull. 197:299-300.
- Young, T., S. Komarow, L. Deegan and R. Garritt. 1999. Population size and summer home range of the green crab, *Carcinus maenus*, in salt marsh tidal creeks. Biol. Bull. 197:297-299.

Morlock, Summer (Duke University, 1997)

- Morlock, S., D. Taylor, A. Giblin, C. Hopkinson, J. Tucker. 1997. Effect of salinity on the fate of inorganic nitrogen in sediments of the Parker River Estuary, Massachusetts. Biol. Bull. 193: 290-292.

Pease, Katherine (Barnard College, 1999)
- Pease, K. M., L. Claessens, C. Hopkinson, E. Rastetter, J. Vallino, and N. Kilham. 1999. Ipswich River nutrient dynamics: preliminary assessment of a simple nitrogen-processing model. Biol. Bull. 197(2): 289.

Perring, Anne (Brown University, Summer 2000)
- Perring, A., M. Williams, C. Hopkinson Jr., E. Rastetter, and J. Vallino. 2000. Solute dynamics in storm flow of the Ipswich River Basin: effects of land use. Biol. Bull. 199(2): 219-221.
- Presentation at 2000 MBL General Scientific Meeting.

Sergeant, Kara (Dickinson College, 2000)
- Sergeant, K., M. Cieri, and L. Deegan. 2000. Bivalve Grazing Pressure on Primary Producers in a New England Estuary. Presentation at the 2000 MBL General Scientific Meeting.

Sichol, Bobbie (University of New Hampshire, 1996)

Sweeney, Jennifer (Hiram College, 1998)
- Sweeney, J., L. Deegan and R. Garritt. 1998. Population size and site fidelity of Fundulus heteroclitus in a macrotidal saltmarsh creek. Biological Bulletin 195:238-239.

Williams, Libby (College of Wooster, 2001)
- Williams, L., C. Noblett, and R. Buchsbaum. The effect of salt marsh haying on benthic algal biomass. In prep for Biol. Bull. and 2001 MBL General Scientific Meetings.

Wolf, Amelia (Colorado College, 2000)
- Wolf, A., C. Tobias, and B. Peterson. 2000. Dissolved Inorganic Nitrogen Uptake Kinetics and Relative Preference Indices for Estuarine Primary Producers. Presentation at the 2000 MBL General Scientific Meeting.

Young, Talia (Swarthmore College, 1999)
- Young, T., S. Komarow, L. Deegan and R. Garritt. 1999. Population size and summer home range of the green crab, *Carcinus maenus*, in salt marsh tidal creeks. Biol. Bull. 197:297-299.
- Komarow, S., T. Young, L. Deegan and R. Garritt. 1999. Influence of marsh flooding on the abundance and growth of *Fundulus heteroclitus* in salt marsh creeks. Biol. Bull. 197:299-300.

Semester in Environmental Science:

The following students assisted with a fish sampling field trip at Plum Island:
- Armstrong, Hyacinth (Mount Holyoke College)
- DeRocker, Abbey (Bates College)
- Diener, Lynn (Bard College)

- Glass, Janice (Lafayette College)
- Meredith, Christy (Allegheny College)
- Parker, Sophie (Wellesley College)
- Rapoport, Shana (Brandeis University)
- Tsie, Marlene (Brandeis University)

The following students did research projects pertaining to the Plum Island Ecosystems:

Congalton, Phoebe (Sarah Lawrence College)
- Research Project: Leaf litter and organic soil quality and decomposition across an urban–rural land-use gradient.

Schoppe, Alexis (Dickinson College)
- Research Project: The effects of urbanization on stream water quality along an urban-rural gradient.

Mathrani, Vandana (Scripps College)
- Research Project: The Effects of Nitrogen Inputs on Soil Processes and Soil Chemistry in Different Land-Use Areas Along the Ipswich River Basin, MA.

Williams, Samantha (Mount Holyoke College)
- Research Project: Water Quality Along a Land-Use Gradient: The Effects of Nutrient-Loading on Primary Production and Bacterial Growth in the Ipswich River Watershed.

Woods Hole Marine Science Consortium:

Horowitz, Julie (Hampshire College, 2000-2001)
- Horowitz, J., L. Deegan, and R. Garritt. 2000. Stable Isotope Analysis of Food Webs in Hayed and Reference Salt Marshes. Presentation at the 2000 MBL General Scientific Meeting.
- Horowitz, J. 2001. Stable isotopic analysis of food webs in hayed and reference salt marshes. Honors Thesis, Hampshire College.

Schmitt, Catherine (University of Massachusetts at Amherst, 1998)
- Schmitt, C., N. Weston, and C. Hopkinson Jr. 1998. Preliminary evaluation of sedimentation rates and species distribution in Plum Island Estuary, Massachusetts. Biol. Bull. 195(2): 232.

Weston, Nathaniel (Hampshire College, 1996)
- Weston, N.B., S.S. Carini, A.E. Giblin, G.T. Banta, C.S. Hopkinson and J. Tucker. 1996. Estimating denitrification in sediments of the Parker River estuary, Massachusetts. Biol. Bull. 191:334-335.

