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In addition, the Editor thanks Barbara Mahoney, Irene Schalla, and Karen Massaro for their assistance in proofreading this volume.

Long Island Sound Foundation Mission:

- To provide access to information about Long Island Sound.
- To enable knowledge and understanding of the Sound, its history, its economy, and its ecological influence.
- To foster a desire to protect and preserve the Sound.

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PREFACE

The Long Island Sound Research Conference (LISRC) was established as a biennial conference to provide a venue for formal and informal dialogue focusing on research activities related to the Sound and its watershed. Since its inception, LISRC has covered a number of timely topics, ranging from dredging and dredge material disposal to water quality and hypoxia issues. The meeting typically draws individuals from research and academic institutions, state and federal management agencies and public interest environmental groups. Through sharing ideas and exchanging information, the many facets of the health and future of the Sound are better understood. This interaction ultimately leads to new insights on ecosystem structure and function.

LISRC 2000 was held at the University of Connecticut's Stamford Regional Campus and local hosts were Dr. Jacqueline Joseph-Silverstein (Associate Vice Chancellor and Campus Director) and Dr. Charles Yarish (Professor, Department of Ecology and Evolutionary Biology). The two-day conference was organized around six general themes of oral presentations: "Historical Trends", "Non-Point Pollution", "Marine Ecosystems", "Diseases and Pathobiology", "Sediment Forms and Monitoring", and "Water Quality, Nutrients and Algae". In addition, there were poster presentations which added a further dimension to research being conducted in the Sound. An after-dinner talk by Daniel Malloy, Mayor of Stamford, Connecticut, provided a perspective on how human activities and coastal development affect and are affected by Long Island Sound.

The conference proceedings will be of use to marine scientists, managers, students, and industries that have interest in or impact the Sound.

Robert B. Whitlatch
Department of Marine Sciences
University of Connecticut

HISTORICAL TRENDS

Environmental Change in Long Island Sound: the Last 35 Years

E. Thomas, T. Gapotchenko and J.C. Varekamp
25 Church Street
Wesleyan University
Middletown, CT 06459

Benthic foraminifera are useful indicator species for monitoring environmental changes in near-shore, environmentally-stressed regions such as Long Island Sound (LIS), where severe anoxia/hypoxia was first observed in the early 1970's. We compared faunal and isotope data on benthic foraminifera collected in 1999 and 1996/1997, with published records for the early 1960's (Buzas, 1965) and the late 1940's (Parker, 1952). The low diversity benthic foraminiferal faunas of the 1940's and 1960's were dominated by *Elphidium excavatum clavatum* with *Buccella frigida* and *Eggerella advena* common in the deeper regions. In 1996/1997 and 1999, faunas in most samples were still dominated by *E. excavatum clavatum* and *B. frigida*, but *E. advena* was rare in all samples. Species diversity had decreased. *Ammonia beccarii*, which was rare (<5%) in 1948 and 1961, formed up to 27% of the assemblage in western LIS in 1996/1997, up to 77% in 1999. The Ammonia-Elphidium (A-E) index, which has been used to indicate low oxygenation levels in other regions, increased greatly in LIS. In LIS, this index is correlated with high counts in the sediment of the bacterial spore *Clostridium perfingens,* a sewage indicator. Comparison of oxygen isotope data for *E. excavatum clavatum* collected in the 1960's and 1990's suggests that no significant salinity changes occurred in this time interval, but carbon isotope data suggest that the oxidation of organic matter in LIS increased dramatically over the last 35 years, especially in western LIS. Sediment cores collected from LIS studies indicate that the abundance of the sewage indicator spore increased over the last few decades. We suggest that the bloom in *A. beccarii* in western LIS, the increased values of the A-E index, and the lighter carbon isotope values may all be related to increased sewage inputs over the last 35 years, and continuing over the last three years.

A Map of the Thickness of Post-Glacial Sediments in Long Island Sound

R.S. Lewis and M.L. DiGiacomo-Cohen
State of Connecticut Department of Environmental Protection
1080 Shennecossett Road
Groton, CT 06340

An isopach map of the thickness (in meters) of the post-glacial sediments of Long Island Sound (LIS) was constructed using 3,500 km of high-resolution, seismic-reflection data (Figure 1). These data were collected in cooperation with the U.S. Geological Survey, between 1982 and 1990. The thick accumulation of marine sediments in the vicinity of the Connecticut River is associated with the draining of glacial Lake Hitchcock. To the west, we calculate that 1.2×10^{13} kg of fine-grained marine sediment has been deposited over the past 13.5 ka. The total volume of this fine-grained sediment can be accounted for by a combination of riverine inputs and significant redistribution of glacial and early post-glacial sediments from within the LIS basin.

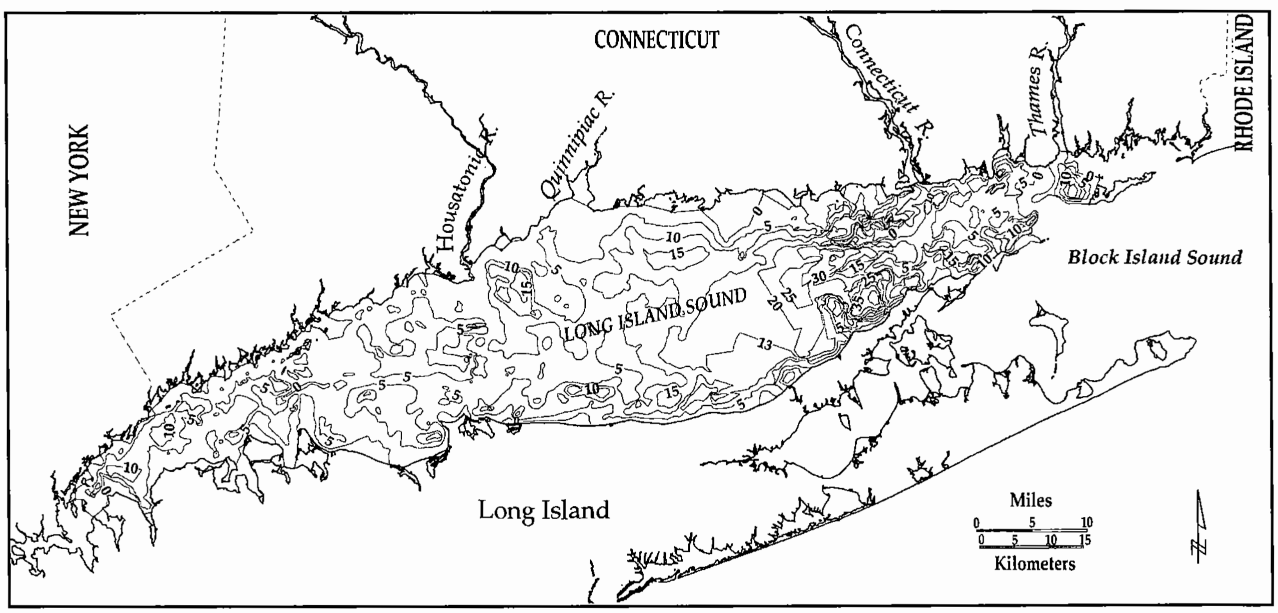

Figure 1. An isopach map of the thickness (in meters) of the post-glacial sediments of Long Island Sound

Climatology of Temperature, Salinity and Density Fields

R.E. Wilson and M.J. Bowman
Marine Sciences Research Center
SUNY at Stony Brook, Stony Brook, NY 11794

Available hydrography data are used to describe the seasonal cycle in vertical structure of temperature, salinity, and density at selected sites. Results afford a description of seasonal variations in the relative contributions of thermal and haline stratification to the density stratification, and they provide insight into the coupling of the thermal and haline fields through vertical mixing.

Long-term Patterns of Recruitment in a Fouling Community of Eastern Long Island Sound

Jeffrey R. Terwin, Robert B. Whitlatch, John J. Stachowicz
Department of Marine Sciences, University of Connecticut
1080 Shennecossett Rd.
Groton, CT 06340
Tel. (860) 405-9155
<jeffrey.terwin@uconn.edu>

A long-standing observation of biologists has been the tendency of many populations of marine organisms to display apparently erratic fluctuations in abundance. A majority of marine benthic species (including many commercially important ones) have complex life-cycles in which two or more very different developmental stages (larvae and adults) live in spatially distinct habitats (open water and the benthos). Early marine biologists noted that species with complex life-cycles exhibited much more pronounced fluctuations than similar species with simple life cycles, and implicated the larval phase as the source of the variability (e.g., Thorson 1950). While much of marine community ecology over the past 30 years has focused on the importance of interactions among adults in determining patterns of species distribution and abundance (e.g., Connell, 1961; Paine 1966), there is strong evidence that the supply of larvae can, under certain circumstances, play a strong role in marine community dynamics (Grosberg, 1982; Gaines and Roughgarden, 1985). Additionally, increased propagule supply has been linked to invasion success in terrestrial environments (Williamson, 1996). Despite the current widespread recognition that recruitment is a key element in the establishment and maintenance of marine benthic populations and communities, we still know little about the processes controlling it for most species and systems.

There are several species that are now part of the epifaunal community that have invaded or have been introduced to eastern Long Island Sound over the last 20 years (Carlton, 1989; Osman and Whitlatch, 1995). These include the colonial ascidians *Botrylloides diegensis* and *Diplosoma macdonaldi*, the solitary ascidians *Styela clava* and *Ascidiella adspersa*, and the bryozoan *Membranipora membranacea.* The recruitment of these species and any others that are introduced have been monitored in the same way as native species. This allows both groups to be contrasted to examine whether invading species exhibit any differences from natives in their ability to recruit into existing communities that might facilitate invasion success. Our current state of knowledge indicates that these four invaders are similar in feeding mode and growth habit (they are all sessile suspension feeders), but they differ considerably in some details of their ecology and life-history strategies. *Botrylloides* and *Diplosoma* brood very short lived larvae (a few minutes to hours) that appear capable of settlement almost immediately upon release (Worcester, 1994) while *Ascidiella* and *Styela* are broadcast spawners whose larvae generally become competent to settle within 12-24h after fertilization (Niermann-Kerkenberg and Hoffmann, 1989). Thus there may be differences in the degree to which populations of each species represent open vs. closed populations. Long-term recruitment data for invaders also allows the testing of invasion models based on the supply of propagules to a community (e.g., reviewed in Williamson, 1996). Studies of terrestrial plant communities (and conventional wisdom) suggest that rapid growth and reproduction rates and widespread dispersal are critical to the success of an invasion.

Since 1991, we have been collecting weekly recruitment data in eastern Long Island Sound for a variety of sessile benthic invertebrate taxa including barnacles, polychaetes, bryozoans, ascidians, sponges, and coelenterates. These taxa span the range of life-histories including planktotrophic and lecithotrophic species and species which are native to the region or have been recently introduced to southern New England (Table 1). The studies have been conducted at several sites in eastern Long Island Sound with one station at Avery Point (41°19'15" N, 72°2' 40"W) continuously monitored for the last ten years. Recruitment was monitored by exposing four or more replicate 100 cm^2 substrates for consecutive one-week periods. In most years, substrates were exposed during the main recruitment period from June through October. However, since 1996 weekly data have been collected throughout the year. Using our currently available data, we can address questions regarding environmental (e.g., temperature) and biological (e.g., pre-emptive competition) control of seasonal and annual variability in recruitment.

Recruitment was dominated by solitary and colonial ascidians and bryozoans. Inter-annually, species diversity and evenness remained fairly constant (H': 1.4 – 1.9; Evenness 0.45 – 0.8), yet the abundance of total recruits, as well as individual species was highly variable (Figure 1). There is often dramatic inter-annual variation in overall recruitment that may reflect annual fluctuations in environmental parameters such as temperature and salinity, and large week to week differences that may reflect the effects of tides or currents on larval distributions or variations among parental populations in the production of larvae. Colonial ascidians maintained much higher recruitment levels than the solitary ascidians (Figure 1a). An extreme inter-annual pattern can be seen for the recently introduced colonial ascidian *Diplosoma.* In some years, such as 1995, it exhibits phenomenally high recruitment while in intervening years it is virtually absent. This pattern appears to be in response to winter temperatures, where colder winters result in smaller populations of *Diplosoma* during the subsequent summer. A seasonal pattern of recruitment occurred for most species, with the onset of recruitment significantly associated with water temperatures in the Spring, and recruitment peaks occurring between July and October (Figure 1b). Invaders such as *Botrylloides* and *Styela* typically exhibit much lower recruitment rates than comparable native species (e.g., *Botryllus, Molgula*), but our personal observations suggest that, at least at one site, they maintain comparable adult abundances. Differences in seasonal timing and duration of recruitment may be more important for these species. As a possible example, the native ascidian, *Botryllus schlosseri* is functionally very similar to the invading *Botrylloides diegensis*: both are colonial ascidians that are semelparous with a very short lived larval dispersal phase (Table 1). Although *Botryllus* typically recruits at much higher densities (Figure 1a), *Botrylloides* recruits at a different time of year from *Botryllus*, with the peaks of *Botrylloides* settlement falling between the two major peaks of *Botryllus* recruitment (Figure 1b). The success of the invader, *Botrylloides*, in this system may relate to its pattern of recruitment which is consistently out of phase with its most closely related competitor, *Botryllus.* However, we need to examine whether this pattern holds at our other sites to assess whether this phenomenon is general and may contribute to the successful invasion of *Botrylloides* in New England epifaunal communities. Currently more stations, across a larger spatial scale, are being utilized to test whether patterns observed locally at the Avery Point dock site also occur across regional scales at multiple locations.

Competition plays an important role in hard substrate communities in a variety of marine systems. If space competition is an important factor in this system (but see Osman and Whitlatch, 1998) then we might expect to see negative correlations between recruitment for different species, especially for similar species types. This does not appear to be the case, however, while positive inter-annual associations among community members were common (see pattern in Figure 1). This may reflect the influence of environmental conditions to the overall population response of the various benthic species. Competition may occur at smaller spatial scales or shorter temporal scales (week to week) which may be detected with a more complete analysis of these data.

We feel that we have a unique long-term data set of weekly variation in recruitment for a large group of species that are taxonomically diverse and differ greatly in their life-histories (Table 1). We know of no other studies that have monitored weekly changes in recruitment for a diverse array of taxa over many years. Most studies that have measured variation in recruitment have either focused on a single taxon or

Species	Phylum	Solitary/ Colonial	Growth form	Larval life	Adult life
Halichondria	Porifera	Colonial	Variable	< 1 d	Years
Tubularia	Cnidaria	Colonial	Vine-like	< 1 d	Mo – yrs
Obelia	Cnidaria	Colonial	Vine-like Arborescent	days- wks	Mo – yrs
Spirorbis	Annelida	Solitary		hrs-days	Months
Hydroides	Annelida	Solitary		1 - 3 wks	Mo – yrs
Balanus	Arthropoda	Solitary		days – wks	Years
Cryptosula	Bryozoa	Colonial	Encrusting	min – hrs	Years
Schizoporella	Bryozoa	Colonial	Encrusting	min – hrs	Years
Microporella	Bryozoa	Colonial	Encrusting	min – hrs	Years
Bugula	Bryozoa	Colonial	Arborescent	min – hrs	Mo – yrs
Bowerbankia	Bryozoa	Colonial	Vine-like	min – hrs	Mo – yrs
Membranipora	Bryozoa	Colonial	Encrusting	days – wks	?
Botryllus	Urochordata	Colonial	Encrusting	min – hrs	Mos – 1 yr
Botrylloides	Urochordata	Colonial	Encrusting	min – hrs	Mos – 1 yr
Diplosoma	Urochordata	Colonial	Encrusting	min – hrs	Mos – 1 yr
Molgula	Urochordata	Solitary		< 1 d	1 – 2 yr
Ascidiella	Urochordata	Solitary		< 1 d	1 – 2 yr
Ciona	Urochordata	Solitary		< 1 d	1 – 2 yr
Styela	Urochordata	Solitary		< 1 d	1 – 2 yr

Table 1: General characteristics of some of the common sessile invertebrate species within the Southern New England shallow water epifaunal community. Bolded species names indicate those which have invaded eastern Long Island Sound in the past 25 years.

have followed recruitment for 1-2 years. Our data on a diversity of species span more than a decade, allowing us to contrast seasonal and annual differences. Additionally, these sampling efforts allow us to investigate the possible differences in the timing, intensity and duration of recruitment among closely related introduced and native species that might facilitate the invasion process.

Because global temperature is on the rise and environmental conditions in near-shore environments are likely to change in the coming years, it is imperative that a long-term database on the responses of marine organisms to these changes be maintained and made widely available. Similar data sets with coarser temporal resolution have proven valuable in the study of shifting species ranges with changes in sea surface temperatures (e.g., Barry *et al.*, 1995; Sagarin *et al.*, 1999). Additionally, this data set will serve as baseline data for the detection of new species that are introduced to the region. As an example, *Bugula neretina,* a non-indigenous bryozoan, was observed for the first time at the Avery Point location this past summer (Terwin pers. obs., 2000). Given the range of life-histories represented by the four common invaders and their overlap with similar native species, it is clear that no single set of life-history traits define successful invaders in the marine environment.

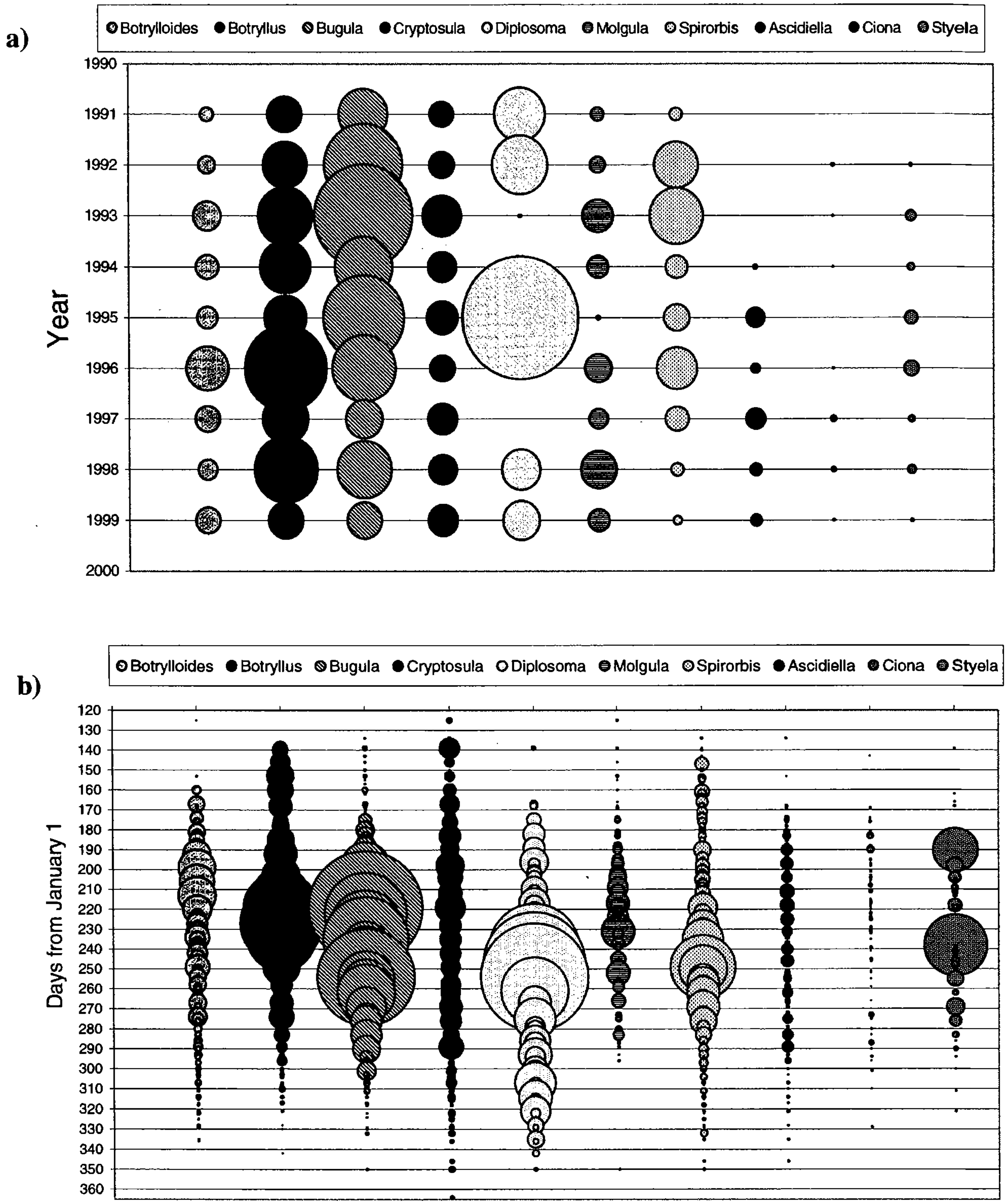

Figure 1: Mean recruitment totals for the ten most abundant species at Avery Point, in Eastern Long Island Sound. The area of the circle represents the total annual recruitment onto 100 cm^2 settlement panels that were scored and replaced weekly. a) Inter-annual mean recruitment totals. b) Mean seasonal recruitment pattern.

This long-term data set is useful for testing the generality of current models of recruitment dynamics because we have gathered data for a diverse set of organisms across six phyla and incorporating the full range of life-history types found in sessile marine invertebrates. The documentation and analysis of patterns of seasonality, tidal effects, and inter-annual fluctuations we will provide will contribute significantly to our understanding of the population and community ecology of benthic species. Long-term data sets play an important role in identifying natural variability in populations and in identifying factors that regulate community composition. By clarifying the mechanisms behind community organization, we are better prepared to understand the success and persistence of members of marine communities and, most notably, non-indigenous species in these systems.

References

Barry, J.P., C.H. Baxter, R.D. Sagarin, S.E. Gilman. 1995. Climate-related, long-term faunal changes in a California rocky intertidal community. *Science* **267**:672-675.

Carlton, J.T. 1989. Man's role in changing the face of the ocean: biological invasions and implications for conservation of near-shore environments. *Conserv. Biol.* **3**:265-273.

Connell, J.H. 1961. Effects of competition, predation by *Thais lapillu*, and other factors on natural populations of the barnacle *Balanus balanoides*. *Ecol. Monogr.* **31**:61-104.

Gaines, S.D., J. Roughgarden. 1985. Larval settlement rate: a leading determinant of structure in an ecological community of the marine intertidal zone. *Proc. Nat. Acad. Sci.* **82**:3707-3711.

Grosberg, R.K. 1982. Intertidal zonation of barnacles: the influence of planktonic larvae on vertical distribution of adults. *Ecology* **63**:894-899.

Niermann-Kerkenberg, E., D.K. Hoffman. 1989. Fertilization and normal development in *Ascidiella aspersa* (Tunicata) studied with Nomarski-optics. *Helgolander Meeresuntersuchungen* **43**:245-258.

Osman, R.W., R.B. Whitlatch. 1995. Ecological factors controlling the successful invasion of three species of ascidians into subtidal habitats of New England. In: Balcom (ed.), *Proceedings of the Northeast Conference on Non-Indigenous Aquatic Nuisance Species*. Connecticut Sea Grant College Program. *Publication # CT-SG-95-04.*

Osman, R.W., R.B. Whitlatch. 1998. Local control of recruitment in an epifaunal community and the consequences to colonization processes. *Hydrobiologia* **375/376**:113-123.

Paine, R. T. 1966. Food web complexity and species diversity. *American Naturalist* **100**:65-75.

Sagarin, R.D., J.P. Barry, S.E. Gilman, C.H. Baxter. 1999. Climate-related changes in an intertidal community over short and long time scales. *Ecol. Monogr.* **69**:465-490.

Thorson, G. 1950. Reproductive and larval ecology of marine bottom invertebrates. *Biol. Rev.* **35**:1-45.

Williamson, M. 1996. *Biological Invasions*. Chapman and Hall, London, UK.

Worcester, S.E. 1994. Adult rafting versus larval swimming: dispersal and recruitment of a botryllid ascidian on eelgrass. *Mar. Biol.* **121**:309-317.

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NON-POINT POLLUTION

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Mercury in Sediments from Long Island Sound

J.C. Varekamp
Wesleyan University, Earth and Environmental Sciences
Middletown, CT 06459

M. R. Buchholtz ten Brink and E. L. Mecray
U.S. Geological Survey
Woods Hole, MA 02543

About 400 surface and core sediment samples from a sampling grid in Long Island Sound (LIS) were analyzed for mercury, *Clostridium perfringens* (a sewage tracer) and many other chemical and physical parameters. The Hg concentrations in surface sediments vary between 30 and 650 ppb, with the highest values in the western end of LIS. A trend of increasing Hg to the west correlates with increasing abundances of fine-grained sediment and C-org; normalization of the Hg data to mean grain size or C-org content leaves a weaker east-west trend. The linear relationship between *C. perfringens* and Hg in sediments from the New York Bight, where sewage disposal is a well-defined source, was used to estimate the contribution of waste water treatment plants to Hg in LIS sediments. Many LIS surface samples have between 10–40% sewage-derived Hg, with values up to 80% in westernmost LIS. The remaining Hg is largely imported from the surrounding watersheds with fine-grained sediments, and hence is a focused flux of the integrated regional atmospheric Hg deposition. The direct atmospheric deposition of Hg onto LIS is only a small part of the overall LIS Hg sediment budget. Sediment cores have contamination profiles with background Hg values of 50 ppb, peak values for cores in depositional environments in the 200-500 ppb range and highest value the reach 1200 ppb Hg at the mouth of the Housatonic River. The onset of Hg contamination at depth in the cores coincides with the first elevated *C. perfringens* levels, indicating an anthropogenic origin for the Hg contamination. The *C. perfringens* concentrations increase exponentially towards the present, or core surface, whereas many cores show a decline in Hg concentrations in the upper 10-15 cm.

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Mercury Methylation in Sediment of Long Island Sound

C.R. Hammerschmidt, C.-M. Tseng, P.H. Balcom, C.H. Lamborg, P.T. Visscher, W.F. Fitzgerald
Department of Marine Sciences
University of Connecticut
Groton, CT 06340

Toxicologically, methylation is the most important transformation of mercury (Hg) in the environment. Monomethylmercury (MMHg) is a highly toxic form of Hg that bioaccumulates in organisms and biomagnifies in food webs. Based on mass balance estimates (Langer *et al.*, in press), we hypothesize that *in situ* methylation is the main source of MMHg in Long Island Sound (LIS), that most MMHg is produced microbially in sediment, and that external sources (e.g., rivers, wastewater treatment facilities, atmospheric deposition) contribute only a minor fraction. We estimate that as much as 12 ± 6 kg y^{-1} of MMHg is synthesized through the microbial methylation of labile reactive Hg species in shallow sedimentary regions (redox transition zones) of LIS. Sulfate-reducing bacteria seem to be the principal Hg-methylating organisms and sulfide, a byproduct of their metabolism, influences availability of Hg for methylation. Given the toxicological significance of MMHg in coastal food webs and the uncertainty of our production estimate, elucidation of *in situ* Hg methylation in LIS is needed.

We examined MMHg in sediments of LIS in November 1999. A gradient in sediment type exists longitudinally in LIS, ranging from fine-grain, organic-rich substrate in western LIS (WLIS) to large grain size (sandy), lower organic material in the eastern Sound (ELIS). We collected surface sediment (top 8 cm) from three representative locations along the sediment-type continuum, determined concentrations of total Hg and MMHg, and evaluated the influence of selected sediment characteristics on Hg levels. From east to west in LIS sediment, dry-weight concentrations of both total Hg and MMHg increased and were related positively with organic matter. Microbial activity and microbial methylation/demethylation potentials were examined in surface sediment from WLIS and ELIS. Microbial activity (measured as net oxygen consumption) was slightly greater in sediments from WLIS than ELIS, as expected from the higher organic content of WLIS sediment. Methylation and demethylation potentials of bacteria were estimated by measuring the rate of ethanethiol (CH_3CH_2SH) methylation and the rate of demethylation of ethylmethylsulfide ($CH_3CH_2SCH_3$). Rates of both reactions were comparatively higher in sediments from WLIS. Also, a larger difference between rates of methylation and demethy-lation was measured for WLIS sediments, indicating a greater potential for accumulation of a methylated species in WLIS.

In contrast to concentrations of total Hg and MMHg, the percentage of total Hg as MMHg in surface sediments decreased from east to west in LIS. The percentage of total Hg as MMHg was 1.8 in ELIS and 0.6 in WLIS, indicating greater net methylation of Hg in sandy as compared to organic-rich, silty sediment; a result not predicted by our methylation/demethylation potential study. We suggest that sulfide inhibits the bioavailability of Hg for methylation in WLIS sediments. Sulfide affects the speciation of inorganic Hg in sediments by forming dissolved Hg-sulfide complexes, including HgS^0, HgS_2^{2-}, and $HgHS_2^-$ (Benoit *et al.*, 1999*a*). HgS^0 is a major dissolved Hg-sulfide complex when sulfide concentrations are low, and charged complexes, mainly $HgHS_2^-$, are dominant at higher sulfide levels. The mechanism for uptake of inorganic Hg by methylating bacteria is not known presently, but may be diffusion of neutrally charged HgS^0 through the cell membrane (Benoit *et al.*, 1999*b*). Consequently, maximum rates of Hg methylation in sediment occur where sulfide levels are low, favoring speciation of Hg-sulfide complexes as HgS^0, and facilitating uptake of inorganic Hg by methylating bacteria. Although it was not measured in this preliminary work, concentrations of dissolved sulfide are presumably lower in ELIS sediment (lower organic content) as a result of lower rates of microbial sulfate-reduction. We measured acid-volatile sulfide as a proxy for porewater sulfide and found that levels were about 100-fold lower in ELIS sediments than those in WLIS, thus favoring methylation of inorganic Hg to MMHg.

Future work will include (1) determining rates of Hg methylation and MMHg demethylation in sediment cores using stable and radioactive Hg isotopes, (2) measuring dissolved sulfide in sediment porewater, (3) examining relationships between microbial activity, Hg methylation, and Hg-sulfide speciation in sediment, and (4) refining current estimates of sedimentary MMHg production in LIS.

References

Benoit, J. M.; Gilmour, C. C.; Mason, R. P.; Heyes, A. 1999*a*. Sulfide controls on mercury speciation and bioavailability to methylating bacteria in sediment pore waters. *Environ. Sci. Technol.* **33**:951-957.

Benoit, J. M.; Mason, R. P.; Gilmour, C. C. 1999*b*. Estimation of mercury-sulfide speciation in sediment pore waters using octanol-water partitioning and implications for availability to methylating bacteria. *Environ. Toxicol. Chem.* **18**:2138-2141.

Langer, C. S.; Fitzgerald, W. F.; Visscher, P. T.; Vandal, G. M. *In press*. Biogeochemical cycling of methylmercury in two Connecticut salt marshes. *Wetlands Ecology & Management.*

Methyl Bromide Degradation by Marine Bacteria Isolated from Long Island Sound

Pieter T. Visscher, Daniel R. Rogers, and Shelley E. Hoeft*
Dept. Marine Science, University of Connecticut, Groton, CT 06340
* current address: USGS, WRD, Menlo Park, CA 94025

Abstract

Methyl bromide (MeBr) is responsible for 10-15% of the global O_3 depletion. Coastal waters are generally believed to be a source of MeBr, where it is produced by kelp and some marine phytoplankters. The MeBr concentrations was determined at five stations in Eastern Long Island Sound (LIS), and in four cases found to be up to four orders of magnitude higher than has been reported for offshore waters. We isolated and characterized four strains of marine methylotrophic bacteria that consumed MeBr and/or dimethyl sulfide (DMS) from LIS. In all strains, MeBr consumption only occurred in the presence of another carbon source. Three of the isolates used MeBr at rates that were higher than chemical loss, and one of these, isolated from coastal LIS, could use this for biomass production. The presence of DMS greatly enhanced MeBr consumption. Inhibitor studies showed that DMS and MeBr were used by the same metabolic pathway in two LIS isolates. Two additional LIS strains isolated on DMS did not use MeBr. Therefore, MeBr utilization is not a common trait of DMS-degrading bacteria. This study indicates that growth on MeBr alone is unlikely to support bacterial growth and that removal of MeBr may be a cometabolic phenomenon. However, regardless of growth, consumption by marine bacteria may limit the flux of MeBr to the atmosphere.

Introduction

During the past decade, the potential role of methyl bromide (MeBr) in the catalytic destruction of ozone has received the attention of the scientific community as well as from policy makers (UNEP, 1992; MBAO 2000). MeBr is a highly soluble gas ($K_H = 6.3\ 10^{-3}$ bar m^3 mol^{-1}; b.p. 4°C; solubility 17 g l^{-1} at 20°C) of both natural and anthropogenic origin and comprises a minor constituent of the atmosphere at a volume mixing ratio of 10 parts per trillion (Butler and Rodriguez 1996). Although this concentration is approximately 400 times lower than that of stratospheric chlorine, the O^{3-}depletion potential of bromine and chlorine are similar since Br is cyclic and 40-100 times more effective in destruction of O^3 than Cl. The O^{3-}depleting potential (ODP) is uncertain for various reasons, including a lack of accurate estimates of the oceanic lifetime of MeBr (Butler 1995). Chemical hydrolysis is well defined; however, microbial consumption of MeBr in the marine water column may also affect the oceanic lifetime. Biological consumption of MeBr in the marine environment has been found, but the organisms responsible have not been identified.

The goal of our study was to investigate microbial processes that are capable of MeBr consumption both at higher rates than chemical destruction as well as at low MeBr (pM-nM) concentrations. We expect that bacteria that are capable to degrade MeBr do so via metabolic routes that are used for other methylated substrates (e.g., dimethyl sulfide [DMS], trimethyl amine [TMA]).

Materials and Methods

Water samples were collected in acid-washed glass bottles and processed in the laboratory within two hours. Gases were stripped from liquid samples by bubbling with He and concentration on a cryogenic Teflon® loop. Alternatively, headspace samples were collected directly from sample bottles. MeBr concentration was determined on a gas chromatograph (GC) with electron capture detection and sulfur gases were measured on a GC equipped with a flame photometric detector. Detection limits were 0.5 nM for both MeBr and DMS.