RESEARCH ASSISTANTS:

Champagne, Jamie (Ecosystems Center, MBL)
Chew, Carrie (Massachusetts Audubon Society)
Chiuchiolo, Amy (Ecosystems Center, MBL)

Drummey, Todd (Ecosystems Center, MBL)
Fleischer, Dirk (University of Kiel, Germany)
Grupposo, John (Massachusetts Audubon Society)
Magnusson, Britta (Massachusetts Audubon Society)

- Buchsbaum, R., T. Purinton, and B. Magnusson. Submitted 2001. The marine resources of the Parker River-Plum Island Sound estuary: An update after 30 years. MCZM publication.

Ridlon, April (Massachusetts Audubon Society)
Salgado, João (Algave University, Portugal)
Saupe, Susan (Ecosystems Center, MBL)

RESEARCH ASSISTANT INTERNS:

Buffam, Ishi (Ecosystems Center, MBL)

- Hopkinson, C.S., I. Buffam, J. Hobbie, J. Vallino, M. Perdue, B. Eversmeyer, F. Prahl, J. Covert, R. Hodson, M.A. Moran, E. Smith, J. Baross, B. Crump, S. Findlay, and D. Foreman. 1998. Terrestrial inputs of organic matter to coastal ecosystems: an intercomparison of chemical characteristics and bioavailability. Biogeochemistry. 43:211-234.
- Alderman, D., B. Balsis, I.D. Buffam, R.H. Garritt, C.S. Hopkinson and J.J. Vallino. 1995. Pelagic metabolism in the Parker River/Plum Island Sound Estuarine System. Biol. Bull. 189:250-251.
- Balsis, B., D. Alderman, I.D. Buffam, R.H. Garritt, C.S. Hopkinson and J.J. Vallino. 1995. Total system metabolism in the Plum Island Sound estuary. Biol. Bull. 189:252-254.

Goldstein, Josh (Ecosystems Center, MBL)
Logan, John (Ecosystems Center, MBL)
Peterson, Greg (Ecosystems Center, MBL)
Weston, Nathaniel (Ecosystems Center, MBL)

- Weston, N., A.E. Giblin, G. Banta, C.S. Hopkinson, and J. Tucker. The effects of varying salinity on the ammonium exchange and ammonium losses of estuarine sediments. In prep.
- Giblin, A.E., N. Weston, G. Banta, C.S. Hopkinson, and J. Tucker. The effect of salinity on nitrogen dynamics in estuarine sediments. In prep.

GRADUATE STUDENTS:

Lunsford, Tammy (Virginia Institute of Marine Science)

Agrawal, Aditya (Clark University)

Becker, Daniel (Louisiana State University)

- Assisted with field sampling for Nisotrex II project.

Brendensteiner, Kim (University of New Hampshire)

- Bredensteiner, K.C., C.J. Vorosmarty, W. Wollheim, T. Loder III, E. Penfold. 2001. Estimation of snowpack nutrient storage and its role in seasonal nutrient flux to the Gulf of Maine coastal zone. *Estuaries*. Submitted.

Burgess, Paul (Clark University)

- Burgess, P. 1999. Conservation and development in conflict. MS Thesis, Clark University.

Castanier, Homero (Clark University)

- Poster presentation: Land modeling in the Ipswich watershed. 2000 LTER All Scientists Meeting at Snowbird, UT.

Dalia, Wendy (Boston University)

- Buchsbaum, R. and W. Dalia. 2001.The impacts of salt marsh haying on the vegetation community and bird use of salt marshes: A preliminary assessment from Plum Island Sound. Abstr. Spring 2001 meeting, New England Estuarine Res. Society.

Daoust, Robert (University of South Carolina)

Erdner, Deana (MIT-WHOI Joint Program)

- Assisted with field sampling for Nisotrex I project.

Ferry, Kristen (University of Massachusetts)

Grace, Arian (Louisiana State University)

- Assisted with field sampling for Nisotrex II project.

Hullar, Meredith (Harvard University)

- Hopkinson, C. S., A. E. Giblin,R.H. Garritt, J. Tucker, and M.A.J. Hullar. 1998. The influence of the benthic boundary layer on growth of pelagic bacteria. Aquat. Microb. Ecol. 16:109-118.

Hunt, Chris (University of New Hampshire)

Leblanc, Justin (Harvard University)

- Buchsbaum, R., A. Cooper and J. LeBlanc. 1999. Conserving the Plum Island Sound/Rivers Ecosystem - A research report and management plan. Produced for the Massachusetts Bays Program and the Towns of Ipswich, Rowley and Newbury by Massachusetts Audubon: North Shore Conservation Advocacy. 31 p.

Lim, EeLin (MIT-WHOI Joint Program)

- Lim, E. L., D. Caron and E. DeLong. 1996. Development and field application of a quantitative method for examining natural assemblages of protists with oligonucleotide probes. Applied and Environmental Microbiology 62:1416-1423.

Lowry, Maggie (Clark University)

Kim, John (University of Massachusetts at Amherst)

Machas, Raquel (Algarve University, Portugal)

Marzouk, Karim (Clark University)

- Pontius, R.G. Jr, L. Claessens, C. Hopkinson Jr, A. Marzouk, E. Rastetter, L. Schneider, and J. Vallino. 2000. Scenarios of land-use change and nitrogen release in the Ipswich watershed, Massachusetts, USA. In B. Parks, K. Clarke, M. Crane, editors. 2000. Proceedings of the 4th international conference on integrating GIS and environmental modeling Boulder: University of Colorado, CIRES. (CD and http://www.colorado.edu/research/cires/banff/upload/6/)

McClelland, Jim (Boston University Marine Program)

McKenna, Jim (University of Rhode Island)

Menard, Stephen (Clark University)

- Menard, S. 1999. Land-use change and regional growth in the Ipswich watershed basin. MS Thesis, Clark University.

Mondrup, Thomas (Roskilde University, Denmark)

- Mondrup, T. 1999. Salinity effects on nitrogen dynamics in estuarine sediment investigated by a plug-flux method. Biol. Bull. 197:287-288.
- Mondrup, T. 2000. Salinity effects on tolerance and adaptation of estuarine nitrifying bacteria investigated by a plug-flux method. MS Thesis, Roskilde University, Denmark. 47pp.
- Mondrup, T., G. Banta, and A.E. Giblin. Salinity effects and tolerance and adaptation of estuarine nitrifying bacteria investigated by a plug-flux method. In prep.

Nelson, Amy (Clark University)

Pellerin, Brian (University of New Hampshire)

Pieri, Nick (Clark University)

- Pontius, R.G., Nelson, and N. Pieri. 2001. Evaluating equitable effectiveness of conservation laws. Presentation at the Human Dimensions of Global Change meeting, Carnegie-Mellon University, Pittsburgh, PA..

Raymond, Peter (Virginia Institute of Marine Science)

Rodriquez, Diana (University of South Carolina)

Schneider, Laura (Clark University)

- Schneider, L. and R.G. Pontius Jr. 2001. Modeling land-use change in the Ipswich watershed, Massachusetts, USA.. Agriculture, Ecosystems & Environment 85(1-3) p. 83-94.
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Schultz, Greg (Georgia Tech University)

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Zappa, Chris (Woods Hole Oceanographic Institution)

SCIENCE WRITERS

The following people have participated in the Marine Biological Laboratory Science Writer's Program and attended an intensive field seminar with PIE LTER scientists:

Allen, Monica (Bangor Daily News, 1998)
Edwards, Randall (Columbia Dispatch, 1998)
Haurwitz, Ralph (Austin-American Statesman, 1998)
Henderson, Diedtra (Seattle Times, 1998)
Roylance, Frank (Baltimore Sun, 1998)
Swafford, Angela (Mas Vida/CBS Telenoticias, 1998)
Toomey, Diane (WUNC Radio, 1998)
Warrick, Jody (Washington Post, 1998)
Bates, Todd (Asbury Park (NJ) Press, 1999)
Beeman, Perry (Des Moines Register, 1999)
Burns, Michael (Baltimore Sun, 1999)
Cohen, Nancy (freelance reporter, 1999)
Grossman, Daniel (Living on Earth producer, 1999)
Hogue, Cheryl (Bureau of National Affairs, 1999)
Lesser, Carolyn (children's book author, 1999)
Pennypacker, Mindy (The Green Guide, 1999)
Schueller, Gretel (Audubon Magazine, 1999)

APPENDIX III

PIE LTER PUBLICATIONS

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ROBERT N. BUCHSBAUM

Coastal Ecologist
Massachusetts Audubon Society
346 Grapevine Road,
Wenham, MA 01984
Phone: 978-927-1122 FAX: 978-922-8487
Email: rbuchsbaum@massaudubon.org

Birthplace: Brooklyn, NY
Birth date: January 20, 1948
Citizenship: U.S.A.
Soc. Sec.#: 104-40-9134

Education:

Ph.D. Boston University Marine Program (Marine Ecology), 1985
B.S. Cornell University (Natural Resources), 1969

Recent Employment History:

1993 to present Co-Director, North Shore Office of the Massachusetts Audubon Society;
Conservation Scientist, 1987-present
1991 Visiting Assistant Professor, Salem State College. Ecology.
1986 Visiting Assistant Professor, Wheaton College, Norton, MA. Biometry.
1985 to 1987 Post Doctoral Scientist, Boston University Biology Department

Professional Organizations:

Estuarine Research Federation
New England Estuarine Research Society (Secr.-Treasurer 1992-94, Treasurer 94-96)
Society for Conservation Biology (Board of Directors of Massachusetts chapter)
Society of Wetlands Scientists (Associate Editor of *Wetlands*, Jan. 1998-Dec. 2000)

Recent and Relevant Publications:

Buchsbaum R., I. Valiela, T. Swain, M. Dzierzeski, and S. Allen. 1991. Available and refractory nitrogen in detritus of coastal vascular plants and macroalgae. Mar. Ecol. Prog. Ser., 72:131-143.