Microbial cultures were obtained using standard methods (Hines *et al.* 1997), either directly or after serial dilution (see Hoeft *et al.,* 2000 for details). MeBr production by *Fucus* spp. was carried out with freshly collected material incubated in stoppered 500-ml Erlenmeyer flasks in the light. Turnover studies were done in glass serum bottles capped with Teflon-lined septa. All experiments were repeated at least three times.

Results and Discussion

The MeBr concentration in Eastern LIS water samples ranged from <0.5 nM in Fisher Island Sound to >200 nM in rocky intertidal areas where *Fucus* spp. thrived (Table 1). The high end of this range is 4 orders of magnitude higher than typical oceanic concentrations (Butler 1995, Baker *et al.* 1999), but not unlike values for other brominated halogens reported for kelp and red seaweeds (Collen *et al.* 1994; Nightingale *et al.* 1995).

Table 1. Concentration of methyl bromide (MeBr) and dimethyl sulfide (DMS) at four stations in Eastern Long Island Sound. Mean of 3-5 observations and in parentheses standard deviation are provided. Data were collected between January 1994 and December 1995. Values for Thames River Estuary represent range determined during 1-yr survey (see Tang *et al.* 2000).

Site Location	[MeBr]	[DMS]
	(nM)	
Fucus spp. canopy (Avery Point)	34-23	1250 (430)
Thames River Estuary	0-3	1-52
LIS (41°15'N, 72°10'W)	9 (7)	115 (27)
LIS (41°13'N, 72°13'W)	1 (1)	nd**
Fishers Island Sound	bdl*	139 (35)

*below detection limit (0.5 nM)
**not determined

We further investigated the production of MeBr by *Fucus* spp. and found a linear increase of the MeBr concentration over a 25-hr period when incubated in filtered and autoclaved LIS water (Figure 1). When the experiment was repeated with seawater that contained live microbes, the MeBr concentration initially increased, but then decreased due to consumption by the native bacterial population.

We then managed to isolate and pure culture several strains of methylotrophic bacteria. Enrichments on MeBr alone were unsuccessful and in any experiment, MeBr concentrations >500 nM were toxic. All strains isolated used a variety of methylated substrates, including methyl amines, methanol, and methyl sulfides, but none used methane. Strain FV, isolated from a Fucus canopy, metabolized MeBr when this was present as the only carbon source. However, no growth occurred and consumption ceased before all MeBr was used. Upon resuspension of strain FV cells in fresh medium,

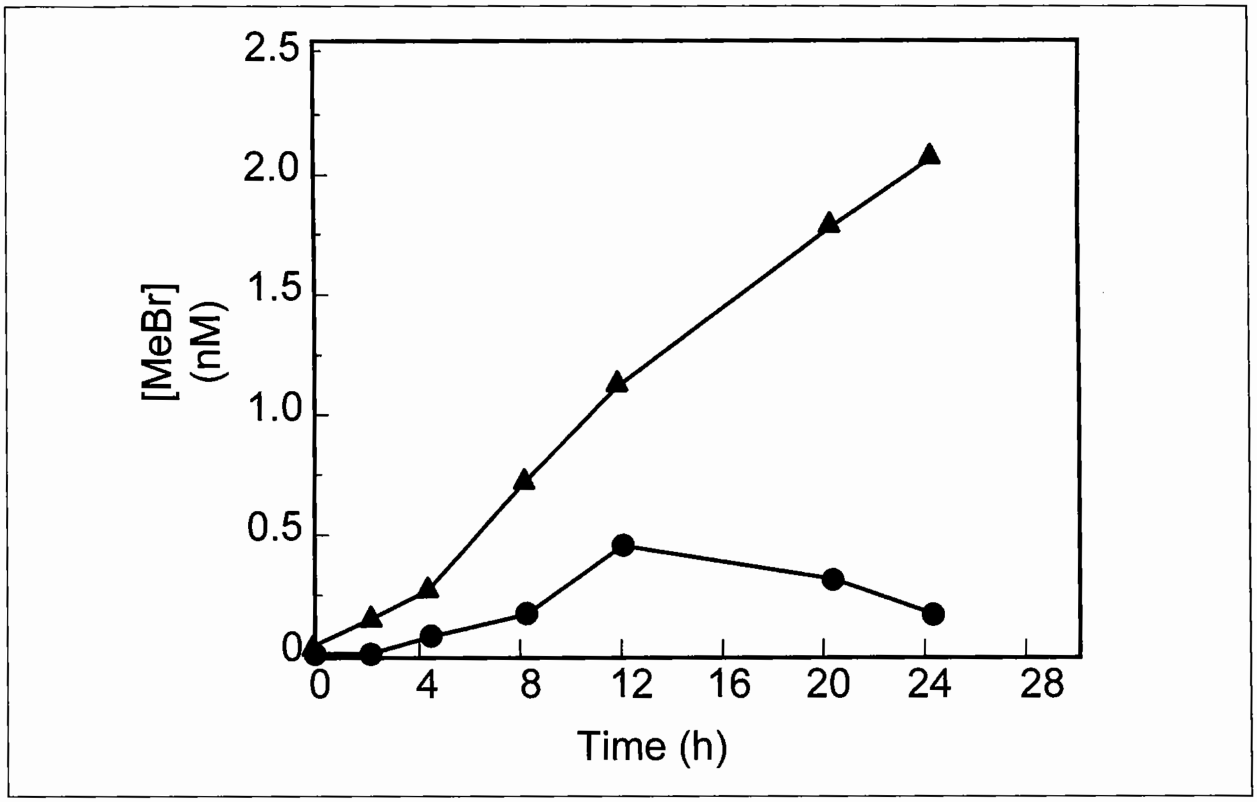

Figure 1. MeBr production in *Fucus* sp. thallus material collected at Avery Point. MeBr concentration is normalized to g wet weight. Incubations were carried out with 3 individuals (8.9 ± 1.2 g wet weight each) in 500 ml of LIS water.

the MeBr consumption resumed, which suggests production of a toxic metabolic product. Another strain, LIS-3, used MeBr for biomass production, but only if there was another carbon source present consecutively. The presence of DMS increased MeBr consumption 4 and 2.5 times in strain FV and LIS-3, respectively. TMA and DMS are common substrates in the marine environment, where they are derived from osmolytes such as glycine betaine and dimethylsulfoniopropionate (DMSP) (King 1983, Kiene 1993). Tang *et al.* (2000) reported the availability of DMSP and production of DMS in LIS. Concentrations of DMS are typically 2-3 orders of magnitude higher (Table 1), and so it seems plausible that marine microbes use this as a primary substrate while consuming other compounds such as MeBr that are present in much lower concentrations as secondary substrates (cf. Goodwin *et al.* 1998). Such co-metabolic phenomenon was first reported for a tropical coastal isolate BIS-6 (Visscher *et al.* 1996). However, not all organisms are capable of MeBr consumption in this way as is demonstrated by several of the isolates on DMS obtained in our study that did not consume MeBr under any condition tested.

Conclusions and Implication for Long Island Sound

The potential MeBr production rate in the *Fucus* canopy was 0.1-0.5 nmol l^{-1} h^{-1}, assuming 3-6 *Fucus* plants l^{-1} and relatively stagnant conditions. The maximum MeBr consumption rate of strain FV was 2.4 and 9.8 amol MeBr h^{-1} $cell^{-1}$ on MeBr alone and MeBr plus DMS, respectively. Strain FV was obtained from a 10^6 dilution of 1 ml of seawater, and so the estimated natural population size of 10^9 cells l^{-1} could consume 2.4-9.8 nmol l^{-1} h^{-1}. As a result, the loss of MeBr to the atmosphere and surrounding waters is likely to be limited. Based on studies in the Gulf of Maine (Sœmundsdóttir and Matrai 1998), the North Sea (Baker *et al.* 1999) and our own observation, the MeBr production rate in LIS is expected to range from 1-30 pmol l^{-1} h^{-1}. The MeBr consumption of strain LIS-3 was 1.8 and 4.0 amol MeBr h^{-1} $cell^{-1}$ on MeBr alone and MeBr plus DMS, respectively. If this strain, or similar organisms, comprise 0.1-1% of the total microbial population in LIS, a potential of 18-40 pmol MeBr l^{-1} h^{-1} can be calculated. This sink also exceeds the source and so there may be a potential for MeBr uptake from the atmosphere in LIS waters (Figure 2).

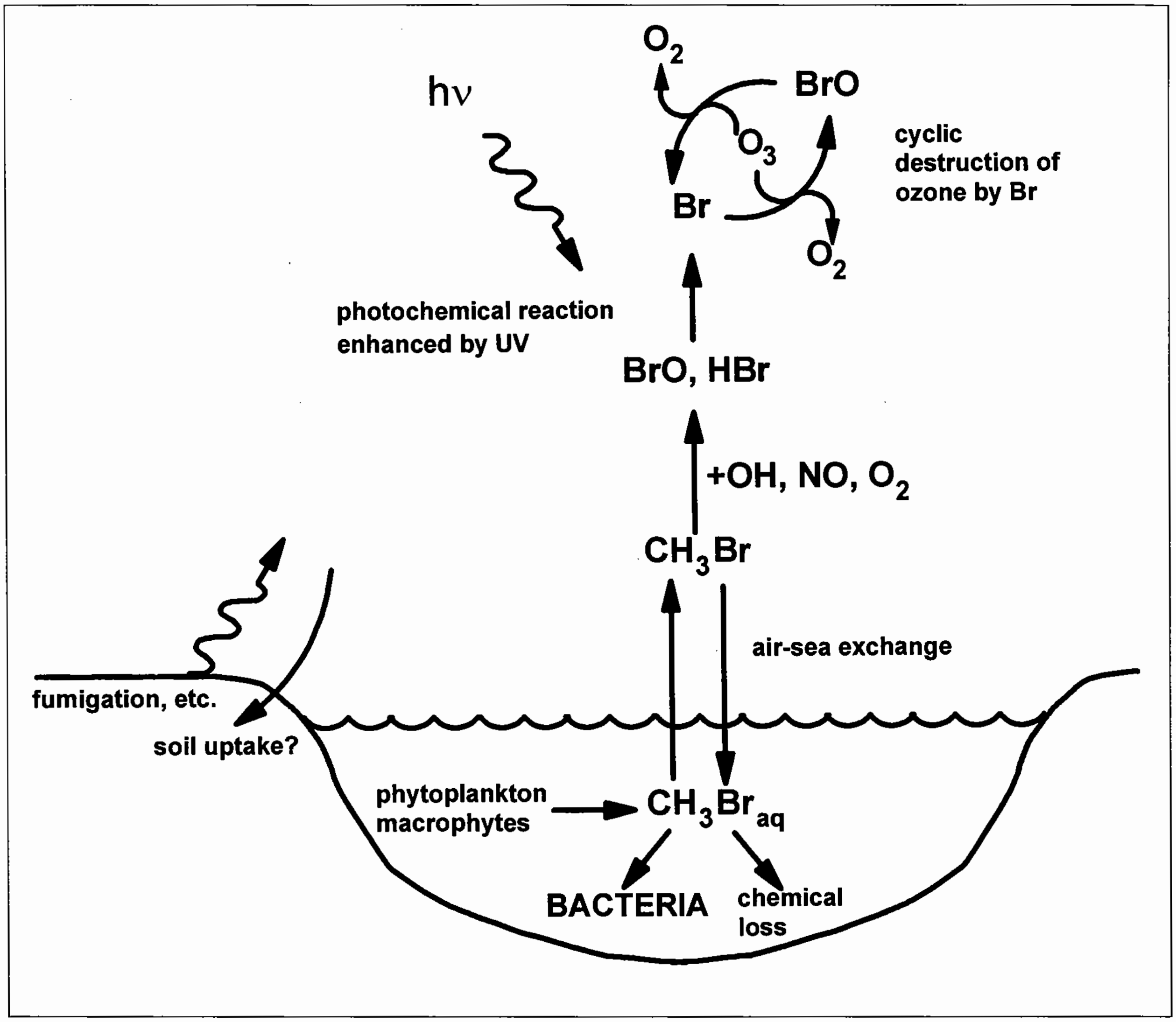

Figure 2. Conceptual model of MeBr production and consumption as it may take place in coastal waters such as LIS. The bacterial population in LIS water is capable to consume MeBr at a higher rate than phytoplankton blooms of species that are known to produce MeBr release it.

We conclude that MeBr-degrading methylotrophic bacteria are readily isolated from LIS. In our study, MeBr alone does not support biomass production, but is degraded at rates higher than chemical destruction. Consumption rates of MeBr, especially those measured in the presence of DMS, seem high enough to prevent significant loss of MeBr to the atmosphere from macroalgal canopies. Similarly, the open waters of LIS may act as a sink for MeBr and despite higher concentrations of MeBr in LIS compared to offshore waters, the expected higher microbial activities in estuaries such as LIS may imply that coastal waters can be important sinks in the global MeBr budget.

Acknowledgments

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References

Baker, J.M., C.E. Reeves, P.D. Nightingale, S.A. Penkett, S.W. Gibb, A.D. Hatton (1999) Biological production of methyl bromide in the coastal waters of the North Sea and open ocean of the north-east Atlantic. *Mar. Chem.* **64**:267-285.

Butler, J.H. (1995) Methyl bromide under scrutiny. *Nature* **376**:469-470.

Butler, J.H. and J.M. Rodriguez (1996) Methyl bromide in the atmosphere, p. 28-90. In C.H. Bell, N. Price, and B. Chakrebarti (ed.), *The Methyl Bromide Issue.* John Wiley, in Mono Lake, California. *Environ. Sci. Technol.* **31**:1489-1495.

Collén, J., A. Ekdahl, K. Abrahamsson, and M. Pedersen (1994) The involvement of hydrogen peroxide in the production of volatile halogenated compounds by *Meristiella gelidium. Phytochem.* **36**:1197-1202.

EPA (2000) URL: <http://www.epa.gov/docs/ozone/mbr/mbrpro00.html>

Goodwin, K.D., J.K. Schaeffer, and R.S. Oremland (1998) Bacterial oxidation of dibromomethane and methyl bromide in natural waters and enrichment cultures. *Appl. Environ. Microbiol.* **64**:4629-4636.

Hines, M.E., P.T. Visscher, and R. Devereux (1997) Sulfur Cycling. In: *Manual of Environmental Microbiology. Aquatic Environments.* Hurst, C.J., G.R. Knudsen, M.J. McInerney, L.D. Stetzenbach, M.V. Walter (eds). Am. Soc. for Microbiology, Washington DC, pp. 324-334.

Hoeft, S.E., D.R. Rogers, and P.T. Visscher (2000) Methyl bromide degradation in marine bacteria. *Aquat. Microb. Ecol.* **21**:221-230.

Kiene, R.P. (1993) Microbial sources and sinks for methylated sulfur compounds in the marine environment, p. 15-33. In J.C. Murrell, D.P. Kelly (ed.), *Microbial growth on C1 compounds.* Intercept, Ltd, Andover (UK).

King, G.M. (1983) Metabolism of trimethylamine, choline, and glycine betaine by sulfate-reducing and methanogenic bacteria in marine sediments. *Appl. Environ. Microbiol.* **48**: 719-725.

Methyl Bromide Alternatives Outreach (MBAO) in cooperation with Crop Protection Coalition, US EPA and USDA (2000) Ann. Internat. Res. Conf. on Methyl Bromide Alternatives and Emissions Reduction, URL: <http://www.epa.gov/docs/ozone/mbr/mbrpro00.html>

Nightingale, P.D. G. Malin, and P. Liss (1995) Production of chloroform and other low molecular weight halocarbons by some species of macroalgae. *Limnol. Oceanogr.* **40**:680-689.

Sœmundsdóttir, S. and P.A. Matrai (1998) Biological production of methyl bromide by cultures of marine phytoplankton. *Limnol. Oceanogr.* **43**:81-87.

Tang K.W., D.R. Rogers, H.G. Dam, and P.T. Visscher (2000) Seasonal distribution of DMSP among seston, dissolved matter and zooplankton along a transect in the estuary Long Island Sound. *Mar. Ecol. Prog. Ser.* **206**:1-11.

United Nations Environment Programme (UNEP) (1992) Report of the fourth meeting of the parties to the Montreal Protocol on substances that deplete the ozone layer, at Copenhagen: UNEP.

Visscher, P.T., J.R. Guidetti, S.E. Hoeft, and R.S. Oremland (1996) Co-metabolic methylbromide degradation by a marine methylotroph, strain BIS-6. Abstracts Am. Soc. Microbiol. 96th Annual Meeting, New Orleans LA, p. 327.

Atmospheric Deposition of Nitrogen along the Connecticut Coastline of Long Island Sound: a Decade of Measurements

Michael Trahiotis[1], Xiusheng Yang[2*], Christopher Perkins[1], Farhad Nadim[1], and Robert Carley[1]

[1] Environmental Research Institute
[2] Department of Natural Resources Management and Engineering
University of Connecticut
Storrs, CT 06269

Abstract

Monitoring stations were established to study the atmospheric deposition of nitrogen into the Long Island Sound (LIS). Two stations at Hammonasset and Sherwood Island were set up in 1991, and two additional ones were in full operation in 1997 at Avery Point and Old Greenwich. Nitrogen species including NO_x, NH_4^+, and total nitrogen in air and rainwater samples collected with filterpacks and wet deposition collectors were analyzed in laboratory and used to infer atmospheric concentrations and dry and wet deposition flux densities, with independently collected meteorological data. Statistical procedures were employed to analyze the spatial and temporal variations of the weekly measurements and quarterly means from the beginning of measurements to the end of 1999. Results indicated that there was a significant reduction in atmospheric concentrations of most nitrogen species during the past decade. The deposition fluxes were also shown to decease with time. However, significant variations were found among sites, species, years, and seasons. The study also revealed a significant gradient of deposition quantities that decreased with distance from the sprawl of New York City.

Introduction

Long Island Sound (LIS) is an estuary located in the northeastern region of the United States bounded by Long Island, New York, to the south, Connecticut and Rhode Island to the north, the Block Island Sound (BIS) and the Atlantic Ocean to the east. It is approximately 176 kilometers long (east to west) and about 34 kilometers across at its widest point. The average water depth in LIS is about 19 meters and it has a volume of 49 million cubic meters (CTDEP 2000b). More than 15 million people live within 80 kilometers of LIS shores. The United States under EPA's National Estuary Program has designated LIS as one of the 17 major estuarine systems of the country to be protected (Hu *et al.* 1998).

* *Corresponding author: Xiusheng Yang, Associate Professor, Department of Natural Resources Management and Engineering, University of Connecticut, 1376 Storrs Road, U-4087, Storrs, CT, 06269, USA. Phone: (860) 486-0135, Fax: (860) 486-5408, Email: xiusheng.yang@uconn.edu.*

Excessive loading of nutrients, especially nitrogen, is one of the major contributors to the hypoxia problems that LIS has been experiencing. Excessive nitrogen fuels the growth of phytoplankton, a kind of microscopic plants, in the Sound. When the plants die, their residuals sink to the bottom and decay, consuming dissolved oxygen in the process. During late summer more than half of the bottom water in LIS becomes hypoxic due to thermal stratification. The oxygen level regularly runs below 1 ppm in areas where it is expected to exceed 5 ppm in normal conditions (CTDEP, 2000a), and is well below the 3.5 ppm oxygen level required to sustain most aquatic life in the Sound.

The LIS gets nitrogen from various sources, among them atmospheric deposition is a significant one statistically as well as physically, chemically, and biologically. Atmospheric nitrogen originating from anthropogenic sources is estimated to cause more than 15% of the dissolved oxygen deficit observed in the Sound and recent studies have clearly shown that it is essential to effectively manage the atmospheric sources of nitrogen if water quality objectives are to be achieved and maintained in the Sound (Carley and Perkins, 2001).

A national network was established to monitor the atmospheric deposition of pollutants under the supervision of the U.S. Environmental Protection Agency. However, no Connecticut site was included in this network. To study the atmospheric deposition of nitrogen into LIS, two monitoring stations were established along the Connecticut shore of LIS since 1991. In 1996, two more stations were set up as an effort to quantify the ambient air quality in the State of Connecticut. This manuscript reports the data collected by these monitoring stations from January 1991 through December 1999, excluding the period of 1995-1996 when the stations were not in full operation.

Materials and Methods

Sites and periods

The locations of the monitoring stations are shown in Figure 1. There were eight monitoring stations in total, selected to represent the spatial distribution of air quality in the State of Connecticut.

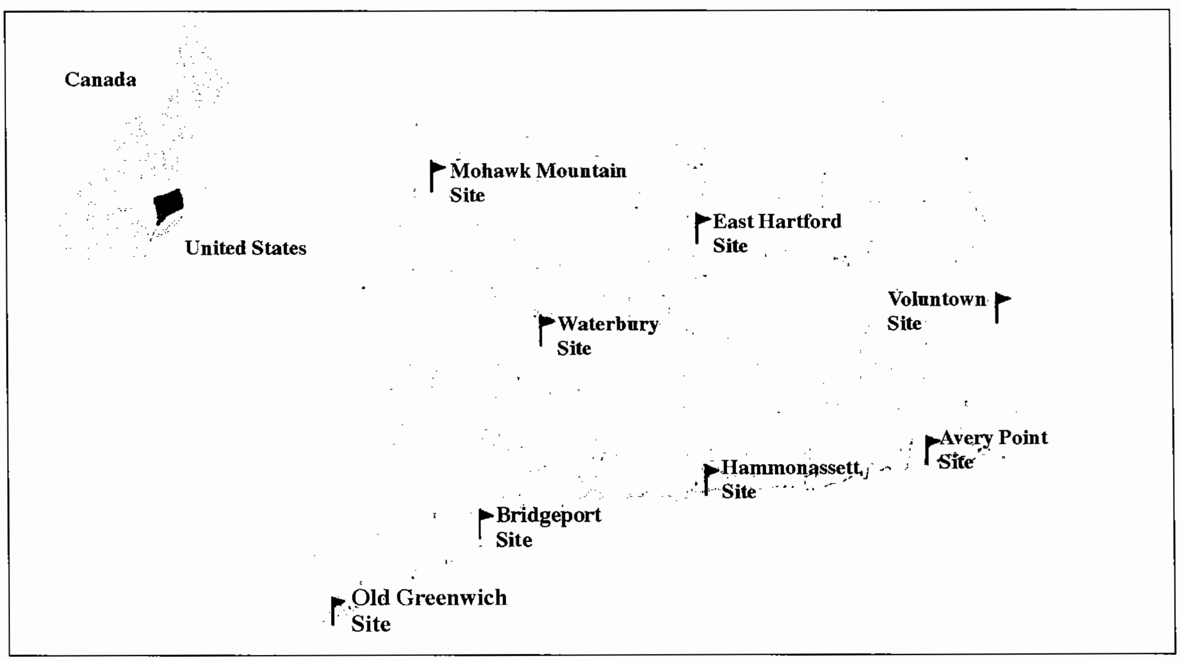

Figure 1. Nitrogen monitoring sites in Connecticut. The site "Bridgeport" is located in the Sherwood Island State Park, and is referred to in the text as "Sherwood Island". Reported were data collected in the four coastal sites, of which Hammonasset and Sherwood Island were run from 1991, while Avery Point and Old Greenwich were in full operation since 1997.

Along the LIS shore, four stations were established, located in Old Greenwich and Sherwood Island in Fairfield county, Hammonasset in New Haven county, and Avery Point in New London county, respectively. Among the four onshore stations, the two in Sherwood Island and Hammonasset were in operation since 1991, while the other two were employed since 1997. For all four stations, data for the period of 1995 through 1996 were excluded, when the network was not in full operation. In total, there were 366 weeks of usable data for Sherwood Island and Hammonasset, and 157 weeks for Old Greenwich and Avery Point. Detailed description of the sites is available in the Environmental Research Institute (ERI), University of Connecticut.

Data collection

Each monitoring station was equipped with an assembly of filterpacks to collect air samples to infer the concentrations of total nitrogen (N_T), ammonium (NH_4^+), and nitrite/nitrate (NO_x) in the lower atmosphere. While NO_3^- captured by nylon filters was attributed to nitric acid gas (HNO_3), the difference between total nitrogen and the sum of NO_x and NH_4^+ collected on teflon filters was regarded as organic nitrogen (N_{ORG}). Organic nitrogen was not measured in the period of 1991 through 1994. Each monitoring station was also outfitted an automated wet deposition collector. Precipitation samples were collected to analyze for NO_x, NH_4^+ and N_T. Weekly air and precipitation samples were collected, analyzed, and reported as mass of nitrogen in each species, by ERI, University of Connecticut. Details of the sampling procedures, laboratory analysis, and quality assurance were given in Carley and Perkins (2001).

In each monitoring station, an automated weather station was in operation to collect meteorological data, including solar radiation, precipitation, temperature, humidity, and wind speed and direction. The meteorological data was collected by University of Connecticut up to the end of 1994, and by Connecticut Department of Environmental Protection after then.

Data processing

Air concentration and dry deposition

Weekly mean atmospheric concentrations (C_a, mg/m^3) of particulate NO_x, NH_4^+, N_{ORG}, and HNO_3, were calculated from the weekly mass of each species in the air samples divided by the total volume of air flow through the filterpacks during the sampling period. The dry deposition flux density for each species (F_d, mg/m^2.week) was estimated by, with proper units conversion,

$$F_d = C_a V_d \tag{1}$$

where V_d is the corresponding weekly mean dry deposition velocity in cm/s. The weekly mean dry deposition velocity was a simple average of the hourly dry deposition velocity calculated from the meteorological parameters, using the dry deposition inference model (DDIM) adopted by the National Dry Deposition Network. Details of the DDIM can be found in Hicks *et al.* (1987), Clarke and Edgerton (1992), and Yang *et al.* (1996).

Wet deposition

Wet deposition flux density (F_w, mg/m^2.week) was calculated by

$$F_w = PC_w \tag{2}$$

with appropriate units conversion, where P is the weekly precipitation (mm/week), and C_w is the corresponding mass concentration of the precipitation samples, reported in mg/liter.

Data analysis

Weekly concentration and deposition fluxes at the onshore sites were the major variables to analyze the temporal trends of air quality and nitrogen loading to LIS. Descriptive statistics were calculated for each species, total particulate matter, and ratio of wet to dry deposition. To examine the spatial and temporal variations, data were processed to quarterly values for analysis. Each year, four quarters were defined approximately according to astronomical conventions, each consisting 13 weeks. Spatial variations were examined for the quarterly means of 1997 through 1999 using analysis of variance (ANOVA), with site and season as factors, year as a replicate measure. The temporal changes were also analyzed with ANOVA, using year and species as factors, site as a replicate measure, for the total seven years summer data collected at the two nearby stations Sherwood Island and Hammonasset. All the statistical analyses were done with MINITAB (MINITAB, 2000).

Results and Discussion

Spatial variation

There were significant differences ($p<0.001$) in atmospheric concentrations and flux densities among sites, components (particle versus gas, dry versus wet), years, and seasons. The mean flux of total nitrogen was 37.7, 31.5, 23.4, and 21.6 mg/m^2.week for Old Greenwich, Sherwood Island, Hammonasset, and Avery Point, respectively, exhibiting a gradient decreasing from the sprawl of New York City. Table 1 lists the descriptive statistics of the pertinent deposition fluxes at the four stations during the period of 1997-1999. Old Greenwich stood out in wet deposition flux, almost three times of the other three stations. On the other hand, the dry deposition flux was lower for Old Greenwich, indicating a very strong scavenging effect. The ratio of wet to total deposition is 0.77, 0.56, 0.74, and 0.70 for Old Greenwich, Sherwood Island, Hammonasset, and Avery Point, respectively. The ANOVA results also showed a significant interaction ($p<0.001$) between site and component, indicating that the relative magnitude of the concentration measurements between particles and gases, as well as that of the flux quantities between dry and wet deposition, was site-dependent.

For dry deposition, it was interesting to find out that the relative magnitude of gaseous to particulate component also varied with the quartile statistic, being 0.17, 0.33, and 0.50 for the first, second, and third quartile, respectively. This association of more gaseous deposition with heavier nitrogen loadings indicated that future air quality control should pay more attentions chemicals than aerosols in the region.

Historical trend

The quarterly means of the weekly air concentration, wet, dry, and total deposition flux densities for the Sherwood Island station during the period of 1991 through 1999 are shown in Figure 2. The ANOVA results indicated that the temporal variation in atmospheric concentrations of the nitrogen species was statistically significant ($p<0.001$). It was evident that the atmospheric concentrations of all the nitrogen species were lower in the last three years of measurements (1997-1999) than those in the first half of the decade (Figure 2a). Except for NH_4^+, of which the concentration was largely unchanged, the other species at the Sherwood Island station all exhibited a significant reduction in concentration. For example, the mean weekly concentrations of NO_x and HNO_3 in the period of 1997-1999 decreased by 45 and 78%, respectively, compared to those over the first four years of measurements (1991-1994). Overall, the deposition flux densities were also lower in the second than the first period of measurements. However, significant variation existed between years, seasons, species, and sites (Figures 2b-2d). Further analyses are being conducted to quantify the variations.

Table 1. Descriptive statistics of the nitrogen deposition data collected along the Connecticut shore of Long Island Sound during 1997-1999.

Statistics of weekly data

Site	Flux	Q1[1] (mg/m^2.wk)	Q2	Q3	*A*	*s*	Annual loading (kg/ha.year)
Avery Point	Dry, gaseous[2]	0.62	1.53	3.21	2.29	2.32	1.19
	Dry, particulate	2.41	3.73	4.60	4.22	2.68	2.19
	Total Dry	3.03	5.26	7.81	6.51	5.00	3.39
	Total Wet	4.31	11.05	21.32	15.12	15.53	7.86
	Total	7.34	16.31	29.13	21.64	20.53	11.25
Hammonasset	Dry, gaseous	0.44	1.23	2.60	1.90	1.88	0.99
	Dry, particulate	2.07	3.07	4.91	4.10	3.32	2.13
	Total Dry	2.51	4.30	7.51	6.01	5.20	3.12
	Total Wet	6.95	11.54	25.69	17.46	16.09	9.08
	Total	9.49	15.84	33.20	23.46	21.29	12.20
Sherwood Island	Dry, gaseous	0.54	2.00	4.68	3.48	3.76	1.81
	Dry, particulate	6.85	9.55	13.67	10.48	5.52	5.45
	Total Dry	7.39	11.55	18.35	13.96	9.29	7.26
	Total Wet	5.64	13.81	25.52	17.60	16.07	9.15
	Total	13.03	25.35	43.87	31.56	25.36	16.41
Old Greenwich	Dry, gaseous	0.56	1.57	3.30	2.51	2.60	1.31
	Dry, particulate	3.94	5.41	7.34	6.34	3.99	3.30
	Total Dry	4.49	6.98	10.63	8.85	6.59	4.60
	Total Wet	3.40	12.10	34.28	28.86	45.75	15.01
	Total	7.90	19.08	44.92	37.71	52.34	19.61

1. Q1=first quartile, Q2=medium, Q3=third quartile, *A*=average, and *s*=standard error of mean.

2. Dry (gaseous and particulate) and wet deposition fluxes were statistics of the weekly data. Total dry was the sum of the dry deposition fluxes of gases and particles. Total nitrogen flux was the sum of the total dry and total wet fluxes. Annual loading was a simple conversion from the mean.

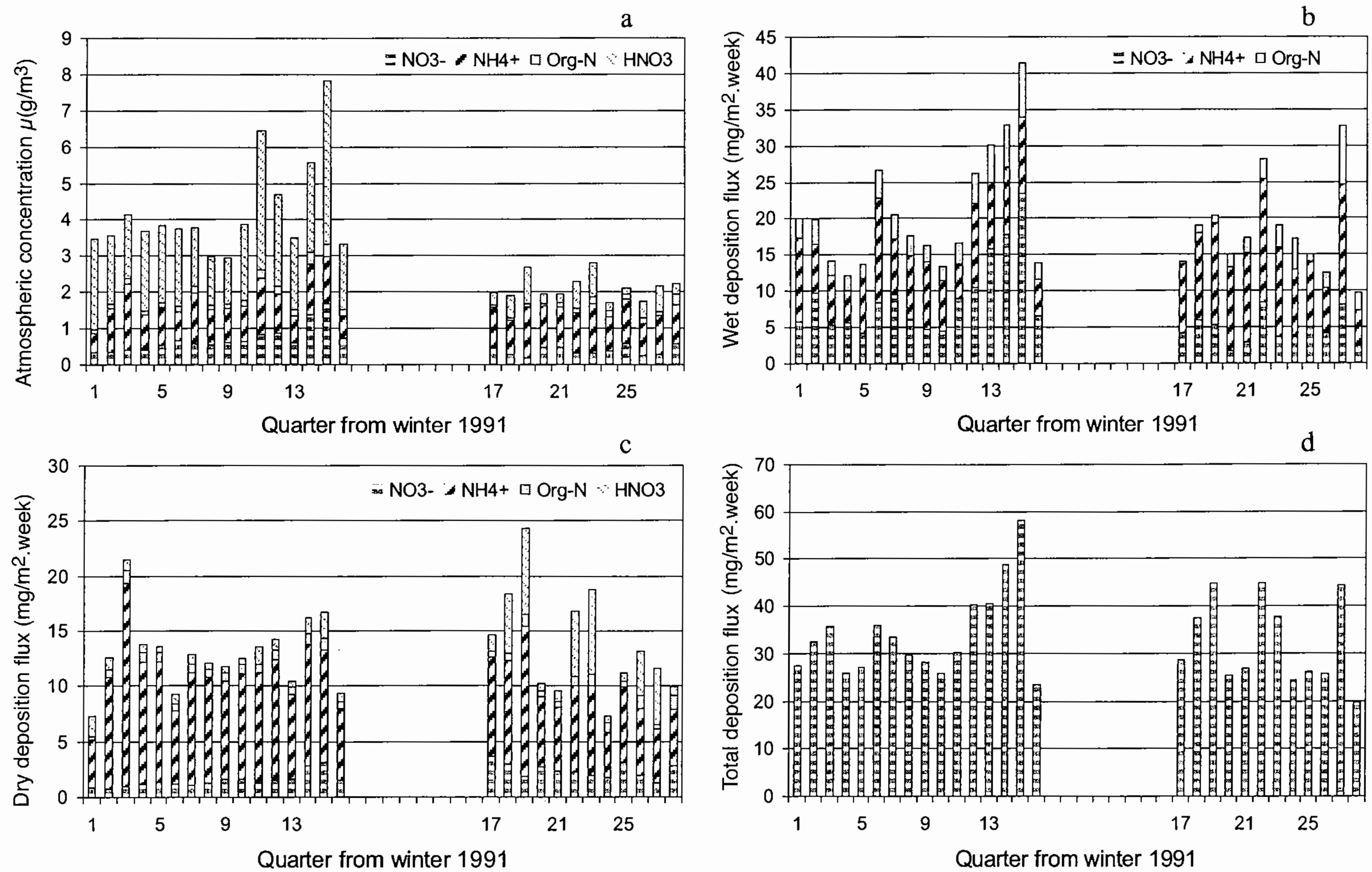

Figure 2. Quarterly means of atmospheric concentration (a), wet deposition flux density (b), dry deposition flux density (c),and total deposition flux (d) of nitrogen species at the Sherwood Island State Park, Connecticut, for the period of 1991-1999.

References

Carly, R. J. and Perkins, C., 2001. Nitrogen Deposition Monitoring in Connecticut: Final Report to Connecticut Department of Environmental Protection. University of Connecticut, Storrs, Connecticut.

Clarke J. F. and Edgerton, E. S., 1992. Dry Deposition Flux calculations for the National Dry Deposition Network. Atmospheric Research and Exposure Assessment Laboratory, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

CTDEP (Connecticut Department of Environmental Protection), 2000a. The atmosphere and hypoxia in Long Island Sound. Connecticut Department of Environmental Protection, Hartford, Connecticut. URL: <http://www.dep.state.ct.us/wtr/lis/atmoslis.htm>

CTDEP, 2000b. Water quality of Long Island. Connecticut Department of Environmental Protection, Hartford, Connecticut. URL: <http://www.dep.state.ct.us/wtr/lis/wtrqual.htm>.

Hicks, B. B., Baldocchi, D. D., Meyers, T. P., Hosker, R. P. Jr., and Matt, D. R., 1987. A preliminary multiple resistance routine for deriving dry deposition velocities from measured quantities. *Water, Air, and Soil Pollution*, **36**:311-330.

Hu, H. L., Chen, H. M., Nikolasdis, N. P., Miller, D. R., and Yang, X., 1998. Estimation of nutrient atmospheric deposition to Long Island Sound. *Water, Air and Soil Pollution*, **105**:521-538.

MINITAB, 2000. MINITAB Reference Manual, Release 13. Minitab Inc., State College, Pennsylvania.

Yang, X., Miller, D. R., Xu, X., Yang. L. H., Chen, H. M., and Nikolaidis, N. P., 1996. Spatial and temporal variations of atmospheric deposition in interior and coastal Connecticut. *Atmospheric Environment*, **30**:3801-3810.

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MARINE ECOSYSTEMS

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Does *Phragmites* Expansion Influence Nekton Habitat Utilization?

Seth C. Pianka
Department of Environmental Science
University of New Haven
West Haven, CT 06516

Jason Lewis
Department of Environmental Science
University of New Haven
West Haven, CT 06516

David T. Osgood
Department of Biology and Environmental Science
University of New Haven
West Haven, CT 06516

David J.Yozzo
Barry A. Vittor and Associates, Inc.
656 Aaron Court, Building 6
Kingston, NY 12401

Phragmites australis (common reed) is expanding into tidal marshes throughout the Gulf and Eastern coasts of the United States (Chambers *et al.* 1999). In addition to reducing plant species diversity (Chambers *et al.,* 1999), development of *P. australis* monocultures decreases flooding and low order drainage density of tidal marshes (Weinstein and Balletto, 1999). These physical changes could impact habitat use by resident nekton species by reducing access to the marsh surface (Weinstein and Balletto, 1999).

Similar nekton abundance and biomass has been documented between *P. australis* and non-*P. australis* marsh surfaces within the creek bank zone (<10m from the creek) (Rilling *et al.*, 1998; Hanson *et al.,* in review; Osgood *et al.,* unpublished data). Able and Hagan (2000) and Osgood *et al.* (2001) found similar abundance of adult nekton *P. australis* and *Spartina alterniflora* (salt marsh cordgrass) marsh surfaces, but smaller size classes were less abundant within *P. australis.*

Previous studies within *P. australis* have addressed only marsh surface nekton populations. The maintenance of marsh resident nekton populations depends upon both adequate foraging time on the marsh surface and supplement feeding in the tidal creeks, especially during neap tides (Weisberg and Lotrich, 1986). Temporal and spatial patterns of size-class distribution and nekton community composition vary predictably between tidal creek and marsh surface habitat within *Spartina alterniflora* marshes (Kneib and Wagner, 1994; Kneib 1997), but this trend has not been adequately investigated for *P. australis* habitat.

We quantified the spatial and temporal distribution of nekton along the tidal creek/marsh surface gradient within and between *P. australis* and non-*P. australis* stands at Iona Island, Hudson River, NY. Species abundance and size classes were quantified along three transects in *P. australis* and *Typha angustifolia* (narrow-leaf cattail) stands with stations at the tidal creek and the marsh surface (low, mid, high elevation). Sampling on the marsh surface also took place during the ebb, flood, and slack high stages of the tidal cycle. Tidal creek characteristics (submerged structure, light intensity, dissolved oxygen, temperature) and flooding depth on the marsh surface were also measured. Fyke nets, with an opening of 3 feet, $^1/_8$ mesh size, were used to collect nekton within the tidal creeks. Wings were extended diagonally out from the front of the net spanning the entire creek width. Three nets were placed 10 meters apart at slack high tide for both vegetation types. Contents of the nets were retrieved at low tide, and total length and number of each species were determined in the field.

Minnow traps were used to determine the spatial distribution of juvenile and adult nekton along the vegetation transects. Minnow traps consisted of rectangular (10" x10" x17") brown mesh, partially buried flush so that the opening was with the marsh surface. One minnow trap was placed at each sampling station (low, mid, and high elevation) on each transect for a total of 3 traps per elevation per vegetation type. At the time of sampling, each minnow trap was positioned at slack low tide. At mid and high elevation stations all the minnow traps were left throughout the duration of the tidal cycle. At the low station, a single trap from each group of replicates on each transect was sampled on ebb, flood, and slack high tidal stages.

Fundulus heteroclitus was the dominant species within the tidal creeks and on the marsh surface. When data were pooled over all the months there was no difference in *F. heteroclitus* abundance

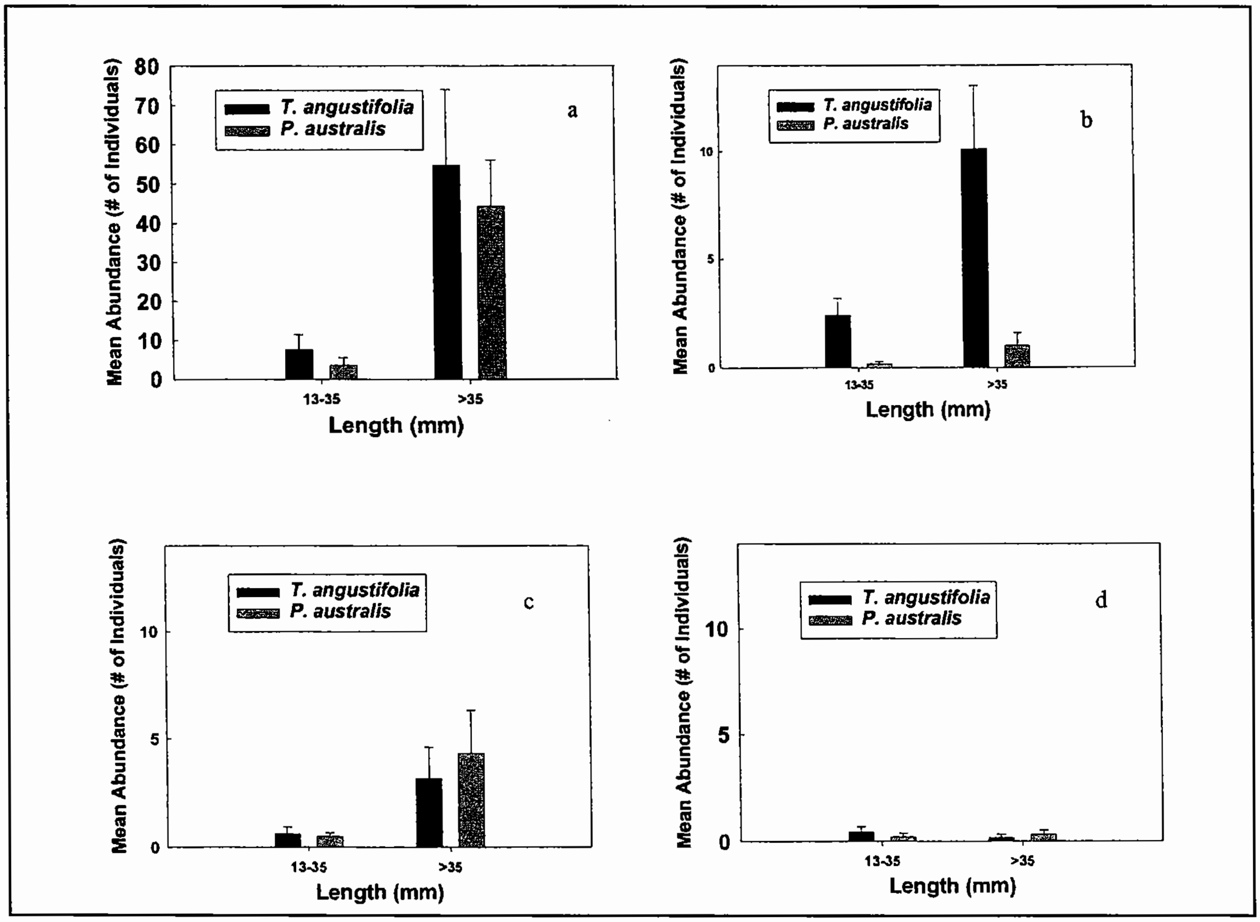

Figure 1. *Fundulus heteroclitus* size class distribution along the tidal creek (a) /marsh surface (b-low station, c-mid-station, d-high station) gradient. Error bars represent standard error of the mean.

between the tidal creeks. There was, however, a significantly higher abundance of F. *heteroclitus* in July and August within the *T. angustifolia* creek relative to the *P. australis* creek (ANOVA, p>0.05). A higher diversity of nekton was found in the *P. australis* tidal creek (14 species) compared to the *T. angustifolia* creek (5 species).

On the marsh surface, *F. heteroclitus* was always significantly higher in *T. angustifolia* stands relative to *P. australis* but only at the low elevation station. There was a trend of increasing abundance of *F. heteroclitus* later in the season within the *P. australis* tidal creek and *P. australis* mid station on the marsh surface. The relative distribution of size classes of *F. heteroclitus* between the two tidal creeks was similar (Figure 1). In contrast, there were proportionally more adults on the marsh surface within *T. angustifolia* but only at the low station. Size class distribution at the high station was similar for both vegetation types (Figure 1). Dissolved oxygen and temperature were similar between the two tidal creeks. Light intensity was significantly higher, however, within the *T. angustifolia* creek relative to the *P. australis* creek, although this trend reversed itself during one sampling event (Oct.) in the afternoon hours. Submerged structure (mostly as litter) was higher within the *P. australis* creek (65%),compared to the *T. angustifolia* creek (30%). Flooding frequency on the marsh surface was simliar between *P. australis* and *T. angustifolia* stands (Figure 2). The low station within *P. australis*, however, experienced deeper flooding than the low station with the *T. angustifolia* (Figure 2).

F. heteroclitus appears to preferentially use *T. angustifolia* stands relative to *P. australis* stands but only in the low marsh habitat. *F. heteroclitus* abundance is also greater within the *T. angustifolia* tidal creek relative to the *P. australis* creek at least during the summer months. Contrary to what we expected, higher abundance of *F. heteroclitus* may correspond with lower submerged aquatic structure in the creek. Light intensity may be an important factor controlling *F. heteroclitus* abundance and species diversity between the two creeks. *F. heteroclitus* appears to select for both tidal creek and low marsh

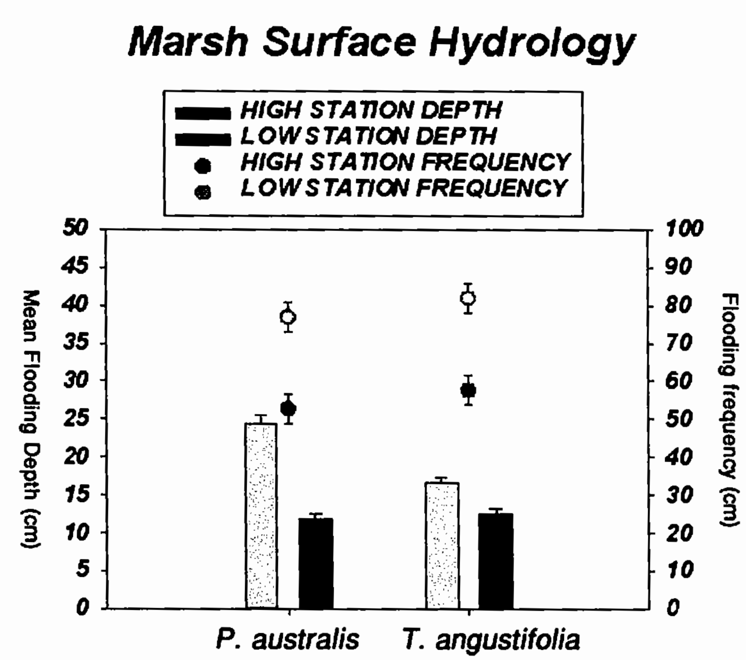

Figure 2. Flooding characteristics of *P. australis* and *T. angustifolia* on the marsh surface. Mean flooding depth (bars) is compared in both vegetation types and in both the high and the low stations. Flooding frequency (circles) is compared over both vegetation types and in both the high and the low stations. Error bars represent standard error of the mean.

habitats within *T. angustifolia* relative to *P. australis.* The lower abundance of *F. heteroclitus* in *P. australis* at the lower station despite deeper flooding suggests that *F. heteroclitus* abundance patterns between the creeks may control patterns on the marsh surface. Mitigation efforts aimed at increasing nekton utilization in stands impacted by *P. australis* may need to consider changes in both creek and marsh surface habitats as controlling factors of nekton abundance patterns.

Literature Cited

Chambers, R. C., L. A. Meyerson, and K. Saltonstall. 1999. Expansion of *Phragmites australis* into tidal wetlands of North America. *Aquatic Botany* **64**:261-273.

Able, K.W, S.M Hagen. 1999. Effects of Common Reed (*Phragmites australis*) invasion on Marsh Surface Macrofauna: Responses of Fishes and Decapod Crustaceans. *Estuaries* **23**: 633-646.

Hanson, S.R., and D.T. Osgood. In Review. Habitat value of *Phragmites australis* for resident nekton in Piermont Marsh, Hudson River, New York. Wetlands.

Knieb, R.T. and S.L. Wagner. 1994. Nekton use of vegetated marsh habitats at different stages of tidal inundation. *Marine Ecology Progress Series* **94**:227-238.

Kneib, R.T. 1997. The role of tidal marshes in the ecology of estuarine nekton. *Oceanography and Marine Biology: An Annual Review* **35**:163-220.

Osgood, D.T., D. Yozzo, and R. Chambers. Unpublished Data. Influence of *Phragmites* expansion on energy transfer within tidal wetlands of the Hudson River Estuary.

Osgood, D.T., D. Yozzo, Dana Jacobson, Timothy Hoffman, Jason Wnek, Jason Lewis, Seth Pianka, Lisa Vasilakos. 2000. Habitat utilization by resident nekton in *Phragmites* and *Spartina* marshes on the Housatonic River. Long Island Sound Conference (this volume).

Rilling, G.C., P.E. Fell, and R.S. Warren. 1998. Fish use of brackish tidal wetlands on the lower Connecticut River: a comparison of a *Phragmites australis* – dominated vs. a restored high marsh. Technical report to CT DEP, Office of Long Island Sound Programs.

Weisberg, S.B., and V.A. Lotrich. 1982. The importance of an infrequently flooded intertidal marsh surface as an energy source for the mummichog *Fundulus heteroclitus*: an experimental approach. *Marine Biology* **66**:307-310.

Weinstein, M.P., and J.H. Balletto. 1999. Does the Common Reed, *Phragmites australis*, Affect Essential Fish Habitat? *Estuaries* **22**(3B):793-802.

Habitat utilization by resident nekton in *Phragmites* and *Spartina* marshes on the Housatonic River

David T. Osgood
Department of Biology and Environmental Science
University of New Haven
West Haven, CT 06516

David J. Yozzo
Barry A. Vittor and Associates, Inc.
656 Aaron Court, Building 6
Kingston, NY 12401

Dana Jacobson
Timothy Hoffman
Jason Wnek
Jason Lewis
Seth Pianka
Lisa Vasilakos
Department of Biology and Environmental Science
University of New Haven
West Haven, CT 06516

Phragmites australis (common reed) is an invasive clonal wetland plant, which has become increasingly prevalent in coastal Connecticut marshes and throughout the Northeast U.S. over the last century (Orson *et al.,* 1987; Chambers *et al.,* 1999). *P. australis* exhibits aggressive growth and often replaces a variety of salt and brackish marsh plant species including *Spartina patens*, *Spartina alterniflora*, and *Typha angustifolia* (Chambers *et al.,* 1999). One effect of *P. australis* expansion in tidal marshes is an increase in elevation (decreased flooding) and a decrease in marsh surface microtopography (Windham and Lathrop 1999) caused by accumulation of inorganic sediments and organic biomass (Rooth and Stevenson 2000). One potential impact of the hydrologic and geomorphic changes associated with *P. australis* expansion is reduced utilization of the marsh surface by resident nekton, such as the mummichog (*Fundulus heteroclitus*) and dagger-blade grass shrimp (*Palaeomonetes pugio*). (Weinstein and Balletto, 1999).

Recent research has shown similarities in species composition and abundance (Fell *et al.* 1998, Rilling *et al.,* 1998; Hanson *et al.* in review), but differences in size classes (Able and Hagan, 2000) of marsh-resident and estuarine-dependent nekton occupying *P. australis* and non-*P. australis* marshes in New Jersey and Connecticut. The spatial distribution of nekton across the marsh surface (i.e. varying distances from tidal creeks and ditches) and the direct impact of surface flooding on nekton utilization in *P. australis* and non-*P. australis* has not been adequately addressed. Our objective was to quantify the utilization of interior *P. australis* and *S. alterniflora* stands and determine the influence of marsh surface flooding on nekton habitat use.

Density of resident nekton was quantified using six replicate bottomless lift nets (Rozas, 1992) in adjacent *P. australis* and *S. alterniflora* stands within the Charles Wheeler Salt Marsh at the mouth of the Housatonic River in Milford, CT. Lift nets were sampled at least once a month on spring tides from May to October. Since regular flooding (at least once a month) was limited within *P. australis* stands, lift nets were positioned within 20 m of the creek bank or mosquito ditch to ensure an adequate frequency of sampling. Specifically, lift nets ranged from 2.5 to 19.2 m from the nearest flooding source with a mean distance of 11 m. Marsh surface flooding (depth, duration, and frequency) was continuously measured from May to October using wells instrumented with remote data loggers and pressure transducer units. One well was situated within the tidal creek or mosquito ditch at each site and two wells were placed on the marsh surface adjacent to the lift nets at each site

Summary of water table data during June, 2000 (Figure 1) shows that the *S. alterniflora* marsh surface flooded on 98% of high tide events. In contrast the *P. australis* marsh surface flooded on 56% of high tide events. Similarly, the average depth of flooding was significantly greater at the *S. alterniflora*

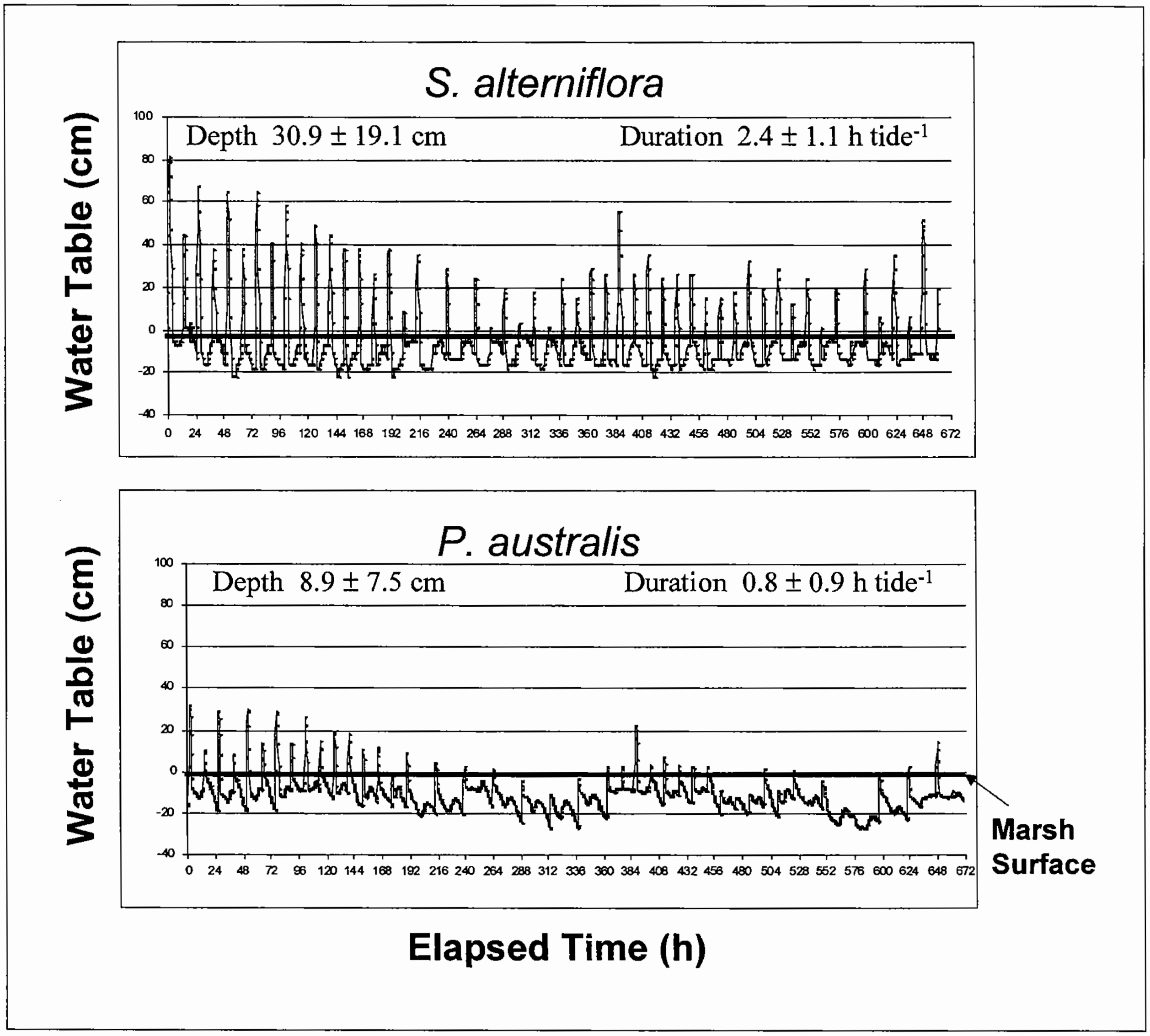

Figure 1. Water table position relative to the marsh surface (bold line) from one well each in *Spartina alterniflora* and *Phragmites australis* stands from June 1-27, 2000. Data were recorded at 24-minute time intervals. Monthly mean and standard error for depth and duration of flooding are also reported.

(30.9 cm) site compared to the *P. australis* (8.9 cm) site (ANOVA, $p < 0.05$). Mean flooding duration was also significantly lower at the *P. australis* site (1.4 h $tide^{-1}$) relative to the *S. alterniflora* site (2.5 h $tide^{-1}$) (ANOVA, $p < 0.05$).

A total of 48 lift net samples for each vegetation zone yielded 3,168 and 706 individuals at the *S. alterniflora* and *P. australis* sites, respectively. *P. pugio* represented the majority (77%) of individuals captured at the *S. alterniflora* site and were significantly more abundant than at the *P. australis* sites (ANOVA, $p < 0.05$). *F. heteroclitus*, *F. majalis* (striped killifish) *F. luciae* (spotfin killifish) *Menidia menidia* (Atlantic silversides), and *Anguilla rostrata* (American eel) were caught within both vegetation stands. The discovery of *F. luciae* at the Wheeler salt marsh is noteworthy. Long Island Sound represents the extreme northern extent of its habitat range and it is rarely observed outside of the Mid-Atlantic states (Whitworth 1996, B. Schmidt, pers. comm.). The mean density of fish was not significantly different between the *S. alterniflora* (2.5 ± 0.3 individuals m^{-2}) and *P. australis* (2.2 ± 0.3 individuals m^{-2}) stands when pooled over all months (ANOVA, $P < 0.05$). Additionally, fish density was not different between nets within 10 m of the flooding source (n = 24) (2.4 ± 0.5 individuals m^{-2}, 2.1 ± 0.4 individuals m^{-2}) and nets between 10-20 m from the flooding source (n = 24) (2.1 ± 0.4 individuals m^{-2}, 2.7 ± 0.4 individuals m^{-2}) (ANOVA, $p < 0.05$) within the *P. australis* and *S. alterniflora* stands, respectively.

Within individual sampling events, there was a trend of higher density of fish in *S. alterniflora*, relative to *P. australis* for the June and July samples (Figure 2a). This trend was manifested in a significantly greater density of juvenile (13 – 30 mm total length) *F. heteroclitus* in the *S. alterniflora* site relative to the *P. australis* site for the June and July samples (Figure 2c). Adult *F. heteroclitus* (> 30 mm total length) were also significantly more abundant at the *S. alterniflora* site, but only for the July sample (Figure 2b).

At the Wheeler Salt Marsh, *P. pugio* appears to favor *S. alterniflora* habitat, where there is a greater amount of creek edge relative to marsh area compared to *P. australis* habitat (Osgood *et al.* unpublished data). This observation may be explained by a greater affinity of *P. pugio* for low order tidal creeks possibly resulting from distribution of food resources or predator avoidance (Kneib and Wagner, 1984; Minello *et al.*, 1994).

Our results show that, when the marsh surface is flooded, equal density and species of fish utilize marsh surfaces of *P. australis* and *S. alterniflora* and do not vary as a function of distance from the flooding source (< 20 m). Because of the reduced duration and frequency of flooding in *P. australis* habitat relative to *S. alterniflora*, however, fish utilization differs between vegetation types due to accessibility. Using the maximum and minimum fish density across all months and the measured flooding frequency and duration, the equivalent of 113-143 individuals m^{-2} $month^{-1}$ would use the *S. alterniflora* stands compared to 24-59 individuals m^{-2} $month^{-1}$ using the *P. australis* stands. Fish would also have 8 times longer access to the *S. alterniflora* stands relative to the *P. australis* stands each month.

The higher density of juveniles caught in June and July at the *S. alterniflora* site suggests that *S. alterniflora* may preferentially be used as nursery habitat. The bottomless lift nets used in the present study are designed to capture juvenile and adult nekton only so at this time we cannot determine if there were differences in abundance of larval fish (i.e. spawning function) between the vegetation zones. Able and Hagan (2000) found that abundance of larvae and juveniles (collected in pit-traps) was lower in *P. australis* stands relative to *S. alterniflora* stands in a New Jersey salt marsh. Differences in the abundance of larval and juvenile fish were attributed to lack of standing water (refuge) and elevation differences between the vegetation types.

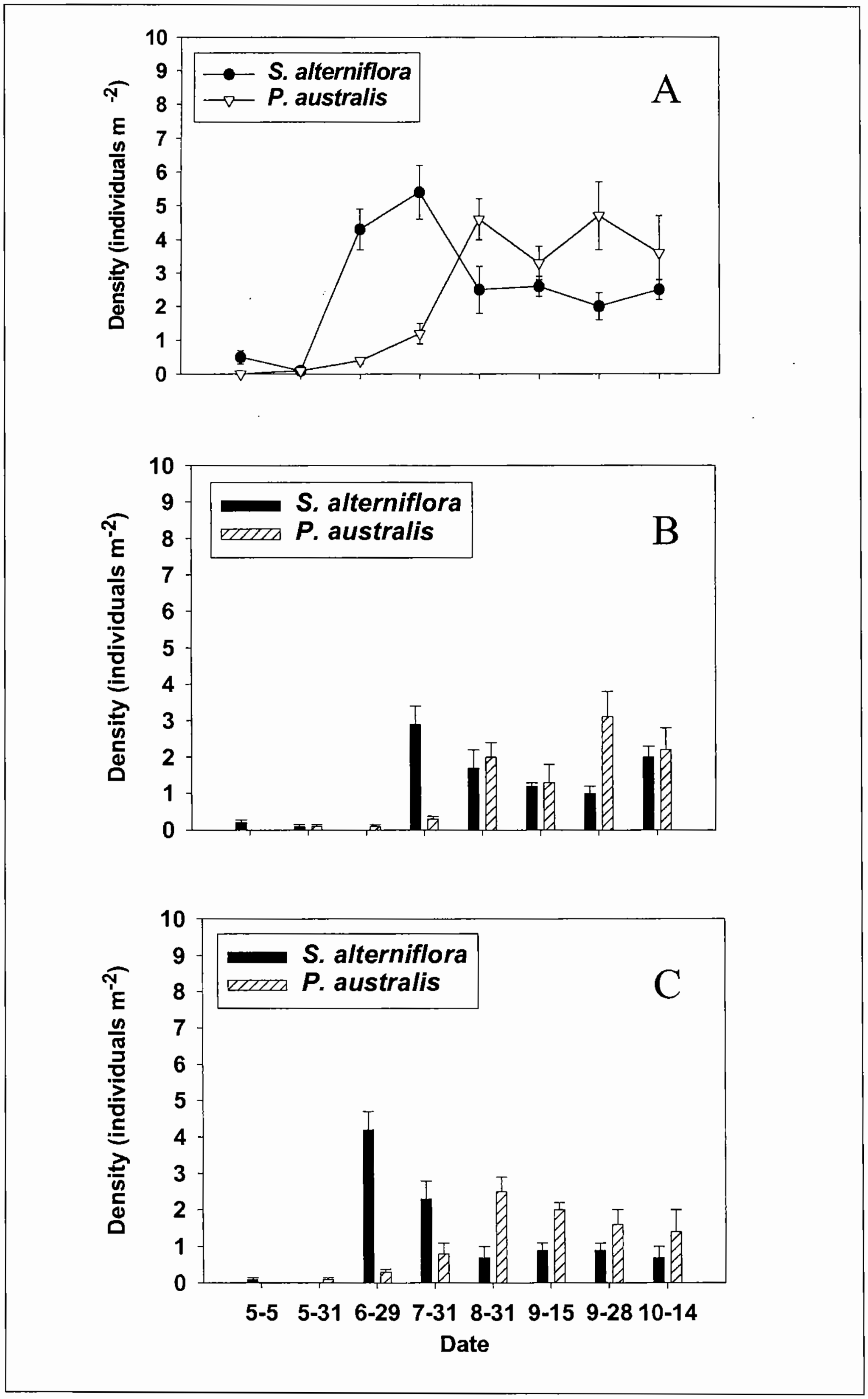

Figure Two. Temporal changes in density (individuals m^{-2}) from May to October, 2000 for all size classes of total fish (A), adult *Fundulus heteroclitus* (B), and juvenile *Fundulus heteroclitus* (C). Data represent mean and standard error for six replicate lift nets per vegetation treatment (*Spartina alterniflora* and *Phragmites australis*).

Our data suggest that nekton utilization of the marsh surface is reduced in *P. australis* stands relative to *S. alterniflora* when *P. australis* expansion results in significant reduction of tidal flooding. A reduction of flooding with time should be most apparent when *P. australis* invades and replaces low marsh vegetation such as *S. alterniflora* as it has on the lower Housatonic River Estuary. Reduced nekton utilization may include use of the marsh surface as spawning and nursery habitat, although further data are required before this can be substantiated.

References Cited

Able, K.W. and S.M. Hagan. 2000. Effects of common reed (*Phragmites australis*) invasion on marsh surface macrofauna: Response of fishes and decapod crustaceans. *Estuaries* **23**:633-646.

Chambers, R.M., L.A. Meyerson, K. Saltonstall. 1999. Expansion of *Phragmites australis* into tidal wetlands of North America. *Aq. Botany* **64**:261-273.

Fell, P.E., S.P. Weissbach, D.A. Jones, M.A. Fallon, J.A. Zeppieri, E.K. Faison, K.A. Lennon, K.J. Newberry, and L.K. Reddington. 1998. Does invasion of oligohaline tidal marshes by reed grass, *Phragmites australis*, affect the availability of prey resources for the mummichog, *Fundulus heteroclitus*? *J. Exp. Mar. Biol. Eco.* **222**:59-77.

Hanson, S., D.T. Osgood, and D.J. Yozzo (in review). Utilization of *Phragmites australis* habitat by marsh-resident nekton at Piermont Marsh in the lower Hudson River Estuary. *Wetlands*

Kneib, R.T. and Wagner, S.L. 1994. Nekton use of vegetated marsh habitats at different stages of tidal inundation. *Mar. Ecol. Prog. Ser.* **94**:227-238.

Minello, T.J., R.J. Zimmerman, and R. Medina. 1994. The importance of edge for natant macrofauna in a created salt marsh. *Wetlands* **14**:184-198.

Orson, R.A., R.S. Warren and W.A. Niering. 1987. Development of a New England river valley tidal marsh. *Estuaries* **10**:20-27.

Rilling G.C., P.E. Fell, and R.S. Warren. 1998. Fish use of brackish tidal wetlands on the lower Connecticut River: A comparison of a *Phragmites australis*-dominated vs. a restored high marsh. Technical Report to the Connecticut Department of Environmental Protection, Office of Long Island Sound Programs.

Rooth, J.E. and J.C. Stevenson. 2000. Sediment deposition patterns in *Phragmites australis* communities: Implications for coastal areas threatened by rising sea-level. *Wetlands Ecology and Manag.* **8**:173-183.