Buchsbaum, R. 1992. Chemical signals from plants and Phanerozoic evolution: Questions and answers. Chapter 14 (in part). In: L. Margulis and L. Olendzenski (eds.), Environmental Evolution: Effects of the origin and evolution of life on planet Earth. MIT Press.

Buchsbaum, R. 1994. Management of coastal marshes. In: D. Kent (ed.), Applied Wetlands Science and Technology. Lewis Publishing Co., pp. 331-362.

Holt, E. and R. Buchsbaum. 2000. Bird use of *Phragmites australis* in coastal marshes of northern Massachusetts. In: J. Pederson (ed.), Proceedings of the 1st National Conference on Marine Bioinvasions, Jan 24-27, 1999, MIT Sea Grant Cambridge, MA., pp 232-240.

Burdick, D., R. Buchsbaum, and E. Holt. Tidal manipulation and *Phragmites* invasion of salt marshes. Physiol. and Environmental Botany. In press.

LINDA A. DEEGAN

The Ecosystems Center
Marine Biological Laboratory
Woods Hole, MA 02543
(508) 289-7487
E-mail: ldeegan@mbl.edu

Birthplace: Montgomery, Alabama
Birthdate: November 20, 1954
Citizenship: U.S.A.
Soc. Sec. #: 264 33 9805

Education:

Ph.D. Department of Marine Sciences, Louisiana State University, Baton Rouge, LA, 1985.
M.S. Zoology Department, University of New Hampshire, Durham, NH, 1979.
B.S. Biology Department, Northeastern University, Boston, MA, 1976. Cum laude with Honors.

Research Experience:

Associate Scientist, The Ecosystems Center, Marine Biological Laboratory, Woods Hole, MA, 1994-present

Assistant Scientist, The Ecosystems Center, Marine Biological Laboratory, Woods Hole, MA, 1989-1994

Adjunct Assistant/Associate Professor, Department of Forestry and Wildlife Management, University of Massachusetts, Amherst, MA, 1989-present

Assistant Professor, Department of Forestry and Wildlife Management, University of Massachusetts, Amherst, MA, September 1985-January 1989

Professional Activities:

New England Estuarine Research Society, President 2000-present, President-Elect 1998-2000, Executive Committee 1988-1989, member 1976-present.

Estuarine Research Federation, Executive Committee Member-at-large 1993-1995, NEERS 2000-2002.

American Fisheries Society, member 1976-present, National Strategy Planning Committee 1993-1994.

Estuaries, Editorial Board 1987-1992.

American Fisheries Society Southern New England Chapter, President 1988-1989, President-elect 1987-1988, Secretary-Treasurer 1986-1987.

Wetland Ecosystem Research Group, Five-College Program, Amherst, MA, Chair 1987-1989.

Selected Publications out of a Total of 60:

Deegan, L A., A. Wright, S. G. Ayvazian, J. T. Finn, H. Golden, R. Rand Merson, and J. Harrison. 2001. Nitrogen loading from upland areas alters seagrass support of higher trophic levels. Aquatic conservation: Marine and Freshwater Ecosystems. In press.

Deegan, L. A., J. Kremer, T. Webler, J. Brawley. 2001. The use of models in integrated resource management in the coastal zone, pp 295-306. In: Von Bodungen, B., and R. K. Turner, eds., Science and Integrated Coastal Management. Berlin: Dahlem University Press, 378 pp.

Deegan, L. A., J. E. Hughes, R. A. Rountree. 2000. Salt marsh ecosystem support of marine transient species, pp. 333 – 365. In: Weinstein and Kreeger, eds., Concepts and Controversies in Tidal Marsh Ecology. Kluwer Academic Publisher, The Netherlands

Hughes, J. E., L. A. Deegan, B. J. Peterson, R. M. Holmes, and B. Fry. 2000. Nitrogen flow through the food web in the oligohaline zone of a New England estuary. Ecology. 81:433-452.

Holmes, R. M., B. J. Peterson, L. A. Deegan, J. E. Hughes, and B. Fry. 2000. Nitrogen biogeochemistry in the oligohaline zone of a New England estuary. Ecology. 81:416:432.

ANNE E. GIBLIN
The Ecosystems Center
Marine Biological Laboratory
Woods Hole, Massachusetts 02543
(508) 289-7488

Birthdate: 8 January 1954
Birthplace: Rockville Center, NY
Citizenship: U.S.A.
Soc. Sec. #: 130-46-1108

Education:

Ph.D., Boston University Marine Program, Woods Hole, MA, 1982, Ecology
B.S., Rensselaer Polytechnic Institute, Troy, NY, 1975, Biology

Awards:

Phi Lambda Upsilon Chemical Honor Society
Aldo Leopold Leadership Fellowship 2001

Research Experience:

Associate Scientist, Ecosystems Center, Marine Biological Laboratory, Woods Hole, MA, 1990-Present
Adjunct Associate Professor, Boston University, Boston, MA, 1991-Present
Assistant Scientist, Ecosystems Center, Marine Biological Laboratory, Woods Hole, MA, 1983-1989
Postdoctoral Investigator, Woods Hole Oceanographic Institution, Woods Hole, MA, 1982-1983
Coordinator, Summer Marine Ecology Course, Marine Biological Laboratory, Woods Hole, MA, 1981
Research Assistant, Boston University Marine Program, Woods Hole, MA, 1977 - 1981
Teaching Fellow, Boston University Marine Program, Woods Hole, MA, 1975 - 1977

Selected Relevant Publications:

Giblin, A. E., and A. G. Gaines. 1990. Nitrogen dynamics in a marine embayment: the importance of groundwater. Biogeochemistry 10:309-328.

Weston, N., S. Carini, A. Giblin, G. Banta, C. Hopkinson, and J. Tucker. 1996. Estimating denitrification in sediments of the Parker River Estuary, Massachusetts. Biol. Bull. 191:334-335.

Giblin, A. E., C. S. Hopkinson, and J. Tucker. 1997. Benthic metabolism and nutrient cycling in Boston Harbor, Massachusetts, U.S.A. Estuaries 20:346-364.

Portnoy, J. W, and A. E. Giblin. 1997. Biogeochemical effects of seawater restoration to diked salt marshes. Ecological Applications: 7:1054-1063.

Hopkinson,C. S., A. E. Giblin, J. Tucker, and R. H. Garritt. 1999 Benthic metabolism and nutrient cycling along an estuarine salinity gradient. Estuaries 22:825-843.

JOHN EYRES HOBBIE
The Ecosystems Center
Marine Biological Laboratory
Woods Hole, Massachusetts 02543
(508) 289-7470
E-mail: jhobbie@mbl.edu

Birthplace: Buffalo, New York
Birthdate: 5 June 1935
Citizenship: U.S.A.
Soc. Sec. #: 097-30-6670

Education: Ph.D., Indiana University, 1962
M.A., University of California, 1959
B.A., Dartmouth College, 1957

Research Experience:

Senior Research Scientist, The Ecosystems Center, Marine Biological Laboratory, Woods Hole, 1976-present; Acting Director, 1984; Director, 1985-1989, Co-Director 1989-present

Tage Erlander Visiting Professor, Askö Laboratories, University of Stockholm, Sweden, September 1988-September 1989

N.S.F. Postdoctoral Fellow, Norwegian Institute for Water Research, 1971-1972

Assistant Professor (1965), Associate Professor (1967), Professor (1971-1976), North Carolina State University, Raleigh

N.I.H. Postdoctoral Fellow, Uppsala University, Sweden, 1963-1965

Research Associate, University of California, Davis, 1962-1963

Honors and Memberships:

President, American Society of Limnology and Oceanography, 1984-1986
President, Association of Ecosystems Research Centers, 1987-1988, 1992-1993
Member, Corporation of the Marine Biological Laboratory
Member, Ocean Studies Board of National Academy of Science/National Research Council
American Society of Microbiology
American Society of Limnology and Oceanography
American Association for the Advancement of Science
Awards - Hutchinson Award for Research (American Society of Limnology and Oceanography), Sigma Xi Research Award
Arctic Research Commission, 1996-present
Chair, Coordinating Committee, Land Margin Ecosystems Research

Publications:

Hobbie, J.E. 2000. Estuarine Science: A Synthetic Approach to Research and Practice. Island Press. Washington. D. C., 539 pp.

Hopkinson, C. S., I. Buffam, J. E. Hobbie, J. Vallino, M. Perdue, B. Eversmeyer, F. Prahl, J. Covert, R. Hodson, M. A. Moran, E. Smith, J. Baross, B. Crump, S. Findlay and D. Foreman. 1998. Terrestrial inputs of organic matter to coastal ecosystems: An intercomparison of chemical characteristics and bioavailability. Biogeochemistry. 43:211-234.

Vallino, J. J., C. S. Hopkinson and J. E. Hobbie. 1996. Modeling bacterial utilization of dissolved organic matter: Optimization replaces monod growth kinetics. Limnology and Oceanography 41:1591-1609.

Deegan, L. A., J. T. Finn, C. S. Hopkinson, A. E. Giblin, B. J. Peterson, B. Fry and J. E. Hobbie. 1995. Flow model analysis of the effects of organic matter-nutrient interactions on estuarine trophic dynamics, pp. 273-281. In: International Symposium Series, Changes in Fluxes in Estuaries: Implications from Science to Management. Olsen and Olsen, Fredensborg, Denmark.

Hines, M. E., G. T. Banta, A. E. Giblin, J. E. Hobbie and J. B. Tugel. 1994. Acetate concentrations and oxidation in salt marsh sediments. Limnology and Oceanography 39:140-148.

CHARLES S. HOPKINSON, JR.