Rozas, L.P. 1992. Bottomless lift net for quantitatively sampling nekton on intertidal marshes *Mar. Ecol. Prog. Ser.* **89**:282-292.

Weinstein, M.P. and J.H. Baletto 1999. Does the common reed, *Phragmites australis*, affect essential fish habitat? *Estuaries* **22**(3B):793-802.

Windham, L. and R.G. Lathrop. 1999. Effects of *Phragmites australis* (Common Reed) invasion on aboveground biomass and soil properties in brackish tidal marsh of the Mullica River, New Jersey. *Estuaries* **22**:927-935.

Whitworth, W.R. 1996. Freshwater fishes of Connecticut. Department of Environmental Protection Bulletin **114**.

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Population Dynamics of the Non-Native Crab *Hemigrapsus sanguineus* and the Native Crabs at Edith Reed Sanctuary (Rye, NY)

M. Sellberg and G.P. Kraemer
Department of Environmental Sciences, Purchase College
State University of New York
Purchase, NY 10577
<gkraemer@purvid.purchase.edu>

Introduction

Humans have a long history of facilitating the movement, both intentional and accidental, of organisms into territories outside their natural ranges (Cox, 1999; Huston, 1994). Perhaps 5-10% of the non-native species establish themselves. While introductions have the potential to produce locally higher species richness, non-native species often cause marked declines in biodiversity (Huston, 1994). One dramatically negative introduction occurred in 1984, when a low temperature-tolerant variety of *Caulerpa taxifolia* (Komatsu *et al.*, 1997) was accidentally released into the Mediterranean Sea near Monaco. *C. taxifolia* has since expanded into large areas of the Western Mediterranean at the expense of the native macrophytes. Declines in animal species richness has accompanied this depauperation of the native flora.

Ecological impacts due to introduced species are varied. Introduced species may alter resource availability (Vitousek *et al.*, 1987), modify the disturbance regime of the invaded habitat, or influence food web structure and energy flow patterns (Vitousek, 1990). Impacts may occur via interspecific competition, and influence survival, growth, and/or reproductive output of the affected organisms (e.g., Hill and Lodge, 1999). Interestingly, native diversity influences the susceptibility of a system to invasion; a recent study supported the conventional wisdom that high native diversity provides food web stability (i.e., resistance to the establishment of a non-native; Stachowicz *et al.*, 1999). This suggests that estuarine environments are at particular risk for invasion, since the diversity of these systems is low compared with other nearshore systems.

Crabs can exert a strong influence on the structure of intertidal communities (Reise, 1985). As omnivorous scavengers and predators, crabs consume large amounts of meio- and juvenile macrofauna, as well as plant material. *Hemigrapsus sanguineus*, the Japanese shore crab, was introduced onto the northeastern coast of the United States approximately ten years ago (McDermott, 1991; 1998). *H. sanguineus* was reported in the western end of Long Island Sound in 1994 (<http://massbay.mit.edu/exotic-species/invaders/hemi-map.htm>).

H. sanguineus possesses life history and autecological characteristics that have helped make it a successful invader: it is a diet generalist (Lohrer and Whitlatch, 1997; Gordon, 1999); females can produce several broods per year of up to 56,000 eggs over a three-year lifespan (McDermott, 1991); and both the larvae and adults show broad salinity tolerances (Epifanio *et al.*, 1998) and (Gordon, 1999), respectively). This crab is found widely distributed within its home range, from Okinawa north into China, indicating broad temperature tolerances. Not surprisingly, *H. sanguineus* has spread north into Maine and south into Virginia, averaging 12 km y^{-1} (Grosholz, 1996).

Materials and Methods

Work was carried out at the Edith Reed Sanctuary (Rye, NY). The substrate at the rocky intertidal site ranges from small pebbles to large boulders. *H. sanguineus* and the native crabs (*Dispanopeus sayi* [Say's mud crab], *Callinectes sapidus* [blue crab], *Carcinus maenas* [green crab], and *Cancer irroratus* [Atlantic rock crab]) are known at this site (Gordon, 1999). From June 1998 – Nov 2000, quarterly transects (n = 3) of crab abundance were conducted across the intertidal gradient during spring tides from approximately +0.2 m above MLLW to the spring high tide mark (+2.0 m, corresponding roughly with pebble-sand transition). At two-meter intervals all crabs with a maximum carapace width ≥ 4 mm within a 0.49 m^2 quadrat were captured and identified. Beginning in June 2000, the maximum carapace width (MCW) of each captured crab was measured and the biomass estimated from empirical relationships between MCW and (fresh weight)$^{1/3}$ ($r^2 > 0.98$ for all species; data not shown). To describe temporal trends in crab community structure, data from summer (June) transects were pooled across the intertidal zone.

Results

The average number of crabs caught per transect in June increased over the course of the study, from 222 (SD = 14) in 1998, to 356 (48) in 1999, to 560 (84) in 2000. In June 1998, *H. sanguineus* were already more abundant than native crabs (52% vs. 48%, respectively; Table 1). Populations of *H. sanguineus* and *D. sayi* (the numerically dominant native crab) reached higher densities and had broader intertidal distributions than did the two other native species. Intertidal distributions of the native crabs and *H. sanguineus* were broad, although the introduced species appeared to be more abundant at upper intertidal elevations (Figure 1). In June 1999, although the number of crabs captured had increased there was no change in the relative abundance of *H. sanguineus* and native crabs in the intertidal zone (Table 1, Figure 1). The dominance by *H. sanguineus* increased to 99% of individuals in June 2000, at which time native crabs were not recorded above approximately mid-tide, and *D. sayi* was the only native crab encountered. June 2000 densities (crabs m^{-2}) of *H. sanguineus* were as high as 105 crabs m^{-2}, while the maximum native crab density was 2 crabs m^{-2}. Average June densities of *H. sanguineus* increased by almost eight-fold from 1998-2000, while the density of native crabs decreased by 96% over the same interval. In June 2000, the biomass ratio of *H. sanguineus* : native crab (at that point only *D. sayi*) averaged 48:1 across the intertidal zone.

Table 1. Species abundances within rocky intertidal zone at Edith Reed Sanctuary (Rye, NY). Crabs pooled across intertidal transects (n = 3) conducted in June of each year. Total number of crabs caught per transect averaged 222 (SD = 14), 356 (48), and 560 (84) for the years 1998, 1999, and 2000, respectively.

Year	Species			
	Hemigrapsus sanguineus	*Dispanopeus sayi*	*Carcinus maenas*	*Cancer irroratus*
1998	22%	75%	2%	1%
1999	61%	38%	1%	0%
2000	99%	1%	0%	0%

During June 1998, *H. sanguineus* and the three native species were captured (though not on all transects; Table 1). In June 1999 only three species were recorded and in June 2000 only *H. sanguineus* and *D. sayi*) were captured. The species richness of the summer crab community in the intertidal zone at Edith Reed Sanctuary decreased by 40% over this period, while species diversity measured by Shannon's H' decreased by 91%, due primarily to an 86% decrease in evenness (J; Figure 2).

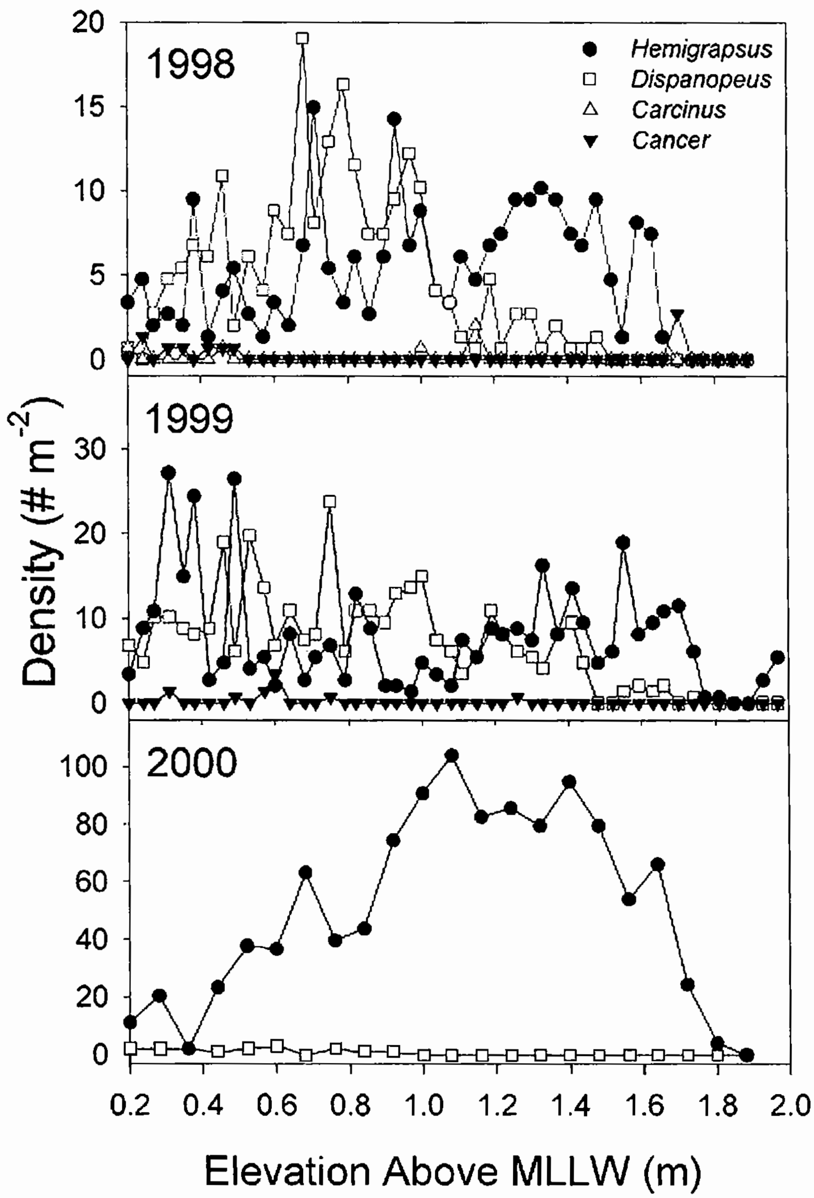

Figure 1. Densities of crabs resident during June at Edith Reed Sanctuary (Rye, NY) from 1998-2000. Data are averages of three 0.49 m^2 quadrats at each tidal elevation.

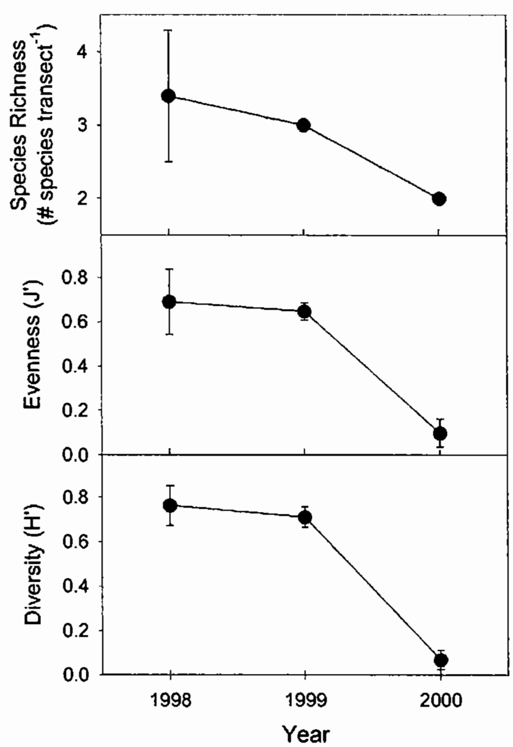

Figure 2. Changes in species richness, evenness, and diversity of the intertidal crab communities during June from 1998-2000. Data from three quadrats across the intertidal zone were pooled for each year.

Conclusions

Total crab abundance increased over the course of the study. From 1998-1999, this trend was due to increases in the abundance of both *H. sanguineus* and *D. sayi* populations. However, from 1999-2000, while the *H. sanguineus* density increased greatly, that of *D. sayi* decreased almost to zero (the other natives were not recorded). The reason(s) for the great increase in *H. sanguineus* numbers (and, hence, biomass) are not known. Recruitment of juvenile *H. sanguineus* during spring and summer of 2000 was very high elsewhere in the Long Island Sound (Avery Point, CT, 160 km to the north; R. Whitlatch, personal communication).

The increase in *H. sanguineus* occurred while other, native crab populations were decreasing. The mechanism for the reduction in the number of native crabs is not known. Competition for mutual food sources and habitat, and direct predation are two likely possibilities (Cox, 1994; Huston, 1994). The latter is supported by experimental studies demonstrating predation by *H. sanguineus* on *C. maenas* (green crab) juveniles and on *Mytilus edulus* (D. Lohrer, in review).

The net result for the period from 1998-2000 has been an overall decrease in biodiversity. This is seen in the decreases in species richness and, to a much greater degree, evenness. Whether these decreases have occurred throughout the Long Island Sound, and whether the native crab populations rebound awaits further sampling. While habitat use by *H. sanguineus* and *D. sayi* overlaps, the latter species may have a natural refuge in its broader substrate requirements. *D. sayi* can inhabit fine grained sediments (Gosner, 1980) while *H. sanguineus* is restricted to cobble – boulder intertidal zones (Lohrer *et al.*, 2000).

Acknowledgments

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Literature Cited

Cox, G. W. 1999. *Alien Species in North America and Hawaii,* Island Press.

Epifanio, C.E., Dittel, A.I., Park, S., Schwalm, S., Fouts, A. 1998. Early life history of *Hemigrapsus sanguineus*, a non-indigenous crab in the Middle Atlantic Bight (USA). *Mar. Ecol. Prog. Ser.* **170**: 231-238.

Gordon, A. 1999. The distributions, salinity tolerances and the food sample consumption of the invasive Japanese crab *Hemigrapsus sanguineus* and the indigenous mud crab *Eurypanopeus depressus*. Senior Research Thesis, Purchase College (SUNY). 27 pp.

Gosner, K.L. 1980. *A Field Guide to the Atlantic Seashore. Invertebrates and Seaweeds of the Atlantic Coast from the Bay of Fundy to Cape Hatteras.* Houghten-Mifflin Co., Boston. 329 pp.

Grosholz, E.D. 1996. Contrasting rates of spread for introduced species in terrestrial and marine systems. *Ecology* **77(6)**:1680-1686.

Hill, A.M., Lodge, D.M. 1999. Replacement of resident crayfishes by an exotic crayfish: the roles of competition and predation. *Ecol. Appl.* **9(2):**678-690.

Huston, M.A., 1994. *Biological Diversity: The Coexistence of Species on Changing Landscapes.* Cambridge Univ. Press., NY. 681 pp.

Kimmerer, W. J., E. Gartside, *et al.* 1994. Predation by an introduced clam as the likely cause of substantial declines in zooplankton of San Francisco Bay. *Mar. Ecol. Prog. Ser.* **113**: 81-93.

Komatsu, T., A. Meinesz, *et al.* 1997. Temperature and light responses of alga *Caulerpa taxifolia* introduced into the Mediterranean Sea. *Mar. Ecol. Prog. Ser.* **146**:145-153.

Lohrer, A. M. and R. B. Whitlatch (1997). Ecological studies on the recently introduced Japanese Shore Crab (*Hemigrapsus sanguineus*), in eastern Long Island Sound. Second Northeast Conference on Nonindigenous Aquatic Nuisance Species, Burlington, VT, CT Sea Grant.

Lohrer, A.M., Fukui, Y., Wada, K., Whitlatch, R. B. 2000. Structural complexity and vertical zonation of intertidal crabs, with focus on habitat requirements of the invasive Asian shore crab, *Hemigrapsus sanguineus* (de Haan). *J. Exp. Mar. Biol. Ecol.* **244**:203-217.

McDermott, J.J. 1991. A breeding population of the western Pacific crab *Hemigrapsus sanguineus*: (Crustacean: Decapoda: Grapsidae) established on the Atlantic coast of North *America. Biol. Bull.* **181**:195-198.

McDermott, J.J. 1998. The western Pacific brachyuran (*Hemigrapsus sanguineus*: Grapsidae), in its new habitat along the Atlantic coast of the United States: geographic distribution and ecology. ICES *J. Mar. Sci.* **55**:289-298.

Reise, K. 1985. *Tidal Flat Ecology: An Experimental Approach to Species Interactions.* (Ecological Studies. Analysis and Synthesis, Volume **54**). Springer, Berlin. 354 pp.

Ruiz, G. M., J. T. Carlton, *et al.* 1997. Global invasions of marine and estuarine habitats by non-indigenous species: Mechanisms, extent, and consequences. *Amer. Zool.* **37**:621-632.

Stachowicz, J. J., R. B. Whitlatch, *et al.* 1999. Species diversity and invasion resistance in a marine ecosystem. *Science* **286**:1577-1579.

Vitousek, P.M. 1990. Biological invasions and ecosystem processes: towards an integration of population biology and ecosystem studies. *Oikos* **57**:7-15.

Vitousek, P.M., Walker, L.R., Whiteaker, L.D., Mueller-Dombois, D., Matson, P.A. 1987. Biological invasion by *Myrica faya* alters ecosystem development in Hawaii. *Science* **238:**802-804.

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An Index of Biotic Integrity Based on Fish Community Structure Applied to Rhode Island and Connecticut Estuaries

J. E. Hughes, L. A. Deegan, J. C. Wyda, and A. Wright
The Ecosystems Center, Marine Biological Laboratory
Woods Hole, MA 02543

Fish are ideal organisms with which to assess the status of aquatic ecosystems. As members of higher trophic levels, fish integrate the effects of environmental change and degradation affecting the base of food webs. As mobile organisms with complex life histories, they require a broad range of intact ecosystem functions for optimal growth and reproduction. Their diversity of body plan, behavior, ontogeny, and ecology allow for the full exploitation of the aquatic environment. Fish communities were first used as multi-metric indicators of biotic integrity in stream ecosystems (Karr, 1981; Karr *et al.*, 1986). Biotic integrity was defined by Karr (1981) as "the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural (reference, minimally degraded) habitats of the region." Subsequently, fish communities have been used as measures of biotic integrity, and hence habitat quality, in a wide variety of freshwater habitats (Simon, 1999), although this approach has more rarely been applied to estuaries (Ramm, 1990; Deegan *et al.*, 1993, 1997; Cooper *et al.,* 1994; Ferreira, 2000; Hughes *et al.,* (b) submitted).

Deegan *et al.* (1993, 1997) developed a multi-metric index of Estuarine Biotic Integrity (EBI) for southern New England. The EBI is an assessment of the condition of estuarine ecosystems based on the abundance, diversity, and composition of the fish community in eelgrass (*Zostera marina*) habitats. The EBI focuses on eelgrass habitats because of their importance to fish and their sensitivity to anthropogenic stress (Costa, 1988; Short *et al.,* 1993, 1995; Short and Burdick, 1996; Valiela *et al.,* 1992, 1997). The development of this index took advantage of the range of nitrogen-induced eutrophication effects present in Waquoit Bay, Cape Cod, during the late 1980s. The EBI was calculated to represent two basic habitat quality categories, "low" or "medium" quality, reflecting the fact that eelgrass has been in general decline in southeastern New England (Costa, 1988), and no estuary there has escaped some level of human impact (Deegan *et al.,* 1997).

Deegan *et al.* (1997) proposed the EBI as an integrated assessment of the capacity of estuarine embayments to function as fish habitat, because the EBI incorporates multiple responses of the fish community to estuarine stressors. The index was tested in Buttermilk Bay, Massachusetts, and was successful in classifying independently-determined habitat quality (Deegan *et al.,* 1997). More recently, the EBI was applied to 14 other estuaries around Buzzards Bay (1993-1998), and to Waquoit and Buttermilk Bays over a longer time frame (1988-1999) (Hughes *et al.*, (b) submitted). The index was a strong correlate of habitat quality and a sensitive indicator of habitat change in these estuaries.

In this paper we apply the EBI to a suite of estuaries along the Rhode Island and Connecticut coasts. Our goal is to to determine whether the index is reliably correlated with (a good indicator of) habitat quality here as well as in southeastern Massachusetts, and, if so, to evaluate the biotic integrity of estuaries in Rhode Island and Connecticut using the EBI.

The EBI as originally developed is a composite of eight variables (metrics) that include both functional group and species-specific indicators of estuarine health. These metrics and their critical values that separate low- from medium-quality sites [in brackets] are: 1) ln (numerical fish abundance/100m^2 + 1) [3.8] or ln (fish biomass/100m^2 + 1) [4]; 2) total fish species per trawl [6]; 3) species dominance (the minimum number of species comprising ≥ 90% of each sample) by numerical abundance or biomass [3]; 4) number of resident species (living lifelong predominantly within the estuary) [4]; 5) number of estuarine nursery species (entering the estuary as adults to spawn, or as larvae or juveniles spawned offshore) [3]; 6) number of in-estuary spawning species (a subset of nursery species, entering the estuary as adults to spawn) [3]; 7) proportion of benthic-associated, or demersal, species by numerical abundance [0.70] or biomass [0.90]; and 8) proportion of diseased or abnormal fish [0.01]. Classifications of fish by principal zone of activity and life history are based on the literature (Bigelow and Schroeder, 1953; Kneib, 1997; Able and Fahay 1998) and our own observations. Unlike the original index of biotic integrity (Karr, 1981, Karr *et al.* 1986) and other indices developed for stream fish communities (e.g., Oberdorff and Hughes 1992), the EBI does not include trophic composition or indicator species metrics because work in Waquoit Bay did not detect a significant association of trophic mode (e.g., invertivore vs. piscivore) or tolerance/intolerance (killifish vs. winter flounder) with habitat quality (Deegan *et al.*, 1997).

To calculate the EBI, measured values for metrics ≥ critical values (< 0.01 proportion of diseased or abnormal fish) are given a score of 5, and scored 0 otherwise. An EBI for each replicate trawl sample is computed as the sum of scores for the 8 metrics; the maximum possible EBI value is 40. Trawl samples containing no fish are given an EBI value of 0. Two forms of the EBI are computed, based on either numerical abundance (EBI-Number) or biomass (EBI-Biomass). The metrics that differ between these are total numerical abundance (A) vs. total wet biomass (B), proportion of benthic species by A vs. B, and species dominance by A vs. B. Proportion of diseased or abnormal fish in these habitats (usually << 0.01) is not a useful discriminator in this study. However, it is included in the computation of the EBI, following Deegan *et al.* (1997). Values of the EBI < 25 indicate low quality sites, and values ≥ 25 indicate medium quality sites.

Three characteristics were used to classify habitat quality in our study: 1) eelgrass shoot density and 2) eelgrass wet biomass, which vary with water clarity (Valiela *et al.*, 1992; Short *et al.*, 1993); and 3) macroalgal abundance, which is strongly influenced by nutrient (especially nitrogen) availability (Valiela *et al.*, 1997; Raffaelli *et al.*, 1998). We used the relative biomass of eelgrass and macroalgae as one measure of habitat quality. The critical values used to separate medium- from low-quality habitats were: eelgrass density ≥ 100 shoots m^{-2} and eelgrass biomass ≥ 100 wet g m^{-2} (Deegan *et al.*, 1997), and ratio of eelgrass wet biomass: macroalgal wet biomass (m^{-2}) ≥ 1. Sites meeting at least two of these criteria were rated “medium quality”, and otherwise, “low quality”.

Fish were collected in 4 Rhode Island coastal estuarine salt ponds, 6-19 July, and in 4 Connecticut estuaries, 21-26 July, 1999 (Table 1). Mid-summer fish communities in these estuaries are expected to be the most stable and exhibit the greatest contrast between sites of different habitat quality (Deegan *et al.*, 1997). Our sampling sites were chosen to be in extant eelgrass habitat or in areas where eelgrass historically existed or has been reported to exist (Short *et al.* 1996; R. Rozsa, Conn. DEP, pers. com.; L. Meng, pers. com.). Water depth at our sampling sites was 1-2.5 m; water temperature ranged from 19-26^{o}C, and salinity from 26-31. Fish were collected using a 4.8-m semi-balloon otter trawl, modified with a small cod end mesh aperture (0.3 cm) to capture juveniles, towed by a 19' boat at 5-6 km h^{-1} (speed determined by a Garmin® global positioning unit). Six two-minute, non-overlapping trawls (approximately 480–600 m^2) were conducted at each site, except when physical conditions restricted the length of the tow or the duration of sampling. Based on results from a variety of estuaries, 6 tows were sufficient to capture 95% of the species present at a site (Livingston, 1975; Heck, 1976; Ayvazian, *et al.*, 1992; Deegan *et al.,* 1993). All fish were identified by species, enumerated, and weighed (± 0.01 g wet weight), and inspected for external pathologies. Fish abundance and wet weight biomass were normalized to 100 m^{-2} by dividing the catch by the estimated area trawled (= estimated width of trawl opening [2.9 m] x length of trawl track). We did not adjust results for catch efficiency, and the number of species per trawl sample was not adjusted for area covered. Each trawl sample was treated as a replicate. Contemporaneously with fish sampling, quantitative samples of submerged aquatic vegetation (eelgrass and macroalgae) were collected by divers using SCUBA. At each site where eelgrass was present, eelgrass shoot density was estimated by diver count in ≥ 8 quadrats (each 0.063 m^2) placed haphazardly in the eelgrass bed. At each site, above-ground biomass of eelgrass and/or macroalgae was estimated by collecting vegetation enclosed by 4 quadrats (each 0.073 m^2) placed haphazardly on the substrate, and returning the samples to the laboratory for wet weight measurement (± 0.1 g). Analysis of variance (ANOVA) techniques were used to test differences in mean EBI among estuaries and between habitat quality classes. The EBI was inherently heteroscedastic (Hughes *et al.*, (b) submitted); to minimize Type I error, we set $\alpha = 0.01$ as the critical level of significance (e.g., Underwood 1981; Ferrell and Bell 1991). A nested factorial design was used to analyze differences in EBI. For the comparisons of EBI, sites were fixed factors nested within habitat quality and estuary (Site [Habitat Quality x Estuary]), using the mean square of the residual sample error as the denominator in all F-ratios (Winer 1971). One-tailed t-tests were used to compare mean EBI values in medium-quality habitats with the critical value of 25.

The 17 sites sampled presented a wide range of vegetated substrate cover and apparent degree of degradation (Table 1). Seven of the sites were considered to be of medium habitat quality, and the remainder of low habitat quality. In Point Judith Pond abundance of eelgrass has declined sharply over the last few decades, particularly at sites PJ1 and PJ3 (L. Meng, USEPA, pers. com.; JEH, pers. obs.). Ninigret Pond contained sites where eelgrass abundance in this survey was greatest (NP2 and NP3), but the once-thriving meadow in the western basin (PJ3) has disappeared and has been replaced by dense aggregations of macroalgae (*Gracilaria* sp., *Ulva lactuca*, *Polysiphonia* sp.). Green Hill Pond, a distinct basin connected to Ninigret Pond, is treated separately in Table 1. There, a dense outer bed of eelgrass (GH1) contrasts with an adjacent habitat (GH2) that is highly degraded, where the turbid water is underlain by black anoxic muds devoid of vegetation (JCW, AW, pers. obs.). Eelgrass in Quonochontaug Pond is mostly limited now to the shallows of the northwestern basin. We could find no eelgrass in Winnapaug Pond, although anecdotal information suggests a small bed in the western portion. Nor could we find any eelgrass in the Pawcatuck River estuary, and Little Narragansett Bay held only isolated stands of short-bladed grass in the high-energy, outer portion. The inner part (off Wequetequock Cove) held high concentrations of *Cladophora* sp., and we found no evidence of eelgrass in the vicinity reported in 1993-1995 fly-over surveys (R. Rozsa, pers. com.), nor anecdotally reported by a local marina manager as recently as 1996. In addition, we found no eelgrass in a visual survey by boat of the Stonington Harbor region reported to have held eelgrass in the fly-over survey. Mumford Cove, Groton, sustained a small eelgrass bed in its mid-northern portion (MC1) that was not documented in the fly-over survey; *Ruppia maritima* occupied its southwestern shallows. We found no eelgrass off the enclosing spit at the entrance to Mumford Cove, where it was indicated in the fly-over survey. Eelgrass habitat has contracted markedly in the Niantic River estuary since the fly-over, and is now absent off Saunders Point and Pine Grove (NR2) and most of the shore opposite, as we determined from boat and diver surveys. It is patchily distributed near the mouth and at NR1.

The species composition and abundance of fishes sampled were similar to those from estuaries of Buzzards Bay and Cape Cod. In 100 trawls we caught a total of 20,990 fish with an aggregate weight of 21943 g, representing 26 species (Table 2). The species caught were about half the total number sampled in 350 trawls from Buzzards Bay and Cape Cod estuaries, 1988-1999 (Hughes *et al.*, (a and b) submitted), but this discrepancy may be primarily due to the smaller sampling effort in the present study. As in estuaries of Buzzards Bay and Cape Cod, most fish caught were young-of-the-year specimens, and averaged about 1 g wet weight. Not surprisingly, the small schooling atherinid *Menidia menidia* (Atlantic silverside) was the numerical dominant, and comprised almost a fourth of the catch

Table 1. Estuaries and sites sampled, July-August 1999, with mean eelgrass shoot densiies and wet vegetation biomass densities and their standard errors (SE). n ≥ 8 for eelgrass shoot density estimates (quadrat sample = 0.063 m^{-2}); n = 4 for most eelgrass and macroalgae wet biomass estimates (quadrat sample = 0.073 m^{-2}). Habitat quality deemed "medium" if at least 2 of the following criteria are met: eelgrass shoot density ≥ 100 m^{-2}; eelgrass wet biomass ≥ 100g m^{-2}; ratio of eelgrass:macroalgae biomass ≥ 1.

				Eelgrass				Macroalgae		
Estuary	Site	Location	NLat, WLong	Shoots m^{-2}	SE	g m^{-2}	SE	g m^{-2}	SE	HabitatQuality
Rhode Island										
Point Judith Pond	PJ1	outer flat	41°23.70', 71°30.59'	10	4.2	0	-	0	-	Low
	PJ2	along channel	41°23.56', 71°30.76'	405	37.6	1041	290.0	27	17.8	Medium
	PJ3	Flat Hill Cove	41°23.13', 71°30.02'	0	-	0	-	54	53.8	Low
Ninigret Pond	NP1	western basin	41°21.29', 71°40.87'	0	-	0	-	867	119.8	Low
	NP2	west of inlet	41°22.04', 71°38.69'	570	16.5	1753	180.4	168	84.4	Medium
	NP3	Grassy Point	41°21.77', 71°39.18'	144	12.5	2299	608.4	0	-	Medium
Green Hill Pond	GH1	outer	41°22.14', 71°37.06'	234	23.6	1104	155.4	0.3	0.3	Medium
	GH2	inner	41°22.54', 71°36.70'	0	-	0	-	0	-	Low
Quonochontaug Pond	QP1	northwest	41°20.06', 71°44.81'	172	16.5	317	158.6	48	47.6	Medium
	QP2	south of inlet	41°19.98', 71°44.15'	13	7.8	0	-	1	1.3	Low
Winnapaug Pond	WP1	northwest	41°19.87', 71°47.63'	0	-	0	-	20	11.4	Low
Connecticut										
Pawcatuck River	PR1	Ram Point	41°20.32', 71°49.90'	0	-	0	-	5	3.3	Low
Little Narragansett Bay	LB1	north, inner	41°20.14', 71°52.70'	0	-	0	-	660	141.5	Low
Mumford Cove	MC1	north, mid	41°19.51', 72°01.22'	51	17.9	871	185.4	31	30.8	Medium
	MC2	southeast	41°19.41', 72°01.06'	0	-	0	-	622	311.7	Low
Niantic River	NR1	east, mid	41°20.18', 72°10.58'	91	21.1	441	87.1	0.5	0.5	Medium
	NR2	Pine Grove	41°19.94', 72°10.89'	0	-	0	-	104	59.9	Low

biomass. More rarely caught, much larger fishes - *Anguilla rostrata* (American eel) and *Pseudopleuronectes americanus* (winter flounder) contributed 50% of the total biomass. As in eelgrass habitats further north, *Apeltes quadracus* (fourspine stickleback), was an important numerical component of the assemblage. Several species were observed in these estuaries that were not found in the samples from Buzzards Bay and Cape Cod - juvenile *Sphyraena borealis* (northern sennet), *Leiostomus xanthurus* (spot), and *Mycteroperca microlepis* (gag grouper) - but these were never common. *Sphoeroides maculatus* (northern puffer), fairly common in eelgrass of Buzzards Bay, was not found in the present study. Overall, however, both regions shared similar common species. The life histories, activity zone, and habitat affiliation of these species is presented in Hughes *et al.* ([a] submitted).

The EBI was strongly correlated with habitat quality in the Rhode Island and Connecticut estuaries (Figure 1). In the analysis, 91 trawl samples were included; 9 were excluded as being unrepresentative of the habitat, including samples from site NP3 due to clogging of the trawl mouth by the dense eelgrass canopy. The most important source of variation in the EBI ANOVA was Habitat Quality ($P < 0.001$), for both EBI-Number and EBI-Biomass. Mean EBI values in medium-quality habitats were more than 2x those in low-quality habitats, and EBI-Number and EBI-Biomass analyses gave highly similar results. Mean EBI values in medium-quality habitats were not significantly less than the critical value of 25 used to separate habitat classes in the original EBI formulation ($P > 0.10$). In the ANOVA, the effect of estuary was not significant at $\alpha = 0.01$. The interaction of Estuary x Habitat Quality was only marginally significant ($P \approx 0.01$). Thus, the effect of habitat quality on the EBI was largely independent of estuary, despite the interesting differences between estuaries suggested in Figure 2. It is worth pointing out, however, that the highest values of the EBI occurred in residual eelgrass habitats of Ninigret Pond, RI, and Mumford Cove, CT. The lack of significance ($P > 0.75$) of the nested term in the analyses, Site(Habitat Quality x Estuary), indicates a high similarity among sites when grouped by habitat within each estuary.