The Ecosystems Center
Marine Biological Laboratory
Woods Hole, Massachusetts 02543
508-289-7688; chopkins@mbl.edu

Home: 48 Hillcrest Drive
Falmouth, Massachusetts 02540
508-457-4649
Soc. Sec. #: 164-40-2092

Education: Ph.D., Marine Science, 1979, Louisiana State University, Baton Rouge
M.S., Marine Science, 1973, Louisiana State University, Baton Rouge
B.S., Biology, 1970, Ursinus College, Collegeville, Pennsylvania

Research Interests: Wetland and aquatic ecology, element cycles in marine and fresh water systems, microbial ecology, nitrogen and phosphorus cycling, land use change and watershed dynamics, land-sea coupling, global ecology, systems ecology – modeling, integrated assessment

Professional Experience:

1997-Present	Senior Scientist, The Ecosystems Center, Marine Biological Laboratory, Woods Hole, MA
1990-1996	Associate Scientist, The Ecosystems Center, MBL, Woods Hole, MA
1988	Visiting Professor, Askö Laboratory, University of Stockholm, Stockholm, Sweden
1986-1989	Associate Marine Scientist, Marine Institute, University of Georgia
1982-1986	Assistant Marine Scientist, Marine Institute, University of Georgia
1980-1989	Assistant Professor, Department of Zoology, University of Georgia
1979-1982	Research Associate, Marine Institute, University of Georgia
1973-1975	Research Associate II, Center for Wetland Resources, LSU, Baton Rouge, LA

Recent Professional Activities:

Editor-in-Chief, Mangroves and Salt Marshes, an international journal. Kluwer Academic Publishers. 1997-2000.

Co-Editor-in-Chief, Wetlands Ecology and Management. Kluwer Academic Publishers. 2000-.

Member of the Committee on the Causes and Management of Coastal Eutrophication. Organized by the National Research Council, Commission on Geosciences, Environment and Resources, Ocean Studies Board. 1998 – 2000.

Selected Publications:

Fry, B., C. Hopkinson, A. Nolin, and S. Wainright. 1998. $^{13}C/^{12}C$ composition of marine dissolved organic carbon. Chemical Geology 152:113-118.

Hopkinson, C. S., A. E. Giblin, H. Garritt, J. Tucker, and M. Hullar. 1998. The influence of the benthos on growth of planktonic estuarine bacteria. Aquatic Microbial Ecology 16:109-118.

Hopkinson, C. S., I. Buffam, J. Hobbie, J. Vallino, M. Perdue, B. Eversmeyer, F. Prahl, J. Covert, R. Hodson, M. Moran, E. Smith, J. Baross, B. Crump, S. Findlay, and K. Foreman. 1998. Terrestrial inputs of organic matter to coastal ecosystems: An intercomparison of chemical characteristics and bioavailability. Biogeochemistry 43:211-234.

Hopkinson, C. S., A. E. Giblin, J. Tucker, and H. Garritt. 1999. Benthic metabolism and nutrient cycling along an estuarine salinity gradient. Estuaries 22:825-843.

Hopkinson, C. S., A. E. Giblin, J. Tucker, and H. Garritt. 2001. Benthic metabolism and nutrient regeneration on the continental shelf off eastern Massachusetts, USA. Marine Ecology – Progress Series, in press.

JAMES T. MORRIS
Marine Science Program
Department of Biological Sciences
University of South Carolina
Columbia, SC 29208
Phone: 803-777-3948; Fax: 803-777-4002
Email: morris@biol.sc.edu; web: zebra.biol.sc.edu/~morris

Education:

B.A. University of Virginia, 1973, Environmental Sciences
M.S. Yale University, 1975, Biology
Ph.D. Yale University, 1979, Forestry and Environmental Studies

Employment:

1992-present: Professor of Biological and Marine Sciences, University of South Carolina
1993: Visiting Professor, Dept. of Plant Ecology., Aarhus University, Denmark
1990: Visiting Associate Professor, Botansk Inst., Aarhus University, Denmark
1987-1992: Associate Prof. of Biology and Marine Science, University of South Carolina
1981-1987: Assistant Prof. of Biology and Marine Science, University of South Carolina
1979-1981: Postdoctoral Fellow, Ecosystems Center, MBL, Woods Hole

Selected Professional Service:

Participant, EPA NOx criteria document review; Research Triangle, NC, April 1992.
Panel member and author, 'The Scientific Principles of Wetland Loss, Restoration and Creation in Coastal Louisiana', Alton Jones Foundation review, Baton Rouge, 1993-1994.
Member, NSF Career Development Awards Panel.
Member, Georgia Sea Grant Review Panel.
Member, EPA workshop on nutrient effects on aquatic habitats, Washington, Dec. 1995.
Member, NSF Ecosystems Panel, 1994-1998.
Steering committee member, National Committee, SCOPE workshop on estuarine synthesis. 1994-1995.
Member, White House Office of Science and Technology Workshop on National Environmental Monitoring and Research, Sept. 1996
Subject Editor, *Wetlands Ecology and Management*, 1997-present.
Member, EPA Salton Sea Authority Review Panel, Washington, D.C., 1998
Member, Barrier Island Study Review Panel, Office of the Governor, State of Louisiana; Dec. 1999

Selected Publications:

Morris, J.T. 1991. Effects of nitrogen loading on wetland ecosystems with particular reference to atmospheric deposition. Ann. Rev. Ecol. Syst. 22:257-279.
Morris, J.T. & A. Jensen. 1998. The carbon balance of grazed and nongrazed *Spartina anglica* saltmarshes at Skallingen, Denmark. J.Ecol.86.
Paludan, C. and J.T. Morris. 1999. Distribution and speciation of phosphorus along a salinity gradient in intertidal marsh sediments. Biogeochemistry 45: 197-221
Morris, J.T. and P.M. Bradley. 1999. Effects of nutrient loading on the preservation of organic carbon in wetland sediments. Limnology and Oceanography, 44:699-702.
Sundareshwar, P.V. and J.T. Morris. 1999. Phosphorus sorption characteristics of intertidal marsh sediments along an estuarine salinity gradient. Limnology and Oceanography 44:1693-1701.