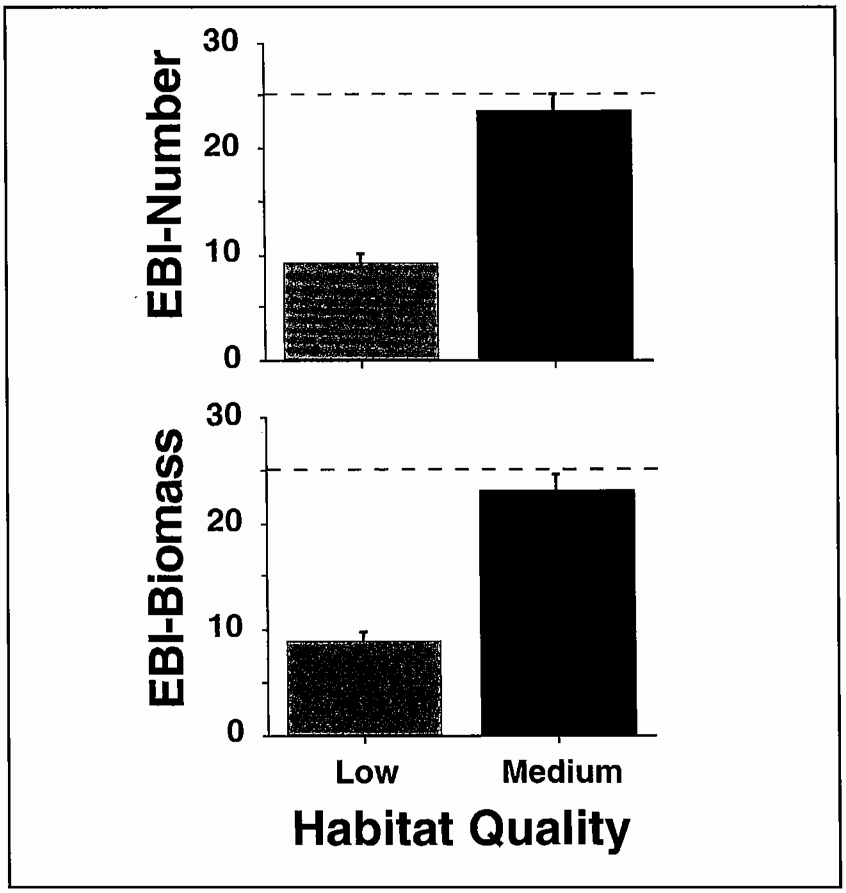

Figure 1. Mean EBI-Number and EBI-Biomass in Rhode Island and Connecticut estuaries, July 1999. Error bars are + 1 S.E. (n = 58 for low-quality habitats; n = 33 for medium-quality habitats). Dashed line indicates the critical EBI value for medium-quality habitats as determined by Deegan et al. (1997). Means for EBI-Number and EBI-Biomass in medium-quality habitats were not significantly lower than the critical value (25; $P > 0.10$).

Our results suggest that the EBI is a useful indicator of habitat quality for these Rhode Island and Connecticut estuaries, and that the shallow-water fish community here responds to habitat quality and habitat change in similar ways to the communities studied in Buzzards Bay and Cape Cod. Further, we suggest that the EBI is applicable to the range of estuaries in the northern portion of the Virginian biogeographic province typified by

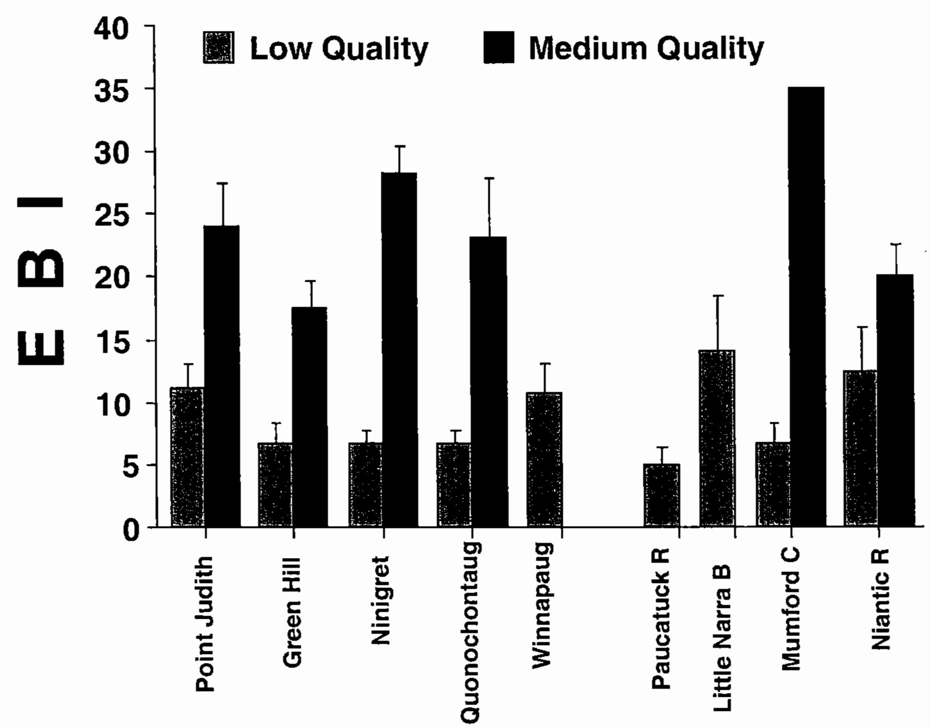

Figure 2. Mean EBI-Number by estuary and habitat quality in Rhode Island (left) and Connecticut (right), July 1999. Error bars are + 1 S.E. (n = 3-13 by habitat type). Green Hill Pond treated separately here from its larger adjoining basin, Ninigret Pond.

extant and historical eelgrass habitat. Extension of the EBI to more southerly portions of the Virginian province, with their greater species richness and different distribution of life history types, will likely require adjustment of critical metric values and perhaps the selection of different metrics (Wyda *et al.*, submitted; Hughes, in prep.).

The EBI shows that extant eelgrass habitats in Rhode Island and Connecticut estuaries, while having undergone serious declines in recent years (Short and Burdick, 1996; R. Rozsa, pers. com.), have retained high value to shallow-water fish communities. The eelgrass meadows in Ninigret Pond and Mumford Cove, for example, while representing less than half of their historical extent, continue to support a high abundance and diversity of small fishes. For many of these species eelgrass is critical nursery habitat, and is also the preferred habitat of several estuarine resident species (Hughes *et al.,* (a) submitted). On the other hand, habitats that have lost eelgrass are typically enmeshed in an autocatalytic syndrome of eutrophication, high turbidity, and oxygen stress (Duarte, 1995, 1999). Their EBI values tend to approach a common nadir (apparently close to 10), as suggested by results in both the present study and for Buzzards and Waquoit Bays (Hughes *et al.*, (b) submitted). The biotic integrity of these systems is depressed similarly, and recovery is uncertain (den Hartog, 1996; Duarte, 1999). Perhaps it is because many of the species affected by eelgrass loss are not "charismatic" or of obvious economic value that their local declines have gone unnoticed. However, these losses may prove to have long-term, cross-ecosystem effects (Ray, 1997).

Table 2. Fish species sorted by number and wet weight as percentage of the total catch in 100 trawl samples, in eight Rhode Island and Connecticut estuaries, summer 1999. Total number of fish caught = 21 x 103; aggregate weight = 21.9 kg.

Species Sorted by % Number	%	Species Sorted by % Weight	%
Menidia menidia	71.4	*Anguilla rostrata*	34.5
Apeltes quadracus	17.0	*Menidia menidia*	23.0
Gasterosteus aculeatus	5.4	*Pseudopleuronectes americanus*	15.7
Osmerus mordax	1.3	*Paralichthys dentatus*	5.7
Syngnathus fuscus	1.2	*Apeltes quadracus*	4.6
Pungitius pungitius	0.9	*Microgadus tomcod*	3.4
Tautoga onitis	0.6	*Morone saxatilis*	3.2
Microgadus tomcod	0.6	*Tautoga onitis*	2.8
Anchoa mitchilli	0.4	*Syngnathus fuscus*	2.0
Fundulus heteroclitus	0.4	*Gasterosteus aculeatus*	1.2
Tautogolabrus adspersus	0.2	*Hippocampus erectus*	0.9
Hippocampus erectus	0.1	*Tautogolabrus adspersus*	0.9
Myoxocephalus aenaeus	0.1	*Osmerus mordax*	0.7
Pseudopleuronectes americanus	0.1	*Myoxocephalus aenaeus*	0.3
Mycteroperca microlepis	0.1	*Pungitius pungitius*	0.3
Anguilla rostrata	0.1	*Pholis gunnellus*	0.2
Stenotomus chrysops	0.1	*Anchoa mitchelli*	0.2
Brevoortia tyrannus	0.1	*Fundulus heteroclitus*	0.2
Pholis gunnellus	< 0.1	*Stenotomus chrysops*	0.1
Leiostomus xanthurus	< 0.1	*Mycteroperca microlepis*	0.1
Lucania parva	< 0.1	*Lucania parva*	< 0.1
Sphyraena borealis	< 0.1	*Sphyraena borealis*	< 0.1
Paralichthys dentatus	< 0.1	*Leiostomus xanthurus*	< 0.1
Morone saxatilis	< 0.1	*Brevoortia tyrannus*	< 0.1
clupeid	< 0.1	clupeid	< 0.1
unidentified	< 0.1	unidentified	< 0.1

With worldwide nitrogen use and release into the environment predicted to rise sharply in the next few decades (Vitousek *et al.,* 1997), the prospects for a rapid return of eelgrass habitats to levels of density and areal extent approaching those of 30 to 50 years ago seem more doubtful than ever. Yet, informed local planning and a public commitment to employ existing advanced sewage treatment technologies could have great positive impact, and might sustain and foster these oases of diversity and productivity in the years to come.

Acknowledgments

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References Cited

Able, K. W. and M. P. Fahay, 1998, *The First year in the Life of Estuarine Fishes in the Middle Atlantic Bight,* Rutgers University, New Brunswick, New Jersey, 343 pp.

Ayvazian, S. G., L. A. Deegan, and J. T. Finn, 1992, Comparison of habitat use by estuarine fish assemblages in the Acadian and Virginian Zoogeographic provinces, *Estuaries* **15**:368-383.

Bigelow, H. B. and W. C. Schroeder, 1953, Fishes of the Gulf of Maine, Fishery Bulletin 74 of the Fish and Wildlife Service, Volume **53**. United States Government Printing Office, Washington, D.C., 577pp.

Cooper, J. A. G., A. E. L. Ramm, and T. D. Harrison, 1994, The estuarine health index: A new approach to scientific information transfer. *Ocean and Cstl. Mgmt.* **25**:103-141.

Costa, J. E., 1988, Eelgrass in Buzzards Bay: Distribution, Production and Historical Changes in Abundance, WH-556F, Environmental Protection Agency, Washington, D.C., 204 pp.

Deegan, L. A., J. T. Finn, S. G. Ayvazian, and C. A. Ryder, 1993, Feasibility and application of the index of biotic integrity to Massachusetts estuaries (EBI). Final Project Report, Massachusetts Executive Office of Environmental Affairs, Department of Environmental Protection, North Grafton, Massachusetts, 86 p.

Deegan, L. A., J. T. Finn, S. G. Ayvazian, C. A. Ryder-Kieffer, and J. Buonaccorsi, 1997, Development and validation of an estuarine biotic integrity index, *Estuaries* **20**:601-617.

den Hartog, C., 1996, Sudden declines of seagrass beds: "Wasting disease" and other disasters, p. 307-314, *In* J. Kuo, R. C. Phillips, D. I. Walker, and H. Kirkman (eds.), *Seagrass Biology*, University of Western Australia, Nedlands, Western Australia.

Duarte, C. M., 1995, Submerged aquatic vegetation in relation to different nutrient regimes, *Ophelia* **41**:87-112.

Duarte, C. M., 1999, Seagrass ecology at the turn of the millennium: Challenges for the new century, *Aquat. Bot.* **65**:7-20.

Ferreira, J. G., 2000, Development of an estuarine quality index based on key physical and biogeochemical features, *Ocean and Cstl. Mgmt.* **43**:99-122.

Ferrell, D. J. and J. D. Bell, 1991, Differences among assemblages of fish associated with *Zostera capricorni* and bare sand over a large spatial scale, *Mar. Ecol. Prog. Ser.* **72**:15-24.

Heck, K.L. Jr., 1976, Community structure and the effects of pollution in seagrass meadows and adjacent habitats, *Mar. Biol.* **35**:345-357.

Hughes, J. E., L. A. Deegan, J. C. Wyda, M. J. Weaver, and A. Wright, (a) submitted, The effects of eelgrass habitat loss on fish communities in estuaries of Southeastern Massachusetts, USA., *Estuaries.*

Hughes, J. E., L. A. Deegan, M. J. Weaver, and J. E. Costa, (b) submitted, Regional comparison of indices of estuarine water quality, submerged rooted vegetation, and biotic integrity based on fish communities, *Estuaries.*

Karr, J. R., 1981, Assessment of biotic integrity using fish communities, *Fisheries* **6**:21-27.

Karr , J. R., K. D. Fausch, P. L. Angermeier, P. R. Yant, and I. J. Schlosser, 1986, Assessing Biological Integrity in Running Waters: A Method and Its Rationale. Illinois Natural History Survey Special Publication 5.

Kneib, R. T., 1997, The role of tidal marshes in the ecology of estuarine nekton, *Oceanogr. Mar. Biol. Ann. Rev.* **35**:163-220.

Livingston, R. J., 1975, Impact of kraft pulp-mill effluents on estuarine and coastal fishes in Apalachee Bay, Florida, U.S.A., *Mar. Biol.* **32**:19-48.

Oberdorff, T. and R. M. Hughes, 1992, Modification of an index of biotic integrity based on fish assemblages to characterize rivers of the Seine Basin, France, *Hydrobiol.* **228**:117-130.

Raffaelli, D. G., J. R. Raven, and L. J. Poole, 1998, Ecological impact of green macroalgal blooms. *Oceanogr. Mar. Biol. Ann. Rev.* **36**:97-125.

Ramm, A. E. L., 1990, Application of the community degradation index to South African estuaries. *Water Res.* **24**:383-389.

Ray, G. C., 1997, Do the metapopulation dynamics of estuarine fishes influence the stability of shelf ecosystems? *Bull. Mar. Sci.* **60**:1040-1049.

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

Short, F. T., D. M. Burdick, J. S. Wolf, and G. E. Jones, 1993, Eelgrass in estuarine reserves along the East Coast, USA. Part I: Declines from pollution and disease and Part II: Management of eelgrass meadows, NOAA - Coastal Ocean Program Publication, Rockville, Maryland.

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

Short, F. T., D. M. Burdick, S. Granger, and S. W. Nixon, 1996, Long-term decline in eelgrass, *Zostera marina* L., limked to increased hosing development, p. 291-298, *In* J. Kus, R. C. Phillips, D. I. Walker, and H. Kirkman (eds.), *Seagrass Biology: Proceedings of a Workshop,* Sciences UWA, Nedlands, Western Australia.

Simon, T. P. (ed.), 1999, *Assessing the Sustainability and Biological Integrity of Water Resources Using Fish Communities*, CRC, New York, 671 pp.

Underwood, A. J., 1981, Techniques of analysis of variance in experimental marine biology and ecology Oceanogr. *Mar. Biol. Ann. Rev.* **19**:513-605.

Valiela, I., K. Foreman, M. LaMontagne, D. Hersh, J. Costa, P. Peckol, B. DeMeo-Anderson, C. D'Avanzo, M. Babione, C.-H. Sham, J. Brawley, and K. Lajtha, 1992, Couplings of watersheds and coastal waters: Sources and consequences of nutrient enrichment in Waquoit Bay, Massachusetts, *Estuaries* **15**:443-457.

Valiela, I., J. McClelland, J. Hauxwell, P. J. Behr, D. Hersh, and K. Foreman, 1997, Macroalgal blooms in shallow estuaries: Controls and ecophysiological and ecosystem consequences, *Limnol. Oceanogr.* **42**:1105-1118.

Vitousek, P.M,, J. D. Aber, R. W. Howarth, G. E. Likens, P. A. Matson, D. W. Schindler, W. H. Schlesinger, and D. G. Tilman, 1997, Human alteration of the global nitrogen cycle: Sources and consequences, *Ecol. Appl.* **7**:737-750.

Winer, B. J., 1971, *Statistical Principles in Experimental Design,* 2nd ed., McGraw-Hill, New York, 907 pp.

Wyda, J. C., L. A. Deegan, M. J. Weaver, and J. E. Hughes, (submitted). The response of fishes to nutrient loading-induced habitat change in two ecoregions of the Mid-Atlantic Bight: Buzzards Bay and Chesapeake Bay, *Estuaries.*

DISEASES AND PATHOBIOLOGY

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Flow Cytometry as a Tool to Quantity Oyster Defense Mechanisms

M. Goedken and S. DeGuise
Department of Pathobiology
University of Connecticut
Storrs, CT 06269

Aquaculture is a fast-growing industry in the United States. The growth of the cultured oyster industry is greatly hindered by the parasites MSX and Dermo, which can kill up to 80% of the harvest. The relationship between the parasites and the oyster defense mechanisms is unclear. Phagocytosis of MSX is rare while Dermo appears to be phagocytized but not destroyed. Oyster defense mechanisms have been previously evaluated for populations of cells though usually indirectly. Fluorescent latex microsphere ingestion allowed quantification of phagocytosis, which occurs rapidly and peaks at 24 hours. Respiratory burst was evaluated by monitoring the molecular alteration of the probe DCFDA by peroxide production. Flow cytometry demonstrated three populations of hemocytes: granulocytes, hyalinocytes and an intermediate population. The three different cell populations had different functional characteristics. Granulocytes were most active at phagocytosis and peroxide production while hyalinocytes were relatively inactive. The intermediate cells had moderate phagocytic and respiratory burst activity. Flow cytometry has the advantage of direct quantification of the morphology and function of a large number of individual cells with the ability to isolate and sort subpopulations. The characterization of oyster defense mechanisms at the single cell level using sensitive and specific assays will allow further study of the pathogenesis of economically important diseases.

Survey of *Brucella* in Marine Mammals Stranded off the Coast of Southern New England.

Jennifer Maratea*, Salvatore Frasca Jr.*, Sylvain DeGuise*, David J. St. Aubin†, J.Lawrence Dunn†, Lech Szkudlarek‡ and Richard A. French*.
*University of Connecticut, Department of Pathobiology, Storrs, CT 06269-3089.
Phone: (860) 486-2745.
†Mystic Aquarium Institute for Exploration, 55 Coogan Blvd., Mystic, CT 06355.
Phone: (860) 572-5955.
‡USDA, APHIS, VS, Sutton Square Plaza, Sutton, MA 01590.
Phone: (508) 865-1421.

Species of *Brucella* infect wild and domestic terrestrial mammals, including humans, and have recently been isolated from several marine mammal species. The prevalence of *Brucella* in marine mammals has not been determined for southern New England populations, and the significance of *Brucella* infection to individual marine mammals is unknown. A collaborative research investigation involving regional Veterinary Services, APHIS, USDA and Mystic Aquarium has been undertaken with the goal of determining 1) the seroprevalence of *Brucella* in stranded marine mammals recovered from the southern New England coastline and 2) the tissue distribution of *Brucella* in infected marine mammals. The exposure to, or presence of, *Brucella* in marine mammals was tested by serologic and bacteriologic culture techniques. Gross and histologic examinations were performed and results correlated with serology and bacteriology. To date, 6 of 118 (5%) archived serum samples, representing 2 species of phocid seals, tested positive for exposure to *Brucella*. *Brucella* was cultured from multiple tissues of 5 of 20 live-stranded seals examined during 1998-2000. Brucellosis remains a zoonosis of world public health and economic importance. Data generated from this research will be integral to future epizootiologic studies designed to assess the spread of *Brucella* within marine mammal populations as well as, the potential risk of disease transmission to marine finfish and shellfish, terrestrial mammals, and humans.

Diagnostic Techniques for the Detection of Dermo, MSX, and SSO in the Eastern Oyster, *Crassostrea virginica*

Spencer Russell, Soledad Penna and Richard A. French
Pathobiology Department
University of Connecticut
Storrs, CT 06269

Protozoan infections are of great concern in oyster cultivation, because they cause economic losses in commercial production. The surveillance, management and control of theses diseases of the oyster require diagnostic aids, which are sensitive, rapid, cost effective and convenient. A multiplex polymerase chain reaction (MPCR) has been developed which rapidly detects the protozoan parasites, *Perkinsus marinus* (Dermo), *Haplosporidium nelsoni* (MSX) and *Haplosporidium costale* (SSO) which infect the cultured oyster, *Crassostrea virginica.* Conventional diagnostic methods (histopathology and Ray Mackin fluid thiogycollate assay) for *H. nelsoni, H. costale* and *P. marinus* respectively were compared and evaluated with the MPCR. Ninety-one adult oysters were collected randomly selected oyster bed in Westport, CT (n=37) and Milford, CT (n=54) and subjected to all three assays. The Ray/Mackin assay detected *P. marinus* infections in 59 of 91 (64%) oysters and the MPCR revealed infections in 73 of 91 (80%) oysters. Histological examination detected 37 of 91 (40%) oysters infected with *Haplosporidium plasmodia.* The MPCR was able to differentiate between the two *Haplosporidium plasmodia*, detecting 9 of 91 (35%) oysters with mixed infections of *H. nelsoni* and *H. costale.* Theses results indicate the MPCR is a more sensitive assay for the detection of *P. marinus* and is able to detect and differentiate between the two *Haplosporidium* species. In addition the MPCR can be useful at low infections intensities by being able to detect pathogen levels as low as 10 fg. for *H. nelsoni* and 1 pg. for both *H. costale* and *P. marinus.*

Long Island Sound Lobster Morbidity and Mortality Diagnostic Investigation

S. DeGuise, S. Russell, T. Burrage, C. Koerting, S. Frasca Jr., and R.A. French
Pathobiology Department
University of Connecticut
Storrs, CT 06269-3089

In 1999, Long Island Sound was devastated by a mass mortality of lobsters which critically damaged the regional lobster industry. Necropsies were performed on 175 individual lobsters collected from six different locations in Long Island Sound. Gross observations observed in 'sick' lobsters included a pink discoloration to the ventral surfaces of the abdomen and viscera and lethargic/limp behavior. Associated with affected lobsters was a coagulopathy of hemocytes, characterized by inability of hemolymph to clot. Bacteriologic findings included isolation of a *Vibrio* sp. from a single sample group. To date, no *Aeromonas viridins* has been isolated. Histopathologic examination has been conducted on numerous tissues, including heart, gill, hepatopancreas, antennary glands, intestine, muscle, exoskeleton, eyes, antennae, ventral nerve cord and nerve ring ganglia. The histopathologic findings are consistent with a systemic inflammatory disease affecting multiple tissues but primarily the nervous system. Associated with the lesions is a protozoan parasite morphologically characterized as an amoeba, tentatively paramoeba sp.

SEDIMENT FORMS AND MONITORING

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The Distribution and Accumulation of Contaminated Sediments in Long Island Sound

Ellen L. Mecray, Marilyn Buchholtz ten Brink, Sunita Shah, and Erin L. Galvin
U.S. Geological Survey, Coastal and Marine Geology,
Woods Hole Field Center, 384 Woods Hole Road,
Woods Hole, MA 02543
(508) 548-8700.

Abstract

Future regulation of contaminant impacts to the Sound, as well as present management issues, dictate the need to understand the distribution and fate of these contaminants (Figure 1). The U.S. Geological Survey conducted a five-year study of the regional sediment quality and dynamics of Long Island Sound (Figure 2). The concentrations of sediment contaminants in the entire Sound were mapped in an effort to understand their regional distribution and transport processes. Samples were collected and analyzed from 219 surface stations and 58 core locations in order to assess the historical trends and anthropogenic indicators of contaminants in the Sound (Mecray and Buchholtz ten Brink, 2000). The measured parameters included major (Al, Fe, Mn, Ca, and Ti) and trace (Ag, Ba, Cd, Cr, Cu, Hg, Ni, Pb, V, Zn, and Zr) elements, grain size, carbon concentrations, and *Clostridium perfringens* spores. Each of these parameters have been mapped for surface distribution and cross-compared to evaluate the anthropogenic impact in Long Island Sound sediments.

Principal Components Analysis was used to group the measured parameters and consider common sources and behaviors (Mecray and Buchholtz ten Brink, 2000). The statistical results showed groups of anthropogenic and lithogenic elements. The anthropogenic parameters included Ag, Cd, Cr, Cu, Hg, Pb, Zn, fine-grained sediment textures, and *Clostridium perfringens* spores. This group had similar patterns in the surface sediment record with high concentrations in the western Sound and low concentrations in the eastern part of the Sound. The lithogenic parameters, Al, Ba, Ca, Fe, Mn, Ti, and V, also had similar distributions with generally low concentrations throughout the Sound, and some patches of high values in the eastern Sound. The distribution of these elements, as well as that of the *Clostridium perfringens* (Buchholtz ten Brink *et al.*, 2000), showed patterns similar to the sedimentary environments (Knebel and Poppe, 2000), the bottom stress model results (Signell *et al.*, 2000), and the texture distribution (Poppe and Polloni, 1998; Poppe *et al.*, 2000; Paskevich and Poppe, 2000).

Work in Progress

1) Sediment toxicity to biota

2) Predictive transport models for fine-grained material

3) Historical records of contaminants using dated cores

4) Contaminant budgets/predictive box models

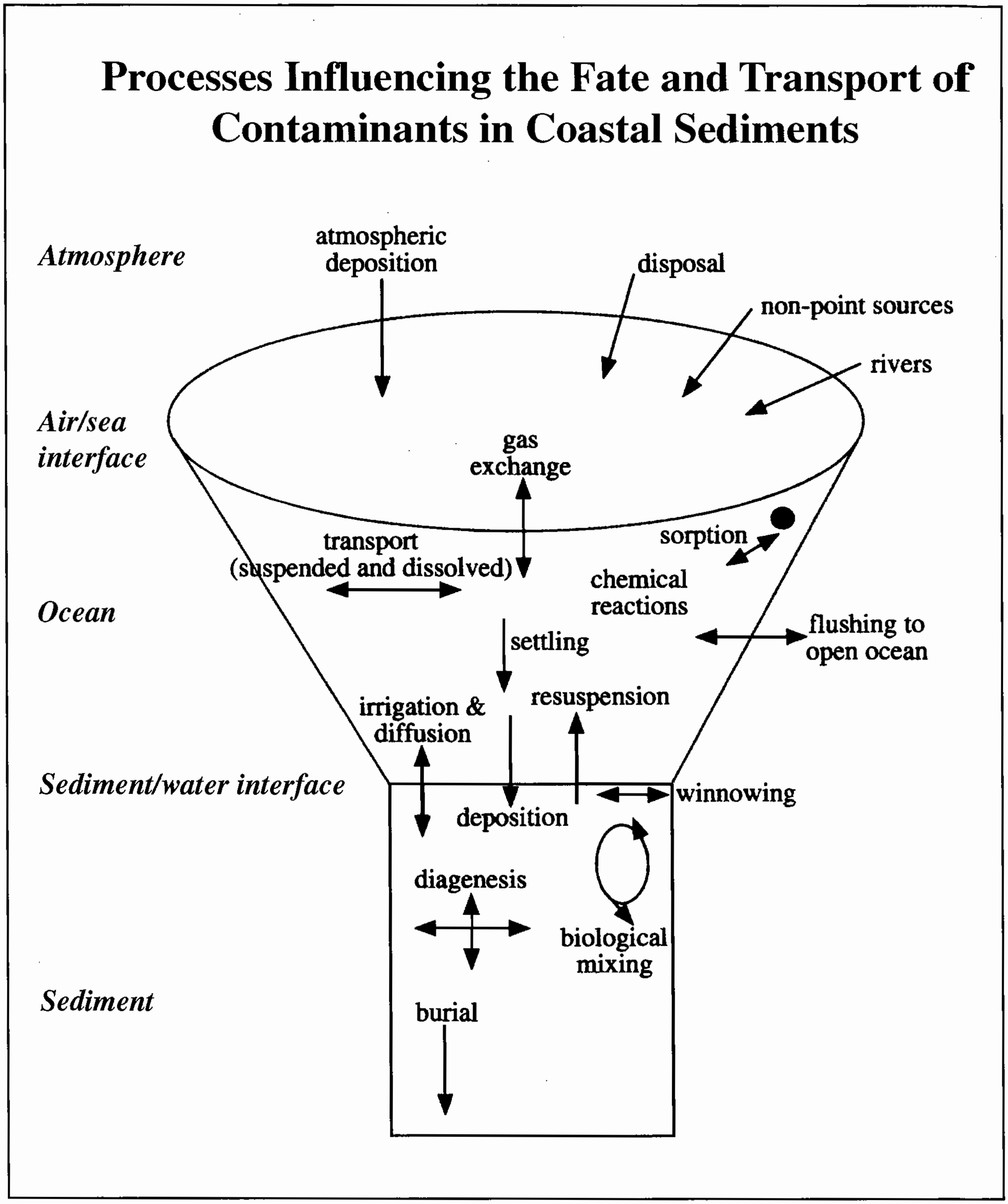

Figure 1. A schematic diagram illustrating the origin, fate, and transport of contaminants in the Long Island Sound system. The processes of primary concern include the sorption of contaminants onto particles in the water column and their ultimate deposition of the sea-floor.

Collaborative Research

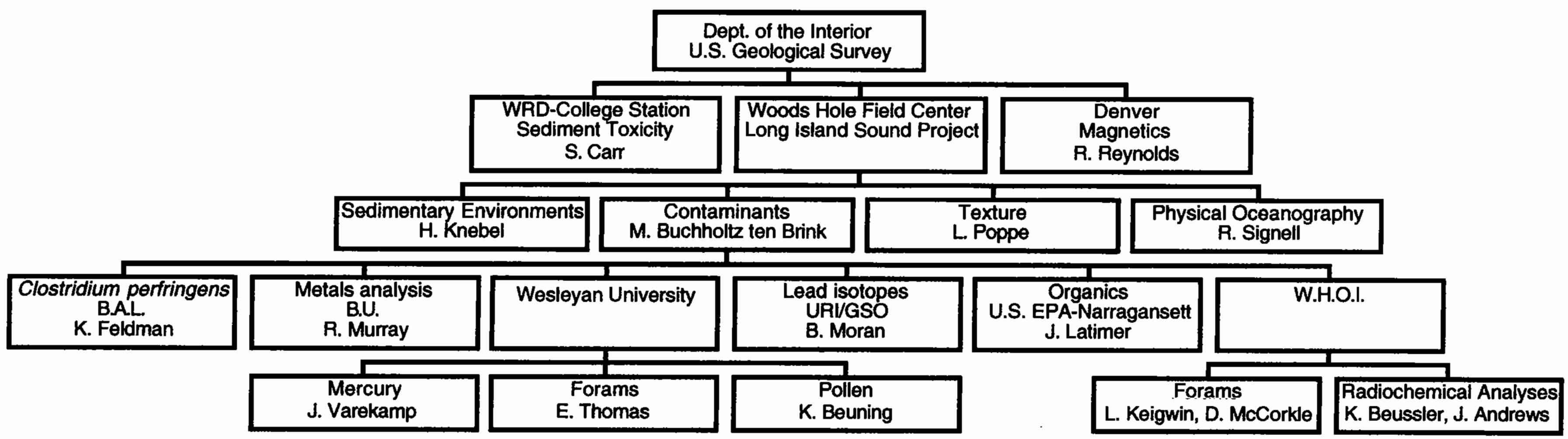

Figure 2: An organizational pyramid illustrating the role of the U.S. Geological Survey in the current and future efforts to study contaminants in Long Island Sound.

Conclusions

1) Geochemical data are used to: (1) establish a regional contamination baseline for temporal studies; (2) identify areas of high concentration; (3) elucidate transport and deposition processes affecting contaminant distributions; and (4) generate tools for regional management.

2) Factor analysis indicates common sources or geochemical behaviors. Factor 1= anthropogenic elements, fines, and *C. perf.*; Factor 2= elements associated with diagenesis; Factor 3= elements derived from source rocks; and Factor 4= non-metal sewage components.

3) Enrichment values indicate the extent of anthropogenic contamination. Ag and Cu were 4-5 times greater than background. Zn, Pb, and Mn were 1-2 times greater, and the major elements were not enriched in the surface sediments.

4) Regional patterns result from bottom energy variations and differing sedimentary environments.

References

Buchholtz ten Brink, M.R., E.L. Mecray, and E.L. Galvin, 2000, *Clostridium perfringens* in Long Island Sound Sediments: An Urban Sedimentary Record, *Journal of Coastal Research* **16**:3, pp. 591-612.

Knebel, H.J. and L.J. Poppe, 2000, Sea-Floor Environments within Long Island Sound: A Regional Overview, *Journal of Coastal Research* **16**:3, pp. 535-550.

Mecray, E.L. and M.R. Buchholtz ten Brink, 2000, Contaminant Distribution and Accumulation in the Surface Sediments of Long Island Sound, *Journal of Coastal Research* **16**:3, pp. 575-590.

Paskevich, V.F. and L.J. Poppe (Eds.), 2000. *Geo-Referenced Sea-Floor Mapping and Bottom Photography in Long Island Sound.* USGS Open-File Report 00-304. (CD-ROM).

Poppe, L.J. and C. Polloni (Eds.), 1998. *Long Island Sound Environmental Studies.* USGS Open-File Report 98-502. (CD-ROM).

Poppe, L.J., H.J. Knebel, Z.J. Mlodzinska, M.E. Hastings, and B.A. Seekins, 2000, Distribution of Surficial Sediment in Long Island Sound and Adjacent Waters: Texture and Total Organic Carbon, *Journal of Coastal Research* **16**:3, pp. 567-574.

Signell, R.P., J.H. List, and A.S. Farris, 2000, Bottom Currents and Sediment Transport in Long Island Sound: A Modeling Study, *Journal of Coastal Research* **16**:3, pp. 551-566.

Monitoring Benthic Habitat Quality and Near-Bottom Dissolved Oxygen, Ammonia and Hydrogen Sulfide Levels in Response to the 1999-2000 Lobster Die-off Event in Western Long Island Sound

R. Valente. and M. Cole
SAIC
Newport, RI 02841

C. Cuomo
Yale University
New Haven, CT 06520

Fishermen began reporting significant numbers of dead and dying lobsters in the western half of LIS in mid-September 1999. The lobster die-off, which continued into the winter of 2000, is considered unprecedented in magnitude and extent. The health of the American Lobster in LIS is potentially affected by multiple stressors, including disease pathogens and environmental factors. In an attempt to examine one potential stressor (degraded benthic habitat quality), sediment-profile images were obtained at 30 stations throughout western LIS in October 1999, while the lobster dieoff was ongoing. This survey showed a thin layer of oxygenated surface sediments overlying highly anoxic, sulfidic sediments at most stations. This is a typical pattern for western LIS and suggests a high potential for reduced compounds to be introduced into the overlying near-bottom water under severe hypoxic conditions. Follow-up surveys was conducted in late summer and fall of 2000 evaluated potential fluctuations in benthic habitat quality during a four-month period (Aug.-Nov.) and examine the relationship between sediment redox depths and levels of DO, hydrogen sulfide and ammonia in water within 10 cm to the bottom. The August survey showed only moderately reduced levels of DO near the bottom (3 to 5 mg/L), a corresponding absence of hydrogen sulfide/ammonia,and the presence of a thin redox layer at most stations. These results are consistent with the observation that near-bottom hypoxia was neither severe nor prolonged in western LIS in summer/fall 2000. The highly anoxic appearance of the sediment at most stations suggests that the potential exists for sulfide/ammonia poisoning of near-bottom waters should oxygen become completely depleted during severe hypoxia events.

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Clostridium perfringens as a Sewage Tracer in Long Island Sound Sediments

Marilyn R. Buchholtz ten Brink[1], Ellen L. Mecray[1], Erin L. Galvin[1] and Kathleen Feldman[2]
[1]U.S. Geological Survey, Center for Coastal and Marine Geology
Woods Hole, MA, 02543

[2]BAL Laboratory
Microbiology Division of Thielsch Engineering, Inc.,
185 Frances Ave
Cranston, RI, 02910

Clostridium perfringens is a conservative tracer and an indicator of sewage-derived pollution in the marine environment. The bacterium, *C. perfringens*, is present in the intestinal tracts of mammals. Its spores survive primary waste treatment and are deposited with fine-grained sediments in coastal environments (Buchholtz ten Brink *et al.*, 2000a, and references therein). *C. perfringens* concentrations, and their distribution, in sediments of Long Island Sound indicate both historical and present-day sewage-derived pollution in the region.

The distribution of *C. perfringens* spores was measured in sediments from Long Island Sound as part of a regional study (Buchholtz ten Brink and Mecray, 1998, 2000; Poppe and Polloni, 1998) designed to: (1) map the distribution of contaminated sediments; (2) determine transport and dispersal paths; (3) identify the locations of sediment and contaminant focusing; and (4) constrain predictive models. Sediment cores were collected in 1996 from 58 stations and surface sediments were collected (1996-1997) at 219 locations throughout the Sound. *C. perfringens* concentrations, sediment grain size, and a suite of chemical properties were measured in these samples (Buchholtz ten Brink *et al.*, 2000b, Mecray *et al.*, 2000).

Concentrations in surface sediments (Figure 1) are highest in the western end of the Sound, intermediate in the central part, and very low in the eastern region (see Buchholtz ten Brink *et al.*, 2000a). *C. perfringens* concentrations range from undetectable amounts to 15,000 spores/g dry sediment. The concentrations are above background levels in the upper 30 cm for nearly all core locations (Figure 2). Sediment focusing and reworking (Knebel and Poppe, 2000) strongly impacts the dispersion and accumulation of *C. perfringens* spores. The steep gradients in *C. perfringens* profiles in muddier cores contrast with concentrations that are generally constant with depth in sandier cores.

Inventories in the cores range from 28 to 70,000 spores/cm^2, and elevated concentrations can extend to depths of 50 cm (Buchholtz ten Brink *et al.*, 2000b). *C. perfringens* concentrations; however, rarely decrease in the uppermost sediment, unlike those for metal contaminants (Buchholtz ten Brink and Mecray, 2000; Varekamp *et al.*, 2000). This suggests that regulatory actions taken to reduce sources of metal pollutants to the environment have been effective in decreasing metals contamination of coastal ecosystems, but improvements in wastewater treatment technologies have not sufficiently alleviated the impact of increasing population on the Sound.

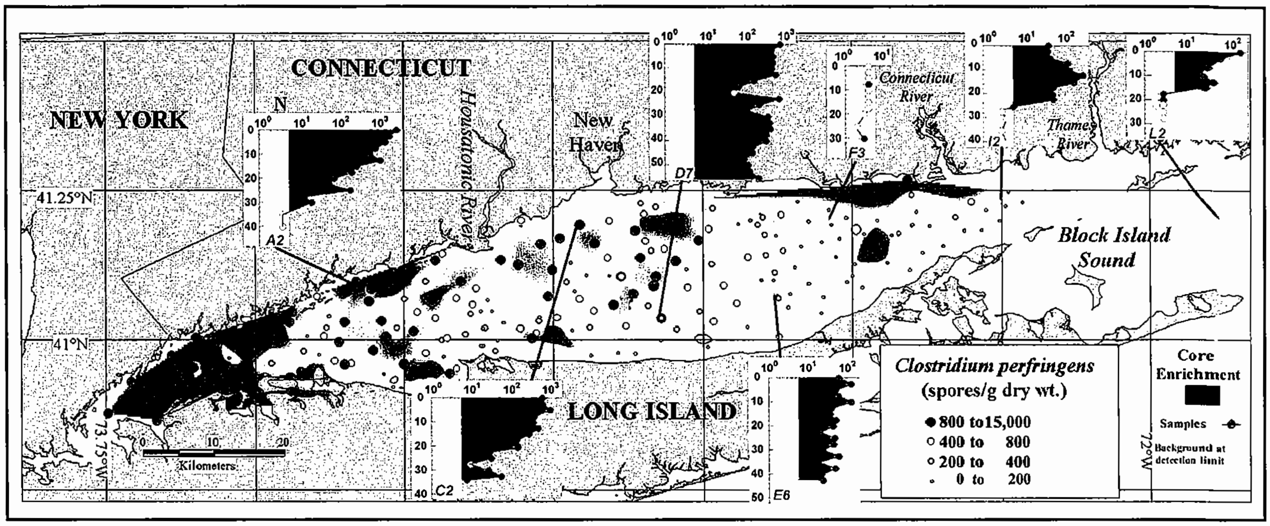

Figure 1. Map of the location of surface sediment samples and the concentration of *C. perfringens* spores in grab (0-2 cm) and selected core samples in Long Island Sound. Higher concentrations are given as larger dots and darker colors. Data was contoured from surface sediment measurements using the triangulation interpolation (TIN) technique. Insets show *C. perfringens* profiles in sediment cores from differing sedimentary environments (Knebel and Poppe, 2000). Cores from stations A2, C2, I2, and L2 show changes over time and have background (≤ detection limit) *C. perfringens* concentrations, indicating pre-anthropogenic sediment, at the core bottom. Stations A2 and C2 are in muddy, depositional regions. Sediment mixing masks the historical record for cores from stations D7 and E6. Concentrations and inventories are low for the sandy core from station E6, and non-detectable at station F3, which is located in an erosional/reworked sedimentary environment.

The distribution patterns of both *C. perfringens* and sewage-derived contaminants (Mecray and Buchholtz ten Brink, 2000; Poppe *et al.*, 2000) reflect (1) winnowing and focusing of *C. perfringens* spores and fine-grained sediment by the hydrodynamic regime (Signell *et al.*, 2000) and (2) the greater volume and proximity of sewage sources to the westernmost Sound (U.S. EPA, 2000).

The *C. perfringens* distributions are useful in studying the history, sources, and fate of other pollutants found in LIS sewage waste-streams, e.g., organic carbon, mercury, and heavy metals, and the impact of these pollutants (Beuning *et al.*, 2000; Mecray *et al.*, 2000; Thomas *et al.*, 2000; Varekamp *et al.*, 2000). Elevated concentrations of *C. perfringens* in the sediments indicate that sewage pollution is present throughout Long Island Sound and has persisted for more than a century. Increases in both population and *C. perfringens* in sediments (Buchholtz ten Brink *et al.*, 2000a) suggests that population pressure may become an increasing cause of ecosystem degradation in the future.

References

Beuning, K.R.M., L. Franse, N. Berna, E.L. Mecray and M.R. Buchholtz ten Brink, 2000. Modern pollen deposition in Long Island Sound. *J. Coastal Research* **16**:656-662.

Buchholtz ten Brink, M.R. and E.L. Mecray, 2000. Regional accumulation of contaminated sediments in Long Island. In: *Long Island Sound 1998 Research Conference Proceedings,* Whitlatch, R.B. and J.R. Wood-Martin (eds.), Connecticut Sea Grant College Program ISBN 1-878301-05-5. pp. 1-19.

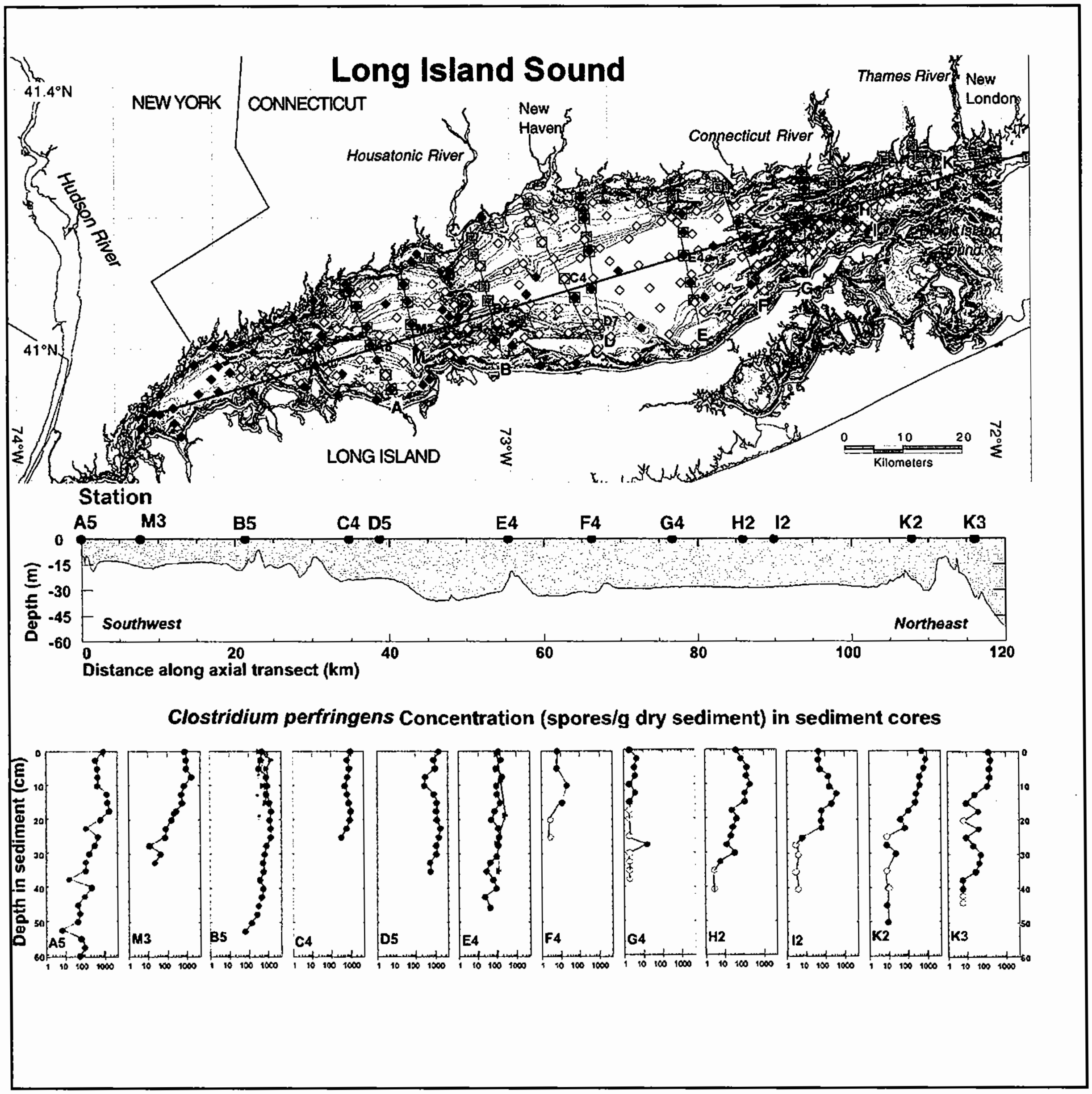

Figure 2.

Bathymetry of Long Island Sound and profiles of *C. perfringens* in cores along an axial transect of the Sound. Top: bathymetric contours (NOAA, 1999), grab locations (diamonds), core locations (squares with N-S transect lines), and axial transect (bold line). Center: cross-sectional bathymetry and core locations long the axial transect. Bottom: profiles of *C. perfringens* concentrations in these cores. Scales are the same for all cores. The log scale for concentration allows comparison of values that range across three orders of magnitude. Plotted samples are in 0.5-cm depth intervals, maximum error bars of ± 25% are shown, and open symbols are ≤ detection limit. The shaded bar indicates a representative, pre-contaminant background value. High inventories and increasing concentrations towards the core tops for *C. perfringens* in the cores along lines A through E (the central and western basins) indicate the presence of long-standing, widespread and continuing sewage-related pollution in the fine-grained sediments of Long Island Sound.

Buchholtz ten Brink, M.R. and E.L. Mecray, 1998. Chapter 5 In: *Long Island Sound Environmental Studies*. L.J. Poppe and C. Polloni (eds), U.S. Geological Survey Open-File Report 98-502, CD-ROM.

Buchholtz ten Brink, M.R., E.L. Mecray and E.L. Galvin, 2000a. *Clostridium perfringens* in Long Island Sound Sediments: An Urban Sedimentary Record. *J. Coastal Research* **16**:591-612.

Buchholtz ten Brink, M.R., E.L. Mecray, E.L. Galvin and K. Feldman, 2000b. *Clostridium perfringens* distribution in Long Island Sound sediments: Data Report. Chapter 8 In: *Georeferenced Sea-Floor Mapping and Bottom Photography in Long Island Sound*, V.F. Paskevich and L.J. Poppe (eds.), U.S. Geological Survey Open-File Report **00-304**, 1 CD-ROM.

Knebel, H.J. and L.J. Poppe, 2000. Sea-floor environments within Long Island Sound: A regional overview. *J. Coastal Research* **16**:533-550.

Mecray, E.L. and M.R. Buchholtz ten Brink, 2000. Contaminant distribution and accumulation in the surface sediments of Long Island Sound. *J. Coastal Research* **16**:575-590.

Mecray, E.L., M.R. Buchholtz ten Brink and S.R. Shah, 2000. Metals in the surface sediments of Long Island Sound. Chapter 6 In: *Georeferenced Sea-Floor Mapping and Bottom Photography in Long Island Sound*, V.F. Paskevich and L.J. Poppe (eds.), U.S. Geological Survey Open-File Report **00-304**, 1 CD-ROM.

NOAA (National Oceanic and Atmospheric Administration), 1999. National Ocean Service Estuarine Bathymetry. URL: <http://SPOserver.nos.noaa.gov/bathy/index.html>.

Poppe, L.J. and C. Polloni (eds.), 1998. Long Island Sound Environmental Studies. U.S. Geological Survey Open-File Report **98-502**, 1 CD-ROM.

Poppe, L.J., H.J. Knebel, Z.J. Mlodzinska, M.E. Hastings and B.A. Seekins, 2000. Distribution of surficial sediment in Long Island Sound and adjacent waters: Texture and total organic carbon. *J. Coastal Research* **16**:567-574.

Signell, R.P., J.H. List and A.S. Farris, 2000. Bottom currents and sediment transport in Long Island Sound: A modeling study. *J. Coastal Research* **16**:551-566.

Thomas, E., T. Gapotchenko, J.C. Varekamp, E.L. Mecray and M.R. Buchholtz ten Brink, 2000. Distribution of benthic foraminifera in Long Island Sound in the 1990s. *J. Coastal Research* **16**:641-655.

Varekamp, J.C., M.R. Buchholtz ten Brink and E.L. Mecray, 2000. Mercury in Long Island Sound sediments. *J. Coastal Research* **16**:613-626.

U.S. EPA (U.S. Environmental Protection Agency), 2000. National Pollutant Discharge Elimination System (NPDES). URLs: <http://www.epa.gov/owm/gen2.htm> and <http://www.epa.gov/enviro/html/pcs/pcs.overview.html>.

Variability in Temperature, Salinity and Dissolved Oxygen Measurements from Time Series Observations in Long Island Sound

M.M. Howard-Strobel, W.F. Bohlen, D.R. Cohen, and P.A. Tebeau
University of Connecticut, Department of Marine Sciences
1080 Shennecossett Road
Groton, CT 06340

The large-scale hydrographic variability of Long Island Sound has been documented by various state agencies using shipboard surveys on fortnightly to monthly time scales. These surveys typically take a single point sample at each station and encompass a 2-3 day period. The contour maps compiled from these data show the spatial distribution and relative value of the parameter of interest (e.g., dissolved oxygen) within the Sound (Figure 1). The interpretation of these contour maps can be misleading in that they suggest that the measured parameter is a static patch over the period of the survey(s), which in turn implies that the bottom biota are subject to conditions which are also static. We believe that the

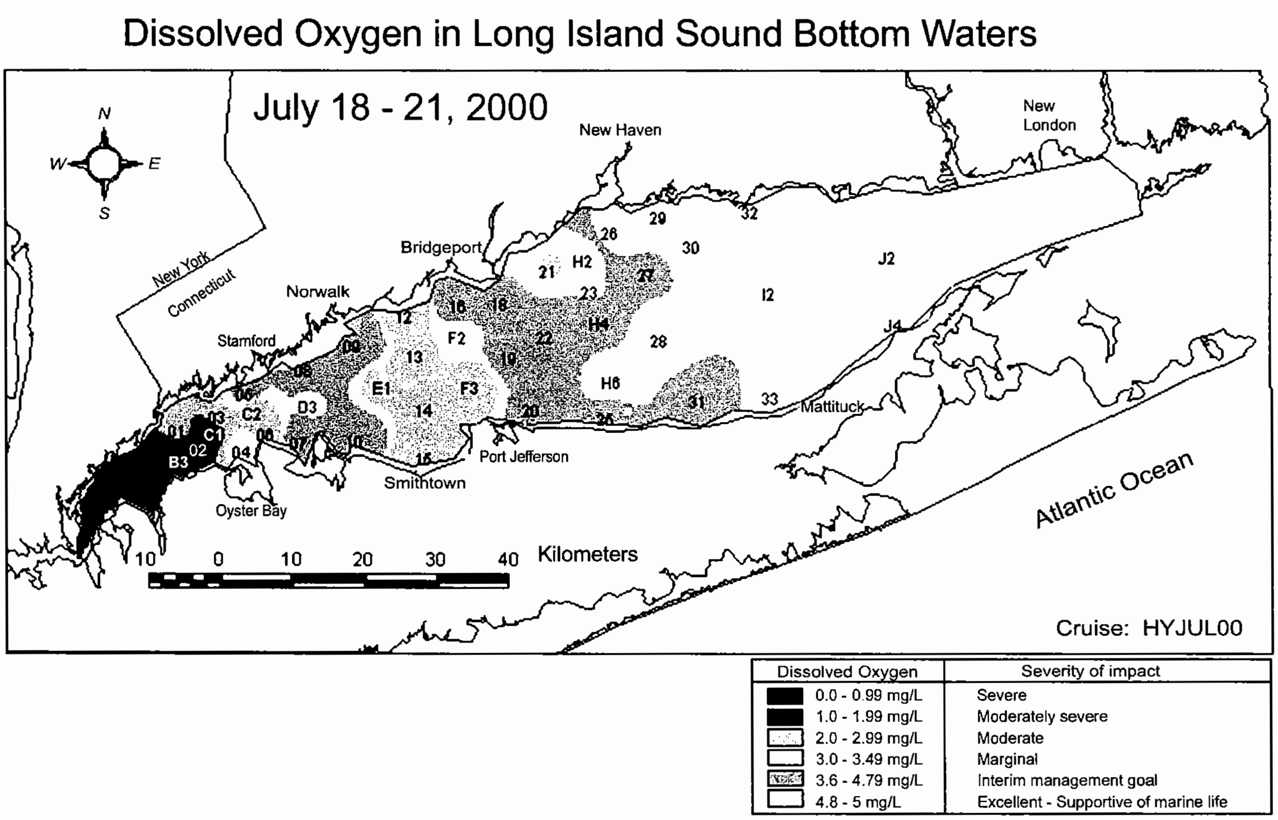

Figure 1. An example contour map of dissolved oxygen concentrations in Long Island Sound from the CT DEP summer survey of July 18-20, 2000.

time variability of hydrographic measurements is under sampled within the Sound, and that sampling at higher frequency can reveal far more information regarding conditions that may contribute to the stress levels to which biota are subjected. Several buoys have been deployed within Long Island Sound (Figure 2), which are measuring temperature (T), salinity (S) and dissolved oxygen (DO) every 15 minutes at two points on the vertical, near bottom and surface. We examine two years of summer time series data collected from Bridgeport Harbor, in the western Sound, and at the New London Disposal Site in the eastern Sound. These data are used to show the greater detail and accuracy to which the extent and occurrence of anomalous water quality conditions can be documented. We also show recently obtained time series data from a third station in the western Sound which captures the duration and timing of the fall destratification event.

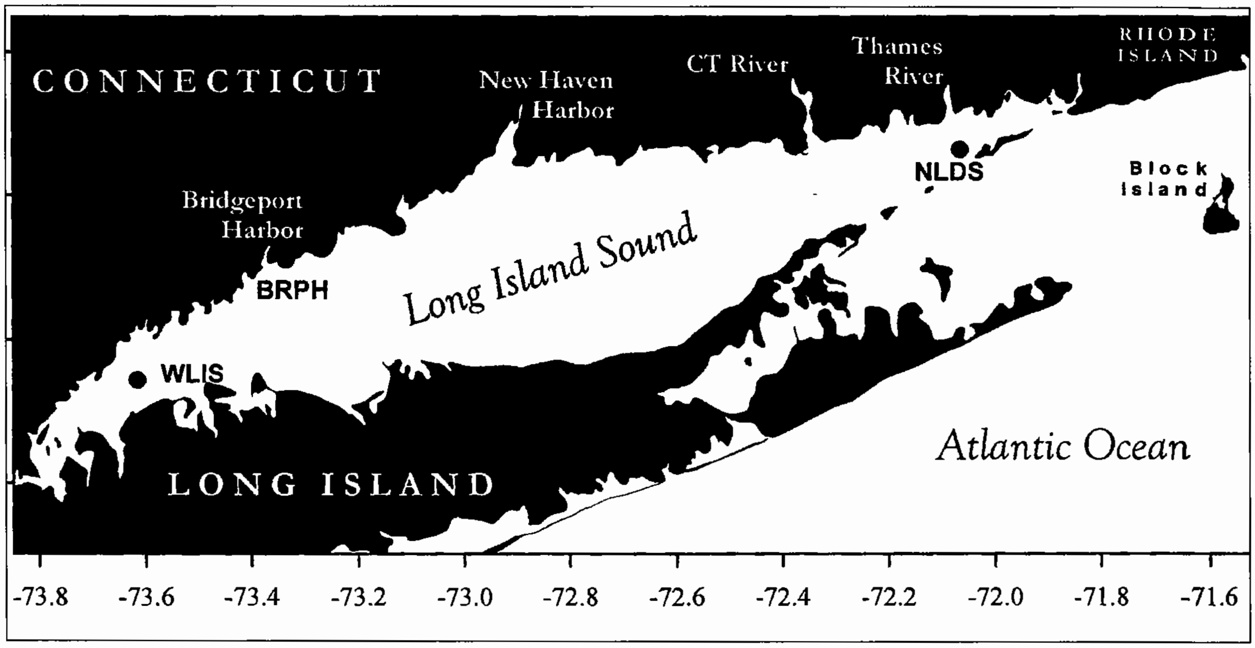

Figure 2. Location of monitoring stations in Long Island Sound; NLDS - New London Dumpsite, BRPH - Bridgeport Harbor, WLIS - Western Sound Lobster Station.

The summer time series data for Bridgeport Harbor and the New London Disposal Site cover the period July 1 through the end of August for both 1999 and 2000. A statistical summary of the time series data reveals significantly higher bottom salinities in 1999 compared with 2000 at both the western and eastern end of the sound. Surface salinity is not significantly different year to year except for the August data from Bridgeport which is higher in 1999 then in 2000 (Figure 3a and 3b). The temperature data show the cooler, less variable nature of the eastern Sound waters. While there is a cooling trend from 1999 to 2000, the differences are not significant in either the bottom or surface waters (Figure 3c and 3d). The dissolved oxygen concentrations are also less variable in the eastern Sound than in the western end, and, again, while there is a trend toward slightly higher concentrations in 2000 relative to 1999, the differences are not statistically significant (Figure 3e and 3f). The dissolved oxygen concentration data can be further summarized using histograms of occurrence *vs.* concentration. Figures 4a and 4b illustrate the greater frequency of occurrence of lower concentration levels in the western Sound at Bridgeport Harbor relative to the eastern sound. These frequency data can be subsequently analyzed as shown in Table 1, where all dissolved oxygen concentrations equal to or lower than 3.5 mg/L (hypoxic conditions) are compiled with dates and duration. The actual duration of these events, in Bridgeport Harbor, is on the order of hours and occur at all stages of the tidal cycle.

Table 1.
Occurrences and Duration of Hypoxic* Events in Bridgeport

Bridgeport Harbor				
	Day	t0	Duration (hrs)	Tide
1999	04-Aug	0700	1.00	mid ebb
	16-Aug	0515	2.00	mid ebb
2000	25-Jul	0330	0.75	mid flood
	09-Aug	0345	2.00	start flood
	10-Aug	0945	1.25	start ebb
	11-Aug	0845	3.50	end flood

* concentrations ≤ 3.5 mg/L

Data from the recently deployed western Sound station (WLIS), south of Greenwich CT (Figure 2), can be analyzed similarly. Although the data only covers several months and no between-year comparisons can be made, a histogram of occurrence *vs.* dissolved oxygen concentration can be compiled (Figure 5) showing a high frequency of occurrence of concentrations near 5 mg/L. Further analysis of the time series data documents the evolution of destratification at this site.

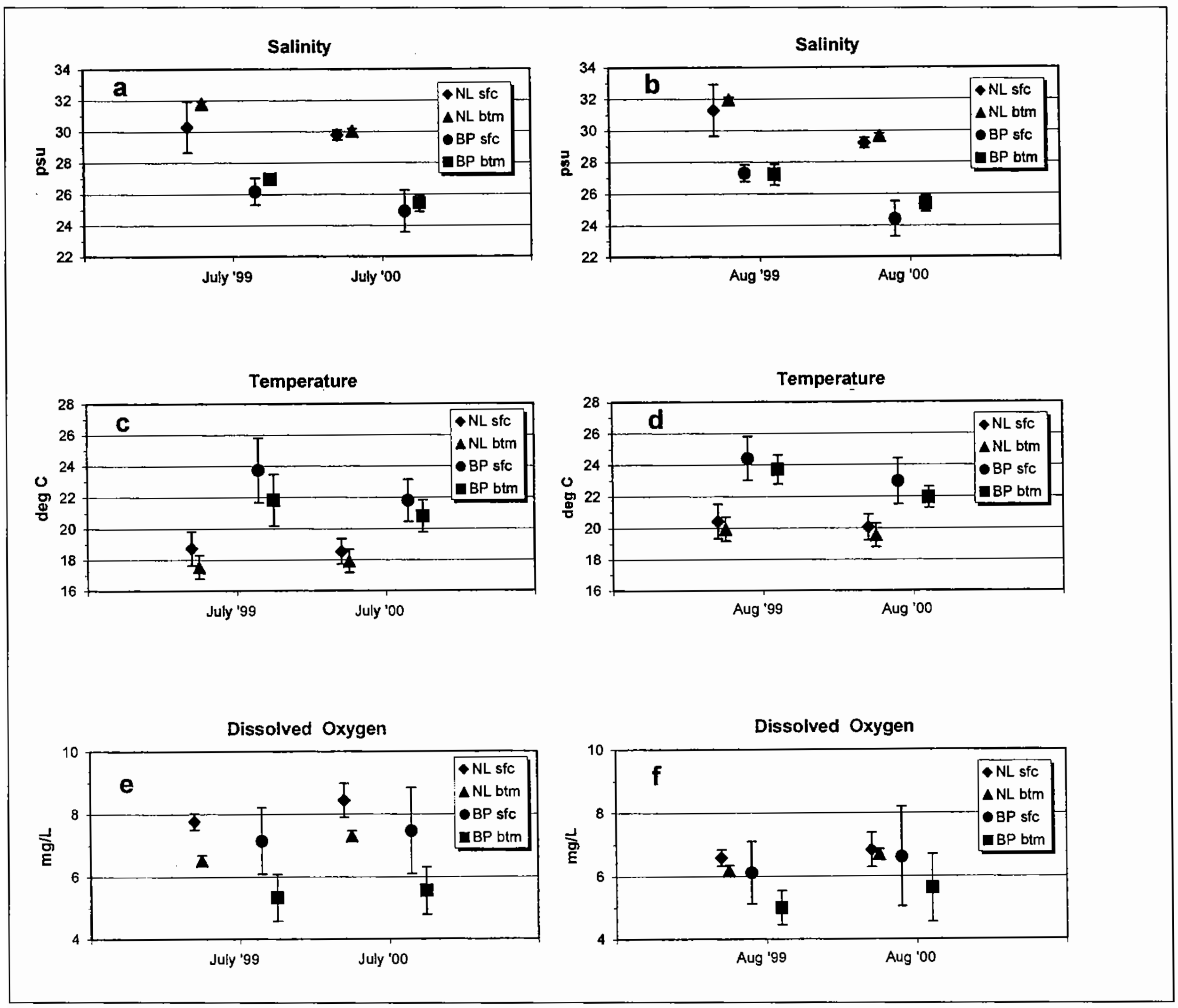

Figure 3. Statistical summary of the summer time series data for the western Sound station in Bridgeport Harbor (BP) and the eastern Sound station at the New London Disposal Site (NL); **a)** temperature data from July, **b)** temperature data from August, **c)** salinity data from July, **d)** salinity data from August, **e)** dissolved oxygen data from July, **f)** dissolved oxygen data from August. Error bars are one standard deviation.

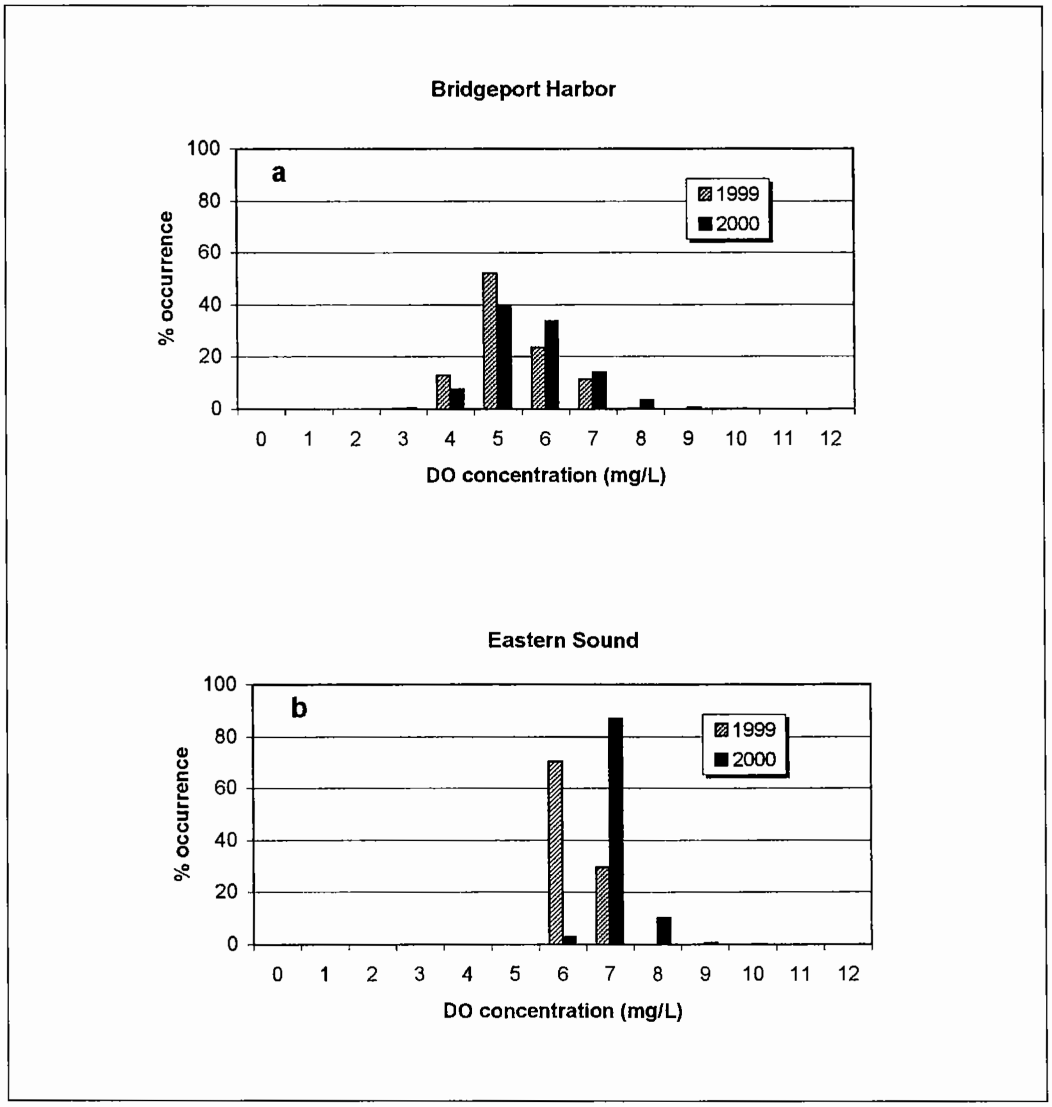

Figure 4. Frequency of occurrence *vs.* dissolved oxygen (DO) concentration for the western Sound station in **a**) Bridgeport Harbor and the eastern Sound station at **b**) New London Disposal Site.