ROBERT G. PONTIUS, JR.
Assistant Professor
Graduate School of Geography
Clark University
950 Main Street
Worcester MA 01610, USA
Phone (508) 793-7761, Fax (508) 793-8881, Email rpontius@clarku.edu

Education:

Ph.D. State University of New York, Environmental Science, 1994
M.S., The Ohio State University, Applied Statistics, 1989
B.S. University of Pittsburgh, Mathematics, Economics, 1984

Experience:

1998-present	Assistant Professor, Clark University
1997-present	President, Ecowise
1995-1997	Associate Scientist, Tellus Institute & Stockholm Environment Institute
1994-1995	Assistant Professor, Boston University
1992-1994	Research Assistant, State University of New York
1990-1991	Teaching Associate, State University of New York, Statistical Consultant, 1990-1994
1989-1990	Mathematical Statistician, United States Department of Agriculture
1987-1989	Teaching Associate, The Ohio State University, Statistical Consultant, 1989
1985-1987	Mathematics Teacher, United States Peace Corps in Tanzania

Publications Associated With The Plum Island Estuary (PIE) LTER:

Pontius, R. G., Jr., and L. Schneider. 2001. Land-use change model validation by a ROC method for the Ipswich watershed, Massachusetts, USA. Agriculture, Ecosystems & Environment 85(1-3):239-248.

Schneider, L., and R. G. Pontius, Jr. 2001. Modeling land-use change in the Ipswich watershed, Massachusetts, USA. Agriculture, Ecosystems & Environment 85(1-3):83-94.

Pontius, R. G., Jr. 2000. Quantification error versus location error in comparison of categorical maps. Photogrammetric Engineering & Remote Sensing 66(8):1011-1016.

Pontius, R. G., Jr, L. Claessens, C. Hopkinson, Jr., A. Marzouk, E. Rastetter, L. Schneider, and J. Vallino. 2000. Scenarios of land-use change and nitrogen release in the Ipswich watershed, Massachusetts, USA. In: B. Parks, K. Clarke, and M. Crane, editors. Proceedings of the 4th international conference on integrating GIS and environmental modeling Boulder: University of Colorado, CIRES. (CD and www.colorado.edu/research/cires/banff/upload/6/).

BRUCE J. PETERSON
The Ecosystems Center
Marine Biological Laboratory
Woods Hole, Massachusetts 02543
(508) 289-7484

Birthplace: Chicago, Illinois
Birthdate: 9 April 1945
Citizenship: U.S.A.
Soc. Sec.#: 041-36-6016

Education: Ph.D. Cornell University, Ithaca, NY, 1971

B.S. Bates College, Lewiston, ME, 1967, Biology (with honors)

Research Experience:

January 1976 - Present: The Ecosystems Center, Marine Biological Laboratory, Woods Hole, Massachusetts. Senior Scientist, December 1987 to Present. Research on biological processes at the ecosystem level with emphasis on cycling of nitrogen, phosphorus, sulfur and carbon. Associate Scientist, January 1980 to December 1987; Assistant Scientist, January 1977 to January 1980; Postdoctoral Associate, January 1976 to January 1977

July 1975 to December 1975 - Research Associate, North Carolina State University, Raleigh, North Carolina. Develop nutrient cycling process models based on field measurements of nitrogen, phosphorus and carbon cycling in the Pamlico River Estuary of North Carolina.

May 1974 to November 1974 - Research Associate, Hubbard Brook Ecosystem Study. Study carbon, nitrogen and phosphorus cycling in plankton and benthos.

June 1968 to April 1974. Cornell University, Ithaca, New York. Research Associate, June 1971 to April 1974. Nutrient limitation, phosphorus cycling and primary productivity in Cayuga Lake, New York. Research Assistant, June 1969 to September 1970. Cayuga Lake studies. Research Assistant, June 1968 to September 1968: Conduct sampling program as part of Bell Station Nuclear Power Plant impact studies.

May 1967 to September 1967, and May 1966 to September 1966 (summer jobs): Assistant Fisheries Biologist, Connecticut Department of Fish and Game.

Honors and Professional Societies:

President, Jordan Ramsdell Scientific Society, Bates College, 1966-1967
Phi Beta Kappa, Bates College, 1967
Cornell Graduate Fellowship, 1967-1968
Cornell Dennison Fellowship, 1968-1969
Member, American Society of Limnology and Oceanography
Member, American Association for the Advancement of Science
Fellow, American Association for the Advancement of Science
Member, Marine Biological Laboratory Corporation
Member, Estuarine Research Federation

Related Publications:

Peterson, B. J., B. Fry, M. Hullar, S. Saupe and R. Wright. 1994. The distribution and stable carbon isotopic composition of dissolved organic carbon in estuaries. Estuaries 17(1B):111-121.