Figure 6 shows the time varying difference (delta) between the surface and bottom parameters of temperature, salinity and dissolved oxygen concentration (*e.g.*, $DT_t = TSFC_t - TBTM_t$, where T = Temperature in degrees C at time, t, SFC is the surface sensor and BTM is the bottom sensor). From September 6th through the 25th, the magnitude of the delta for each parameter is much greater relative to the latter half (after September 26th) indicating a stronger vertical gradient and the existence of stratified conditions. Diurnal and tidal fluctuations are superimposed on the record, which decrease in magnitude and frequency until about September 25th; at which point these fluctuations all but disappear. An examination of the meteorological data obtained from LaGuardia Airport (Long Island, NY) at that time, shows the onset of a high-pressure system with north-northwest winds of 15-20 knots over a 2-day period, conditions which effectively destratified the western end of the Sound.

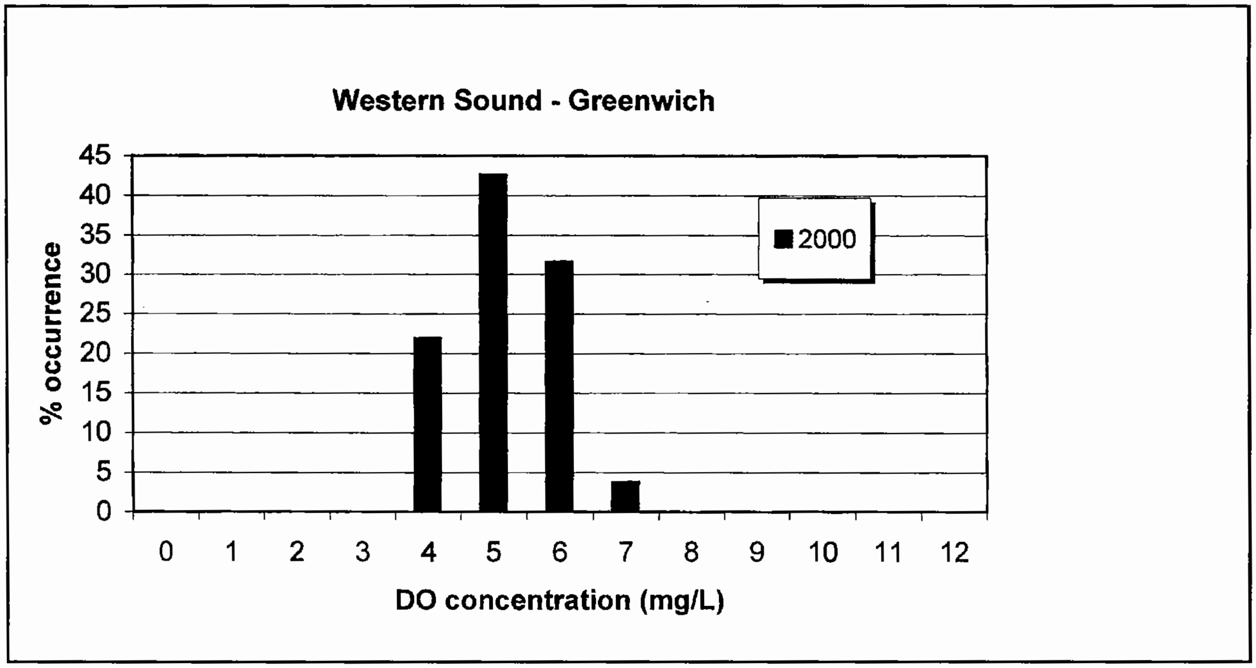

Figure 5. Frequency of occurrence *vs.* dissolved oxygen (DO) concentration for the western Sound located near the lobster die-off event of 1999.

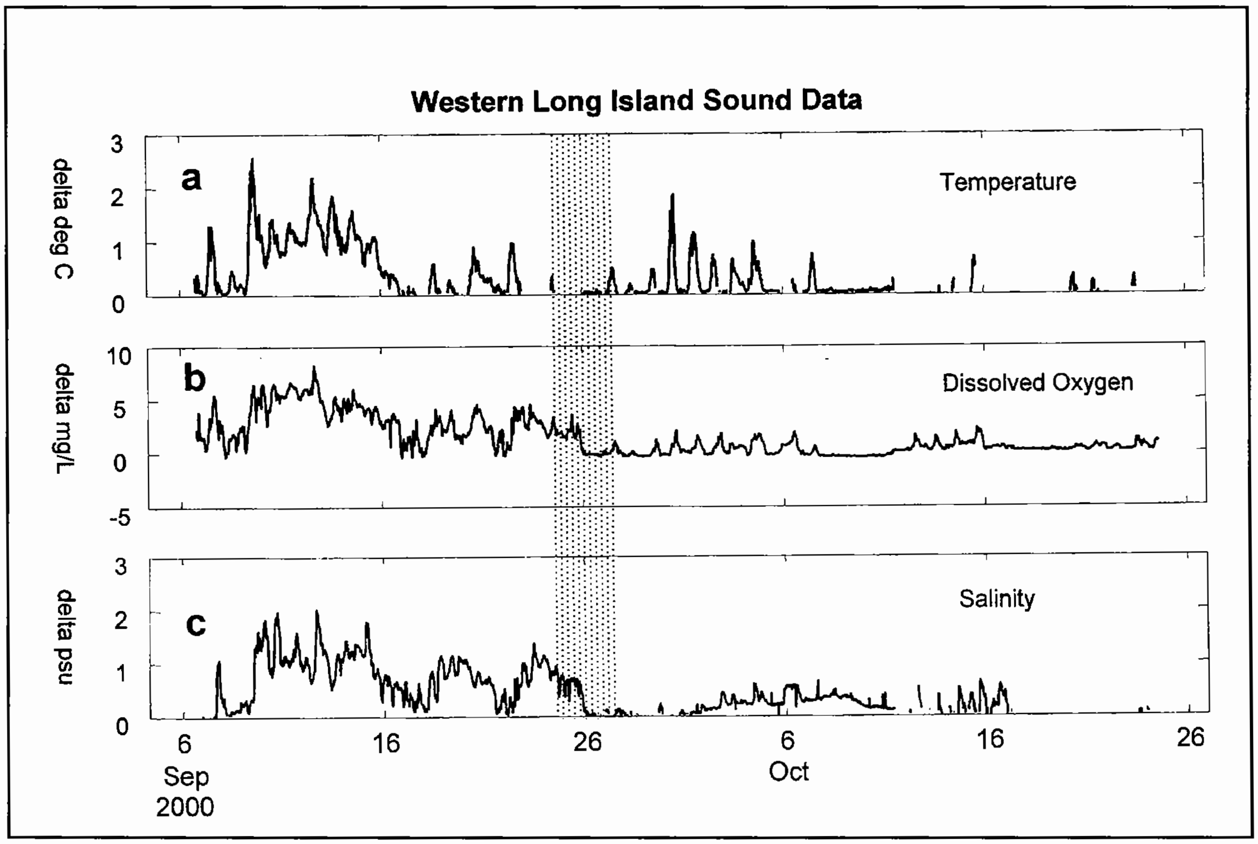

Figure 6. Time series of the difference (delta) between the surface and bottom sensors for **a**) temperature, **b**) dissolved oxygen, and **c**) salinity at the western Sound station located near the lobster die-off event of 1999. The vertical gray bar highlights the time during which meteorologic events destratified the western Sound.

We conclude that the high frequency time series data reveals far more information regarding the time variability, occurrence and duration of anomalous hydrographic conditions, providing more realistic assessments of the potential stress experienced by the biota. The shipboard surveys, while documenting the presence and extent of stressful conditions, imply large-scale spatial and temporal homogeneity. We believe that both techniques can and should be used as complements to one another - the surveys identifying adversely impacted areas, and the high frequency time series detailing the hydrographic conditions and dynamics of those areas.

Optimal Interpolation and Mapping of the Hydrography of Eastern Long Island Sound and the Adjacent Coastal Ocean

K. Coleman, K. Dias, M.J. Bowman and R.E. Wilson
MSRC, SUNY at Stony Brook
Stony Brook, NY 11794

Historical data sets maintained by NODC and USGS (EPIC) have been analyzed using objective interpolation and mapping, particularly using the kriging algorithms. Contours of the horizontal distribution of the monthly averaged temperature and salinity at the surface and at depth clearly show the seasonal hydrographic cycle in eastern Long Island Sound, Block Island Sound and the contiguous coastal ocean. They provide new insights into tidal mixing variations, air-sea interaction and the exchange of water between the Sounds and the adjacent coastal ocean.

WATER QUALITY, NUTRIENTS AND ALGAE

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Nitrogen Uptake by *Porphyra purpurea*: its Role as a Nutrient Scrubber

[1]R. Carmona, [2]L. Chanes, [3]G. Kraemer, [4]T. Chopin, [5]C. Neefus, [6]J.A. Zertuche, [7]R. Cooper and [1]C. Yarish

[1]Dept. of Ecol. and Evol. Biol., University of Connecticut, One University Place, Stamford, CT 06901-2315, USA; [2]DGETI-CBTis41, Mexico; [3]Division of Natural Sciences, State University of New York, Purchase, NY 10577, USA; [4]CCSA, Dept. of Biol., University of New Brunswick, Saint John, N.B., E2L 4L5, Canada; [5]Department of Plant Biology, University of New Hampshire, Durham, NH 03824, USA; [6]IIO, Universidad Autonoma de Baja California. P.O. Box 453. Ensenada, B.C. 22860 Mexico; [7]Marine Sciences and Technology Center, 1084 Shennecossett Road, Groton, CT 06340-6097, USA

Introduction

Finfish mariculture along the Northeast U.S. coast continues to grow, developing into a vibrant industry. But it can be, at a regional level, a significant contributor to nutrient loading in coastal waters (Kautsky *et al.*, 1997). One solution to the need to comply with local, state and federal legislative standards, is to develop a balanced ecosystem approach, based on integrated aquaculture with other marine organisms, i.e. macroalgae or seaweeds and shellfish (Chopin *et al.*, in press).

The contribution of macroalgae importance in coastal waters have frequently been either ignored or misunderstood, especially in the Western World. Macroalgae are able to concentrate nutrients and grow at high rates. In addition, seaweed mariculture is by itself a multi-billion dollar industry. The red alga *Porphyra* (commonly called nori) is a major source of food throughout the world and has an annual value of over $US 1.8 billion (Yarish *et al.*, 1998). The ecological role (Yarish *et al.*, 1998) and the potential productivity (Kraemer and Yarish, 1999) of native *Porphyra* in Northeast America have been studied. It has also been reported the capability of *Porphyra* to remove N and P and its growth in sites of experimental nori/salmon integrated aquaculture (Chopin *et al.*, 1999).

In conventional aquaculture systems, seaweeds not only can act as renewable biological nutrient scrubbers for coastal water quality enhancement, but also represent marine crops of commercial value (Chopin *et al.*, in press).

Within the general goal of determining the capacity of local species of *Porphyra* in integrated aquaculture, the specific goals were to study the growth and nitrogen accumulation by a common northeast American species of *Porphyra*, *P. purpurea*.

Materials and methods

Two types of experiments were carried out: long-term experiments, to understand the interaction of inorganic nitrogen (NO_3^- *vs.* NH_4^+) and the DIN (dissolved inorganic nitrogen) concentration and its effects on growth; and short-term experiments to study the N uptake kinetics.

The long-term experiments were carried out with blades of *P. purpurea* (Long Island Sound strain, LIS) grown at 15°C, 150 μmols m^{-2} s^{-1} for 30 days at different N concentrations (NO_3^- or NH_4^+): 25, 75, 150, 300 μM .

The short-term experiments were done with strains from LIS and Maine, at 150 μmols m^{-2} s^{-1}, different temperatures (5, 10, 15 °C) and several N concentrations (10, 25, 40, 75, 150 μM). N uptake rates were quantified over of 20 minutes.

All the blades were grown from conchocelis cultures at the Marine Biotechnology Laboratory of the University of Connecticut at Stamford.

Results and Discussion

Growth of *P. purpurea* in NO_3^- was saturated at 75 μM, while growth continued to increase up to 300 μM when plants were supplied with NH_4^+, with a rate of 8 % d^{-1} (Figure 1). The high growth rates under high NH_4^+ concentration were noteworthy, because it has been reported that this form of N can be toxic for some marine species of macrophytes (van Katwijk *et al.,* 1997). This is fortunate since ammonium is the major source of N to which *Porphyra* would be exposed in integrated aquaculture (150 μM is the mean value of this nutrient in the effluent of Great Bay Aquafarms in New Hampshire, G. Nardi,

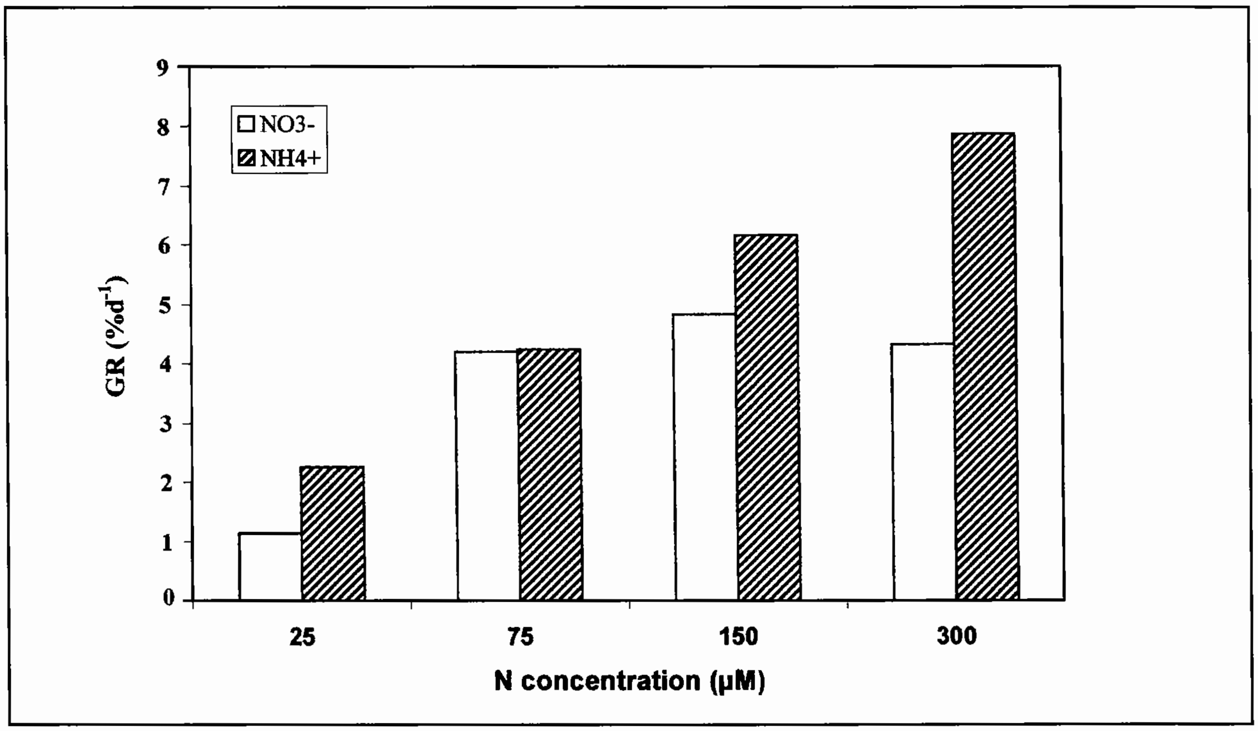

Figure 1. Growth rate of *P. purpurea* (LIS strain) at different concentrations of two N sources. (The standard deviations are not shown in the graph and were quite high due to the fact that blades started to reproduce and that was reflected in the biomass weight variation).

Table 1. N content (% DW) in *P. purpurea* (LIS strain) initially and after 30 days growing at different concentrations of two N sources. Standard deviations are shown in parenthesis (n=3).

N concentration	NO_3^-	NH_4^+
Initial	2.92 (0.02)	2.92 (0.02)
25 μM	2.92 (0.02)	2.53 (.052)
75 μM	1.57 (0.3)	3.56 (0.92)
150 μM	2.78 (0.22)	4.91 (0.63)
300 μM	5.37 (0.18)	6.5 (0.55)

pers. com.).

Porphyra blades presented a significant higher N content after 30 days, in relation to the initial value, under 150 and 300 μM, especially when NH_4^+ was the N source. The obtained value of ca. 7% (DW) indicates that *Porphyra* can take NH_4^+ from the medium and concentrate it in the tissue (Table 1).

In short-term experiments, there was no significant difference between the two N sources (Table 2). These uptake rates were similar to those presented by starved algae (data not shown), indicating that they are capable of removing nutrients from the medium even when they are replenished or at least with a high internal N content.

In the experiments carried out with the strain from Maine at three different temperatures, a higher NH_4^+ uptake rate was observed at the lowest temperature of 5 ^oC, regardless the N concentration,

Table 2. Nitrate and ammonium uptake rate (μmols/DW g min) in *Porphyra purpurea* (LIS strain). Standard deviations are shown in parenthesis (n=6).

N concentration (μM)	NO_3^-	NH_4^+
20	0.11 (0.04)	0.07 (0.03)
40	0.14 (0.04)	0.11 (0.06)
75	0.24 (0.12)	0.34 (0.11)
150	0.77 (0.23)	0.80 (0.05)

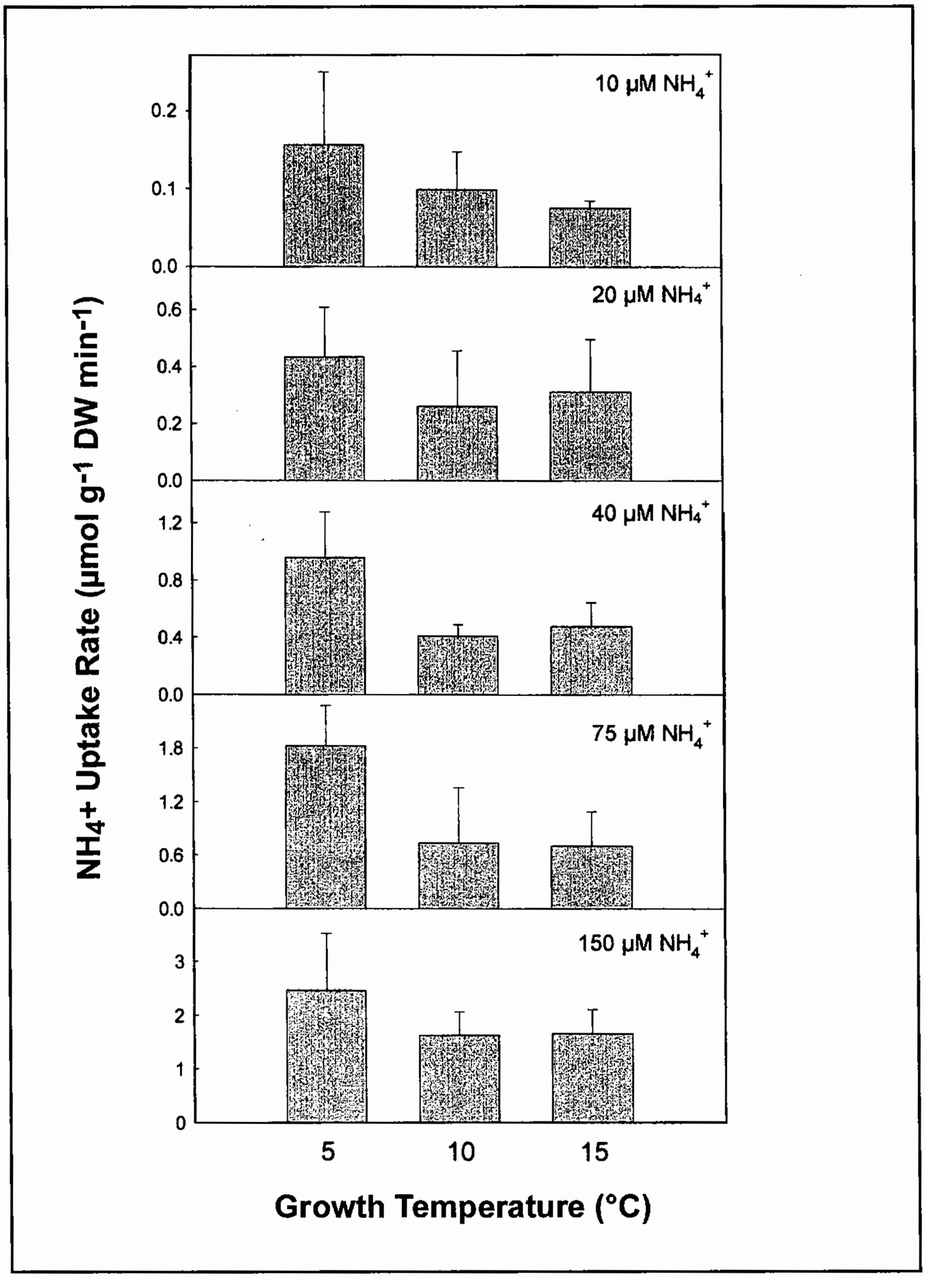

Figure 2. NH_4^+ uptake in *P. purpurea* (Maine strain) at different temperatures.

whereas rates at 10 °C and 15 °C were similar (Figure 2). The kinetics showed no saturation up to 150 µM and the uptake at 15 °C was higher than that recorded for LIS strain.

Conclusions

The results showed that *P. purpurea* is good candidate for bioremediation. This species presents the highest growth rate and tissue N accumulation at 300µM of NH_4^+. There is no difference in NO_3^- and NH_4^+ uptake in short-term experiments, which was not saturated within the range of N concentrations assayed (10-150 μM). On the other hand, the strain from Maine has a higher NH_4^+ uptake rate than the one from Long Island Sound, showing that interstrain differences exist and that the Maine strain could be used in the winter months and be an efficient nutrient remover.

Acknowledgments

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References

Chopin T., Yarish C., Wilkes R., Belyea E., Lu S. and Mathieson A. (1999). Developing *Porphyra*/salmon integrated aquaculture for bioremediation and diversification of the aquaculture industry. *J. Appl. Phycol.* **11**:463-472

Chopin T., Yarish C. and Sharp G. (in press). Beyond the monospecific approach to animal aquaculture...The light of integrated aquaculture. In: T. Bert (Ed.) *Ecological and Genetic Implications of Aquaculture Activities.* Kluwer Academic Publ. *Ser. Rev. Fish. Biol.*

Kautsky N., Troell M. and Folke C. (1997). Ecological engineering for increased production and environmental improvement in open sea aquaculture. *In* Etnier C, Guterstam B (eds), *Ecological Engineering for Waste Water Treatment,* 2nd Edition. Lewis Publishers, Chelsea: 387-393.

Kraemer, G. P. and Yarish C. (1999). A preliminary comparison of the mariculture potential of *Porphyra purpurea* and *P. umbilicalis*. *J. Appl. Phycol.* **11**:473-477.

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

Yarish, C.,Wilkes R., Chopin T., Fei X.G., Mathieson A.C., Klein A.S., Friel D., Neefus C.D., Mitman G.G. and Levine I. (1998). Domesticating indigenous *Porphyra* (nori) species for commercial cultivation in Northeast America. *World Aquaculture* **29** (4):26-29, 55.

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Nitrogen Reductions and Ambient Water Quality Conditions in Long Island Sound

P.E. Stacey., C.B. Olsen, M.P. Gates, and M.J. Lyman
Connecticut Department of Environmental Protection
Bureau of Water Management
Long Island Sound Water Quality Monitoring Program
79 Elm Street
Hartford, CT 06106-5127

Abstract

Since 1991, the Connecticut Department of Environmental Protection (CTDEP) has been monitoring the water quality of Long Island Sound. The primary goal of this monitoring program is to develop a long-term database from which the effectiveness of management actions to reduce nitrogen inputs to the Sound may be evaluated. Year-round monthly samples at 18 stations, from the Western Narrows to Block Island Sound, provide nutrient and chlorophyll-a concentrations and water column profiles of temperature, salinity, irradiance and dissolved oxygen. Additional biweekly summer sampling at 40 stations provides data on the recurrent low dissolved oxygen condition known as hypoxia. Nitrogen management activities in the states of Connecticut and New York have resulted in a 15-20% reduction in nitrogen discharged into Long Island Sound from point sources. Corresponding reductions in the ambient nitrogen levels and increases in summertime bottom-water dissolved oxygen concentrations are expected. We provide an analysis of monitoring program data from the past ten years in light of these reductions. The CTDEP encourages the research community to make use of the monitoring program and the resultant database as an aid to complementary research efforts in Long Island Sound.

Introduction

The Connecticut Department of Environmental Protection's (CTDEP) Long Island Sound Monitoring Program (LISMP) has been measuring oxygen levels, nutrients, and other parameters relevant to hypoxia since 1991 with funding from the U.S. EPA Long Island Sound Study (LISS). One of the objectives of the program is to track trends in hypoxia and nutrients that might result from nitrogen management activities implemented in Connecticut and New York. Hypoxia has been shown to occur in the late summer period, with oxygen levels occasionally falling to anoxic conditions in the most severely impacted areas of western LIS (Figure 1). The severity of hypoxia varies each year, depending on stratification strength and duration (Figure 2). Water quality modeling of Long Island Sound (LIS) has shown the primary cause of the severe hypoxia seen today to be nitrogen over-enrichment. The nitrogen stimulates the growth of phytoplankton, which ultimately adds to the respiration pool in the bottom waters, driving oxygen levels well below what might have existed during pre-Colonial days. Differentiating the effect that anthropogenic sources of nitrogen have on hypoxia from other uncontrollable factors, such as stratification strength and weather conditions is a challenge.

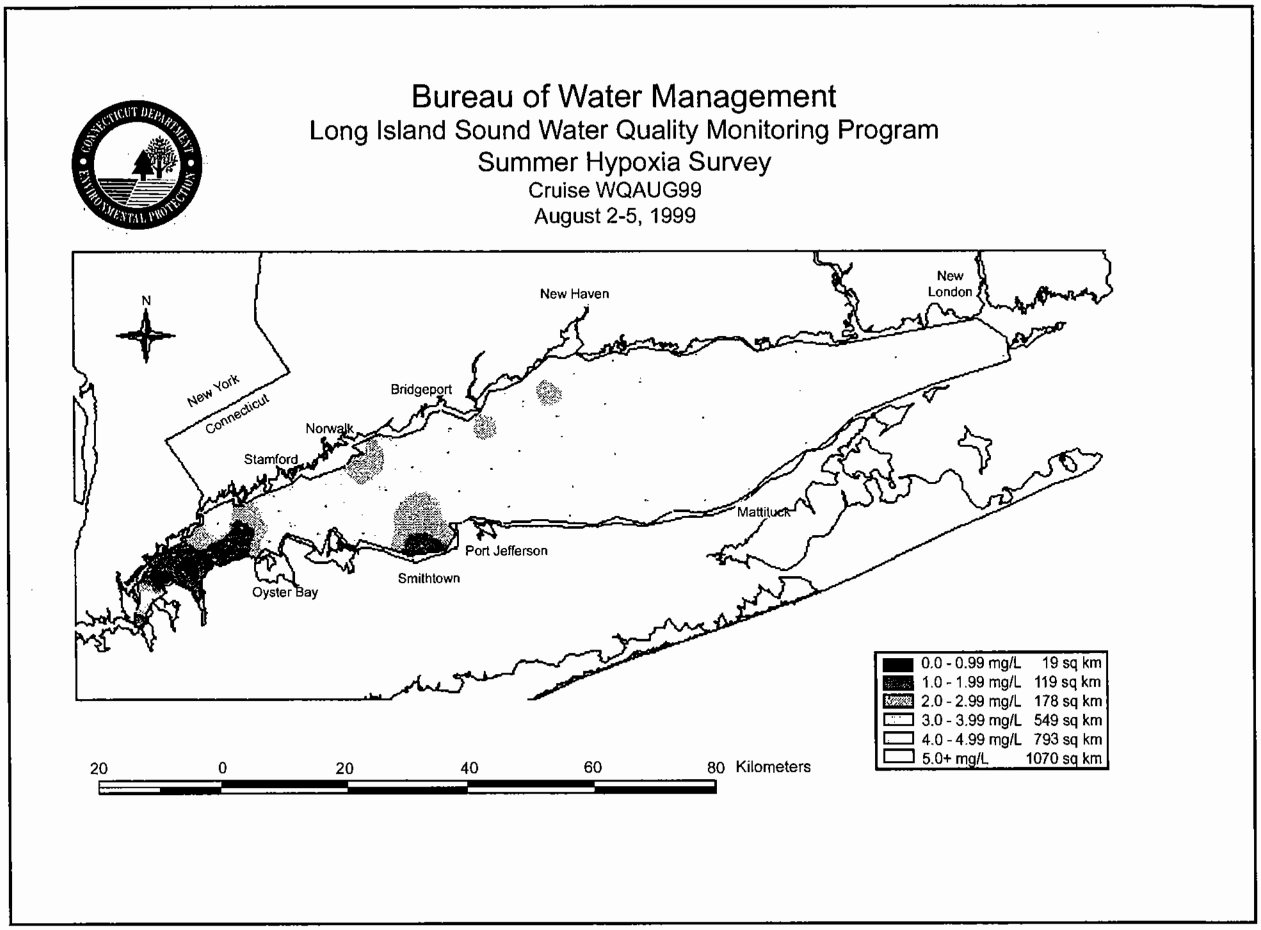

Figure 1. Typical bottom hypoxia in Long Island Sound from the LISMP August 2-5, 1999 survey.

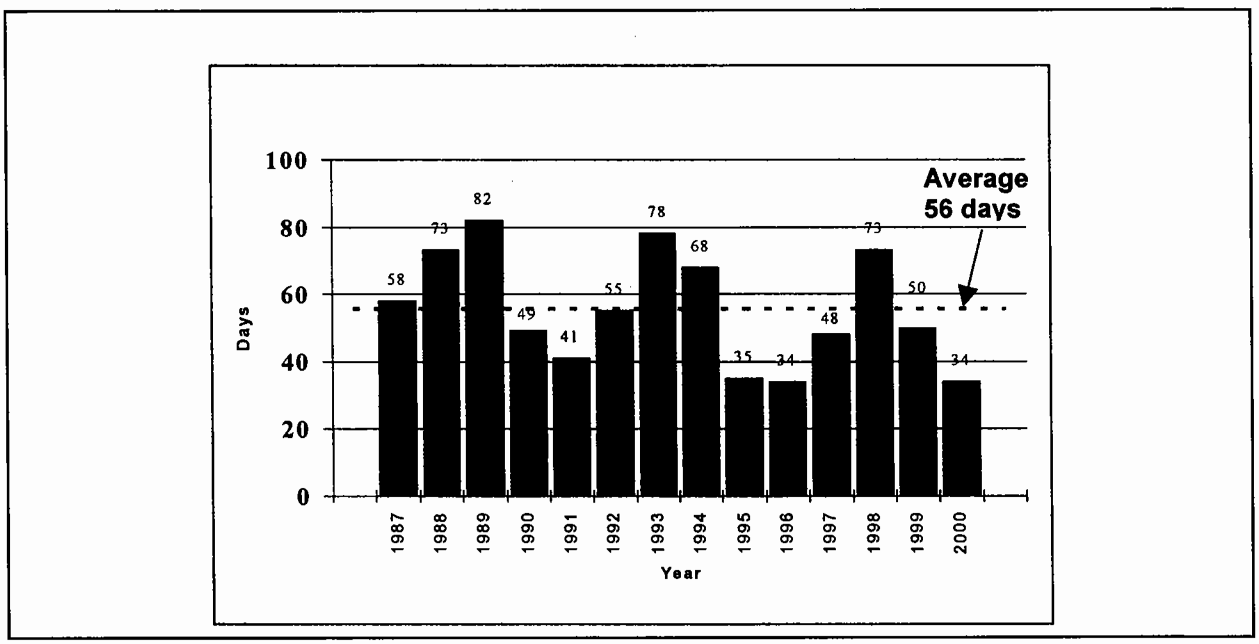

Figure 2. Duration estimates of summer hypoxic conditions in LIS, 1987-2000. 1987-1990 data are from Welsh and Welsh (1992).

This presentation will provide a preliminary look at the relationship between nitrogen loads and effects on nitrogen concentrations in LIS, as well as changes in chlorophyll-a levels. A complete statistical analysis of all of the data has not yet been conducted and it would be impossible to present the full breadth of the surveys in this brief overview. Therefore, this analysis will focus on a few of the most interesting observations at stations that appear to show clear trends in water quality. While the evidence shows that nitrogen levels in the Sound do respond to changes in loading, these observations should not be considered final or even representative of conditions throughout the Sound. Such conclusions will require more sophisticated analyses.