Hullar, M. A. J., B. Fry, B. J. Peterson, and R. T. Wright. 1996. Microbial utilization of estuarine dissolved organic carbon: A stable isotope tracer approach tested by mass balance. Applied and Environmental Microbiology 62(7):2489-2493.

Hughes, J. E., L. A. Deegan, B. J. Peterson, R. M. Holmes, and B. Fry. 2000. Nitrogen flow through the food web in the oligohaline zone of a New England estuary. Ecology 81:433-452.

Holmes, R. M., B. J. Peterson, L. A. Deegan, J. E. Hughes, and B. Fry. 2000. Nitrogen biogeochemistry in the oligohaline zone of a New England estuary. Ecology 81:416:432

Vorosmarty, C. J. and B. J. Peterson. 2000. Macro-scale models of water and nutrient flux to the coastal zone, pp. 43-79, Chapter 3. In: J. E. Hobbie (ed.), Estuarine Science. A Synthetic Approach to Research and Practice. Island Press, Washington, DC.

JOSEPH J. VALLINO

The Ecosystems Center
Marine Biological Laboratory
Woods Hole, MA 02543
(508) 289-7648; FAX: (508) 457-1548
Email: jvallino@mbl.edu; WWW: http://eco37.mbl.edu

Education:

Ph.D. Massachusetts Institute of Technology, Cambridge, 1991, Chemical Engineering
M.S. California Institute of Technology, Pasadena, 1985, Chemical Engineering
B.S. University of California, Berkeley, 1983, Chemical Engineering

Experience:

1997-Present Assistant Scientist, The Ecosystems Center, Marine Biological Laboratory, Woods Hole, MA.
1997-1997 Research Associate, The Ecosystems Center, Marine Biological Laboratory, Woods Hole, MA.
1994-1997 Postdoctoral Research Associate, The Ecosystems Center, Marine Biological Laboratory, Woods Hole, MA.
1993-1994 Lakian Postdoctoral Scholar, The Ecosystems Center, Marine Biological Laboratory, Woods Hole, MA.
1991-1993 Mellon Postdoctoral Fellow, Scripps Institution of Oceanography, San Diego, CA

Relevant Publications:

Vallino, J. J. 2000. Improving marine ecosystem models: use of data assimilation and mesocosm experiments. J. Mar. Res. 58:117-164.

Vallino, J. J., and C. S. Hopkinson. 1998. Estimation of Dispersion and Characteristic Mixing Times in Plum Island Sound Estuary. Estuarine, Coastal and Shelf Science 46:333-350.

Vallino, J. J., C. S. Hopkinson, and J. E. Hobbie. 1996. Modeling Bacterial Utilization of Dissolved Organic Matter: Optimization Replaces Monod Growth Kinetics. Limnology and Oceanography 41:1591-1609.

Hopkinson, C. S. and J. J. Vallino. 1995. The Relationship Between Man's Activities in Watersheds and Rivers and Patterns of Estuarine Community Metabolism. Estuaries 18:598-621.

Hopkinson, C. S. and J. J. Vallino. 1994. Toward the Development of Generally Applicable Models of the Microbial Loop in Aquatic Ecosystems. Microb. Ecol. 28:321-326.

CHARLES J. VÖRÖSMARTY
Director, Water Systems Analysis Group
Complex Systems Research Center
Institute for the Study of Earth, Oceans and Space
University of New Hampshire
Durham NH 03824-3525
Phone: 603-862-1792
Fax: 603-862-1088

Education:

Ph.D. University of New Hampshire (1991)
M.S. University of New Hampshire (1983)
B.S. Cornell University (1977)

Professional Experience:

2001 – Present	Research Professor (University of New Hampshire)
1998 – 2001	Research Associate Professor (University of New Hampshire)
1991 – 1998	Research Assistant Professor (University of New Hampshire)
1977 – 1991	Research Scientist (University of New Hampshire)

Selected Publications:

Bredensteiner, K. C., C. J. Vorosmarty, W. Wollheim, T. Loder III, and E. Penfold. 2001. Estimation of snowpack nutrient storage and its role in seasonal nutrient flux to the Gulf of Maine coastal zone. Estuaries. Submitted.

Vörösmarty, C .J., P. Green, J. Salisbury, and R. Lammers. 2000. Global water resources: Vulnerability from climate change and population growth. Science 289:284-288.

Vörösmarty, C. J. and D. Sahagian. 2000. Anthropogenic disturbance of the terrestrial water cycle. BioScience 50:753-65.

Vörösmarty, C.J., B. Fekete, M. Meybeck, and R. Lammers. 2000. A simulated topological network representing the global system of rivers at 30-minute spatial resolution (STN-30). Global Biogeochemical Cycles 14:599-621.

Vörösmarty, C.J. and B.J. Peterson. 2000. Macro-scale models of water and nutrient flux to the coastal zone. In: J. Hobbie (editor), Estuarine Science: A Synthetic Approach to Research and Practice, pp. 43-80. Island Press, Washington DC.