Methods

CTDEP's LISMP, which has grown since 1991, samples 48 stations from the Execution Rock area in the west to Block Island Sound in the east (Figure 3). Nutrient analyses, including all nitrogen and phosphorus species, biogenic and total silica, and total organic carbon, are conducted on samples from surface and bottom waters at 18 stations on a monthly basis year round. Laboratory analyses are conducted by ERI according to protocols defined in their standard operating procedures manual and in CTDEP's Quality Assurance Project Plan approved by EPA. Oxygen is monitored using a Sea Bird SBE-19 CTD profiler concurrently with the nutrient surveys plus at an additional 30 stations during the June through September period. In addition, during June through September, oxygen, conductivity, temperature, and light attenuation profiling is conducted at all 48 stations on a bi-weekly basis to better

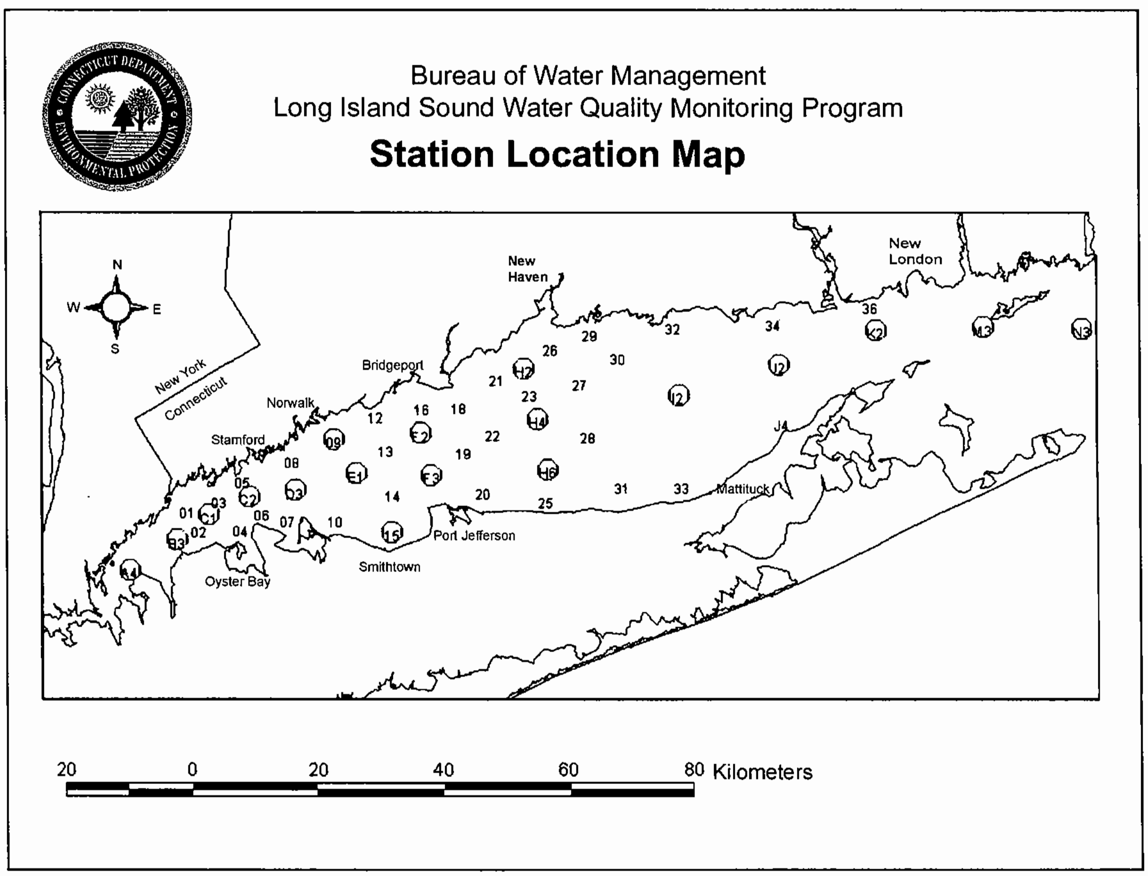

Figure 3. Location of LISMP sampling stations. Circled stations are stations where nutrient concentrations are regularly monitored in surface and bottom waters.

define the hypoxic conditions and relevant parameters. Data from January 1991 through December of 1999 were included in this evaluation. The CTDEP's web site (http://dep.state.ct.us) provides more detailed information on the LISMP.

Nitrogen loads to LIS were approximated in three groups. River loads, which include nitrogen from all sources, were estimated from USGS monitoring data at their stations located at the lowest, non-tidal location of each major tributary. Major tributaries were the Quinebaug and Shetucket in the Thames River basin, the Farmington and the Connecticut at Thompsonville in the Connecticut River basin, and the Naugatuck and Housatonic at Stevenson in the Housatonic River basin. While those stations capture a large percentage of the land area draining to LIS, the coastal areas below those stations provide a large percentage of the nitrogen load that had to be estimated to complete the load estimates. Total nitrogen load was simply calculated as the product of the flow times the nitrogen concentration for that month. In cases where monthly nitrogen concentrations were not available, an average of the previous sample

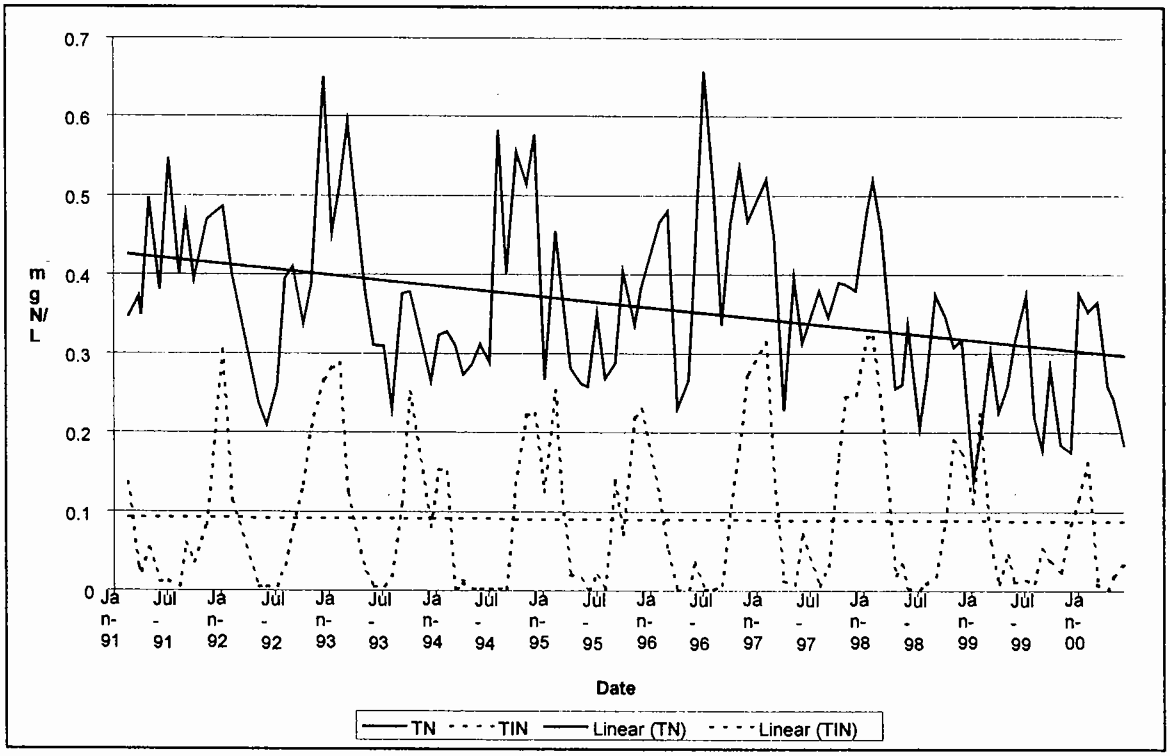

Figure 4. TN and TIN concentrations (mg/L) at Station D3 surface from January 1991-June 2000. Trend lines are fit to both datasets.

and the next sample were used. Flow data are taken continuously and were available for the entire period. USGS water years 1991 through 1999 were included in the analysis. A water year runs from Oct. 1 through Sept. 30.

All sewage treatment plant nitrogen loads in the coastal area were estimated using best available monitoring data. Data were sketchy for the early years, but availability steadily improved since 1993. Monthly data were available for most of CT's treatment plants since 1993; NY treatment plant data were on an annual average and were divided evenly among the months for that year. Coastal nonpoint and stormwater sources were estimated by using average annual estimates used by the LISS and adjusting them upward or downward for each month proportionally to the change observed at the nearest USGS monitoring station. It was assumed that nitrogen loads were largely driven by rainfall and that fluctuations observed at the monitoring stations would therefore be paralleled in the coastal areas. More detailed analyses on total nitrogen loading are anticipated from ongoing USGS studies that will greatly improve on this preliminary analysis.

Results

Temporal Changes in Chlorophyll-a, Nitrogen Loads and Nitrogen Concentrations

Relationships between loading and response could not be drawn unless there were some changes in key parameters through the sampling period. Were there observable changes over time in nitrogen loads, nitrogen concentrations in the Sound, and in chlorophyll-a levels that might be related to nitrogen loading and availability? Significant trends in nitrogen and chlorophyll exist at some stations, but are best exemplified at Station D3, which will be emphasized in this presentation. Levels of total inorganic nitrogen (TIN) in the Sound exhibit a clear annual pattern of seasonal change, from peaks in the fall-winter to limitation in the spring-summer (Figure 4). Total nitrogen (TN) exhibits a more irregular pattern (Figure 4), probably a result of biological mediation, but a trend line fitted to the data indicates a downward trend not seen for TIN.

Long-term trend analyses using de-seasonalized data supports a significant downward trend in the TN data and no significant trend in the TIN data. The pattern of TIN is more clearly elucidated using a

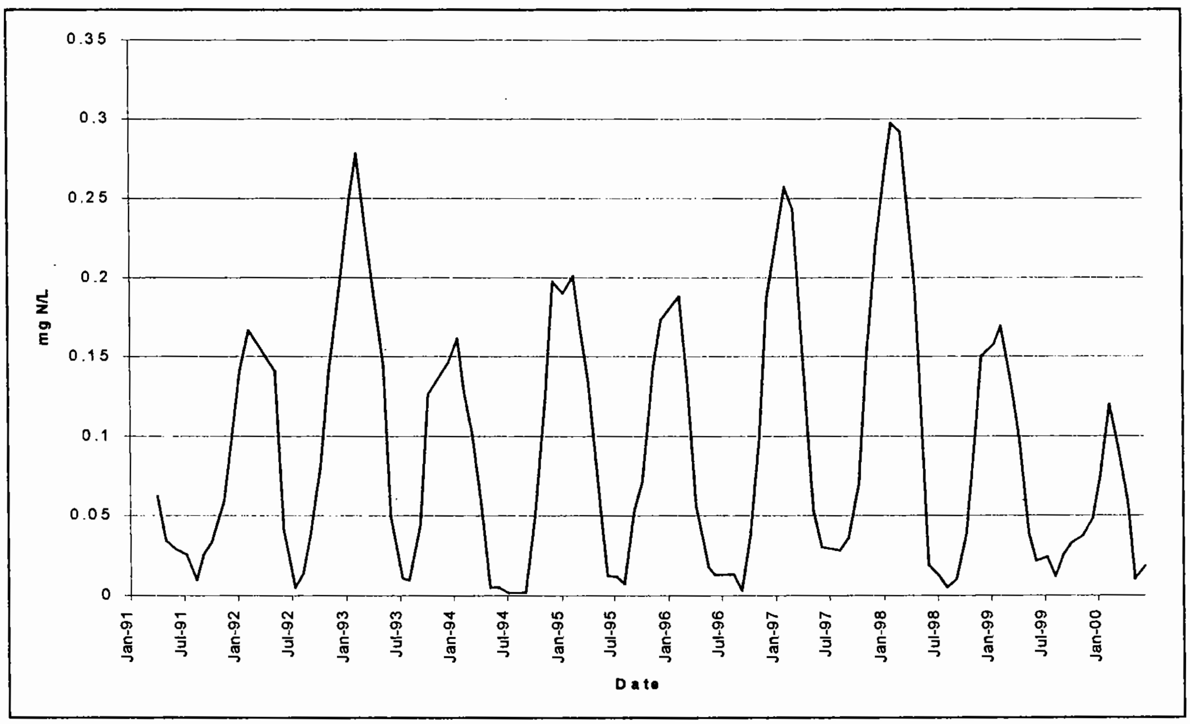

Figure 5. Three-month moving average of TIN concentrations (mg-N/L) at Station D3 surface, January 1991-June 2000.

three-month moving average (Figure 5), that dampens out some of the anomalous observations. A close look at the TIN 3-month moving average (Figure 5) highlights the peaks and bottoms of the annual TIN pattern typical of LIS. The near zero concentrations of TIN clearly show seasonal nitrogen limitation.

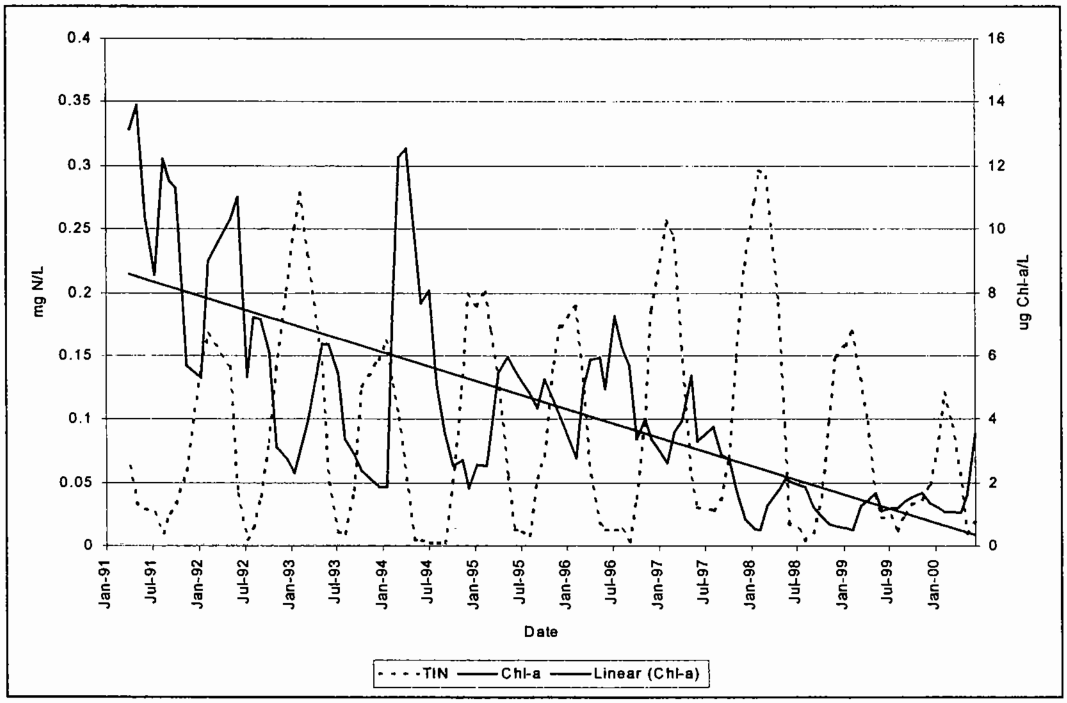

Figure 6. Relationship between TIN and chlorophyll-a concentrations at Station D3 surface, January 1991-June 2000. Trend line shows what is a significant downward trend for chlorophyll-a.

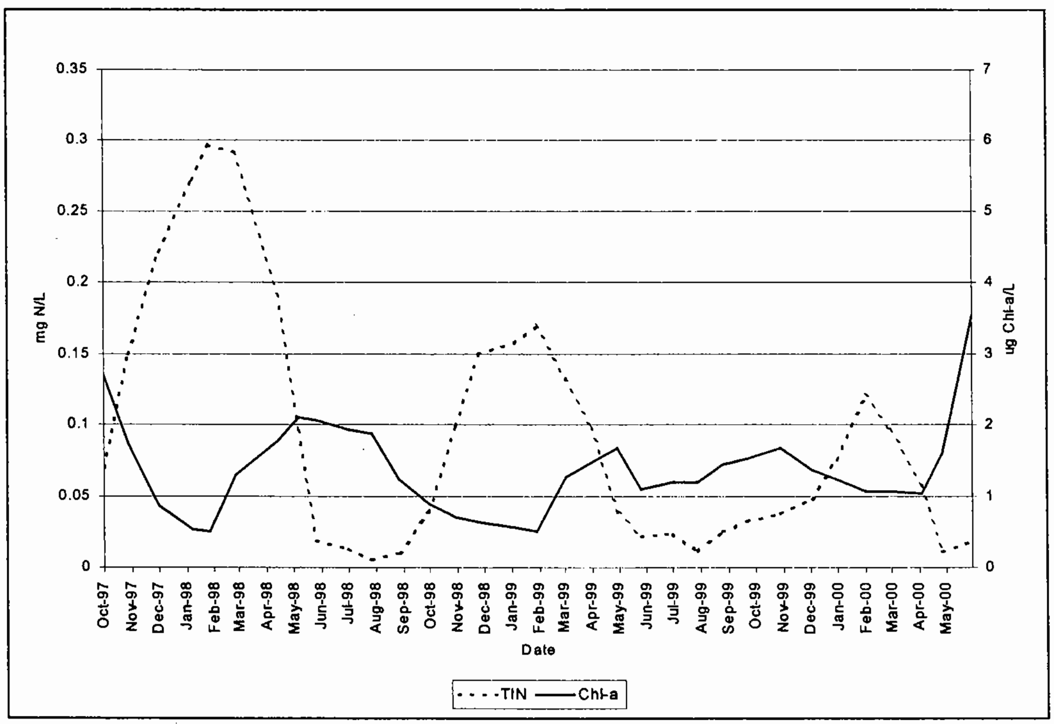

Figure 7. Three-month moving average of TIN and chlorophyll-a concentrations at Station D3 surface, October 1997-June 2000. Note TIN minima with attenuated chlorophyll peaks.

The annual cycle of TIN is largely driven by phytoplankton uptake as the spring and summer blooms take hold. At Station D3, the 3-month moving average concentration of chlorophyll-*a* mirrors the pattern of TIN, peaking when TIN is low, demonstrating how TIN fuels the growth of algae (Figure 6). TN, as noted earlier, does not follow such a clean pattern as cycling in and out of biomass and new nitrogen loads from the land complicate the picture. The 3-month moving averages of TIN paired with chlorophyll-*a* at Station D3 better demonstrates the relationship and also show a remarkable reduction of chlorophyll-*a* levels in recent years (Figure 6). Like TIN, there is a steep drop in the trendline for chlorophyll that is statistically significant, a common trend observed at several stations. However, an examination of the last few years when the chlorophyll-*a* decline was most dramatic shows TIN, although somewhat attenuated, still following the same pattern as earlier years as if chlorophyll-*a* production were going on as before (Figure 7). While TIN levels were lower than most earlier years, there still appears to be other forces in effect, keeping chlorophyll-*a* levels low despite the apparent production continuing as evidenced by the seasonal decline in TIN. We speculate, as suggested by Dr. Candace Oviatt at the University of Rhode Island, that production is higher than suggested by the chlorophyll-*a* levels but the phytoplankton is either being quickly grazed by zooplankton or senescing quickly and sinking to the bottom. Given the higher than normal temperatures observed in recent winters, Oviatt hypothesized that zooplankton are active earlier in the winter/spring bloom and grazing the phytoplankton down, a phenomenon she believes might be occurring in Narragansett Bay.

Have there been any changes in nitrogen loads to LIS that might be related to some of these changes, particularly the reduction in TN and TIN levels observed at Station D3? Using the rough estimates of TN loading described above, the monthly data show the pattern of loading for USGS Water Years (WY) 1991 through 1999 (Figure 8). Peak flow events are easily picked out of the data and the relative stability of coastal point source loads is evident. The coastal point sources clearly exhibit a downward trend in TN loading over time, being reduced from about 31 million kg in WY1991 to less than 23 million kg in WY1999, about a 27% reduction. Total loading from all sources is also significantly lower in recent years, falling from 72 million kg in WY1991 to less than 54 million kg in WY1999.

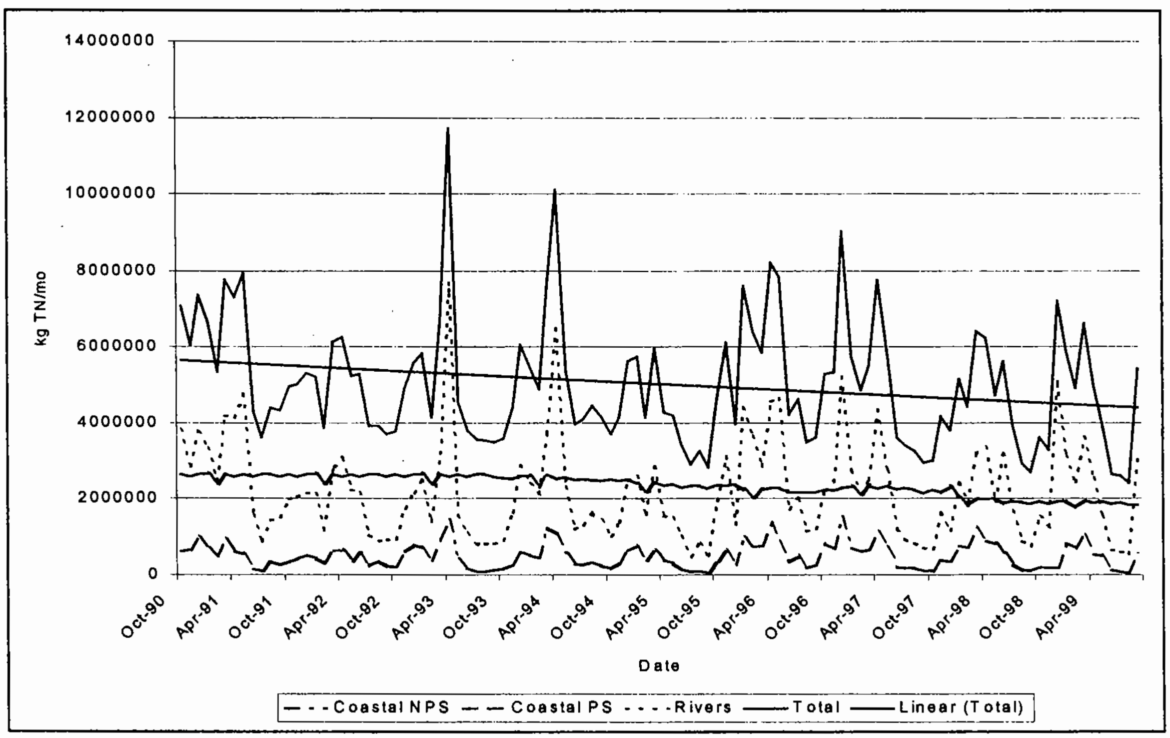

Figure 8. Monthly TN loads (kg/mo) from coastal nonpoint, coastal point, and river sources to LIS, October 1990-September 1999. Trend line is fit to total load of TN from all sources.

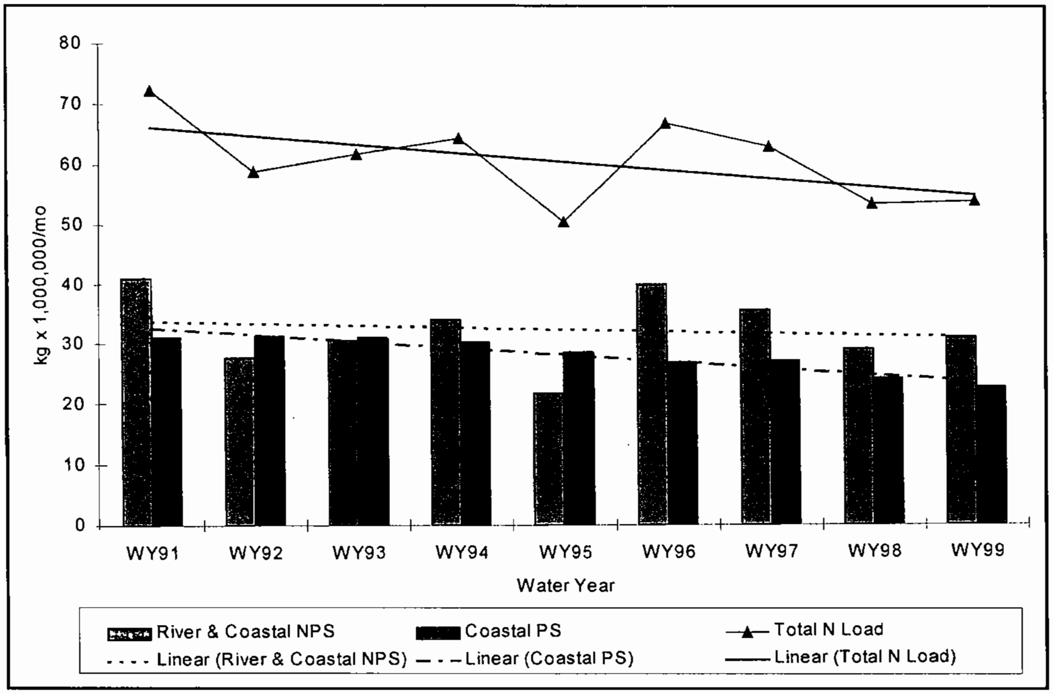

Figure 9. Annual TN loading and river and coastal nonpoint source TN loading v. coastal point source TN loading, WY 1991-WY1999.

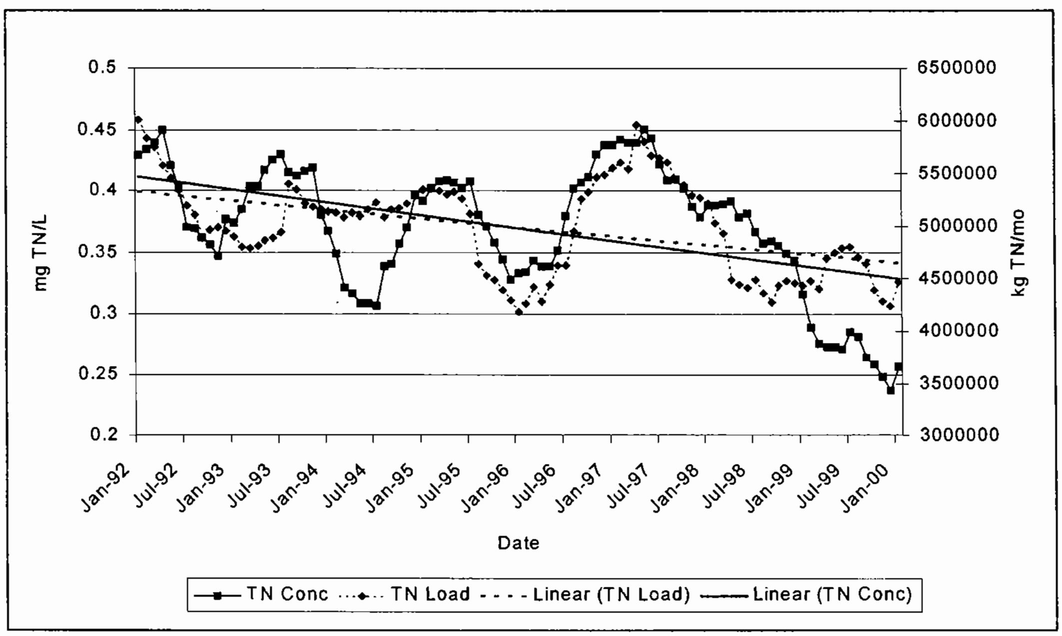

Figure 10. Tweleve month moving average of TN loading (kg/mo) to LIS compared to TN concentration (mg/L) at Station D3 surface, January 1992-June 2000.

However, the non-point source data are rough estimates and subject to the vagaries of weather, particularly stream flow, and cause for the trend is more likely coincidental to weather changes rather than to any specific management activity. For example, the total nitrogen load was lowest in WY1995, reflecting the dry weather conditions experienced that year. These relationships between point source of TN and the river and coastal non-point sources can be more clearly seen as an annual load (Figure 9), with the low WY1995 river/coastal non-point load, but the steady reduction in coastal point sources from management actions taken in CT and NY over the years. This also highlights the importance of coastal point sources of nitrogen to LIS, comprising nearly half of the TN load each year.

*Relationship Between TN Loading and Observations of TN and Chlorophyll-*a *in LIS.*

Given the uncertainty of the loading data and the natural variability of conditions in LIS, described relationships between loading and conditions should be considered preliminary. Complicating the analysis is the need to identify "lead time" or an offset from loading period to effect in LIS. The nitrogen, once loaded to the Sound, needs some time to mix, arrive at a station and equilibrate. Offsets of from one month to 12 months were tested and a 3-month offset appeared to correlate the best, although no correlation between TN loading and response came close to significance, not surprising given the nature of environmental data. A look at Station D3 surface data, however, shows some interesting possibilities that the Sound is responding to changes in TN loading when a 3-month offset and 12-month moving average were used to compare the data (Figure 10). The TN loading and ambient concentration data

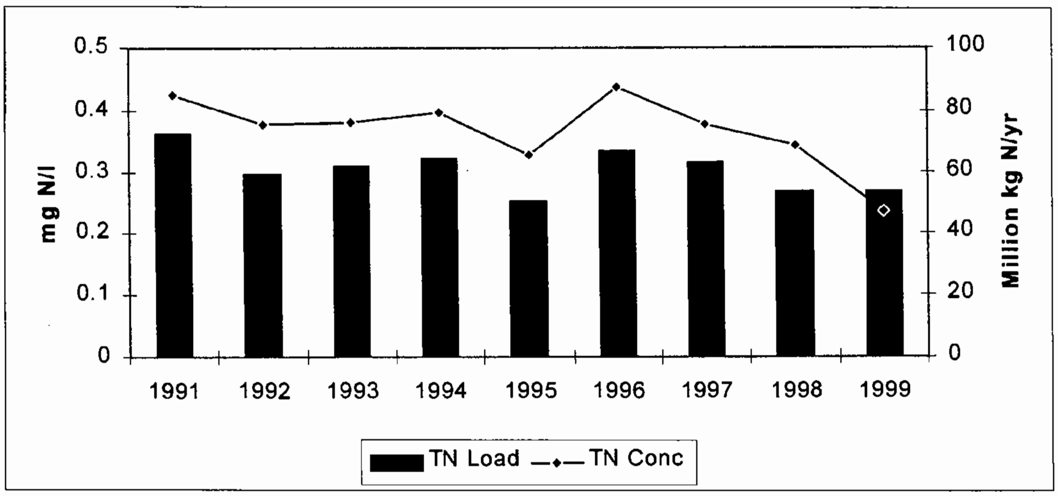

Figure 11. Annual TN load and mean annual TN concentration at station D3 surface, 1991-1999.

track each other fairly well, with obvious deviations in 1994 and 1999. The downward slope of the trendline of TN loading and TN concentration are similar to each other and both represent statistically significant downward trends, as noted earlier. As an annual load, TN loading appears to be correlated to ambient TN concentration at Station D3 (Figure 11).

TIN correlation with TN loading was not good, probably because TN represents more of a "standing stock" of the element than TIN, which moves in and out of the organic phase. However, if TIN concentrations were to be offset by another eight or 9 months, the data would track each other much better, probably a coincidental occurrence.

As expected, chlorophyll-*a* did not correlate with TN loading very well (Figure 12). The sharp drop in chlorophyll, possibly a biological effect of increased zooplankton grazing, may not reflect productivity very well, which is the parameter that should be correlated to loading. However, no productivity studies are conducted on LIS on a regular basis so the comparison cannot be made. Clearly, chlorophyll

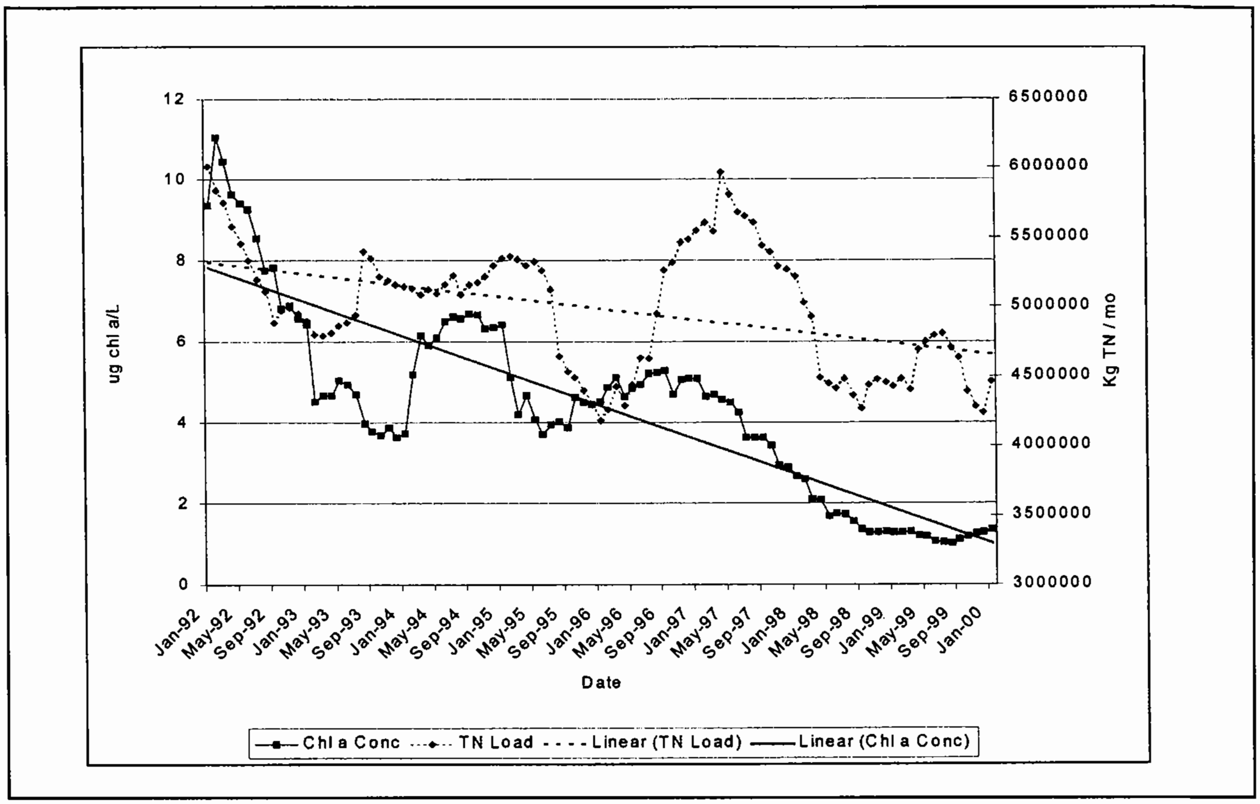

Figure 12. Twelve month moving average of TN load and chlorophyll-a concentration at Station D3 surface, January 1992-June 2000.

levels are much reduced in recent years, which is the same general trend seen in TN loading on the graph. Optimistically, LIS could be responding to the lower TN loading experienced in recent years and exhibiting lower primary productivity, but additional field monitoring and more sophisticated analyses are needed to confirm this.

Comparison of TN loads with TN:TP Atomic Ratios. A final analysis sought to compare TN loading with changes in ambient TN/TP atomic ratios. Dr. Gerald Capriulo hypothesized that management of nitrogen exclusive of phosphorus might lead to an imbalance in nutrient ratios, particularly TN to total phosphorus (TP) (Capriulo, *et al.*, 1996). This imbalance might cause a shift in phytoplankton communities that could disrupt trophic relationships in the Sound or promote harmful algal blooms. It appears that TN loads are lower in recent years and, while P loads have not been estimated, a look at TN/TP ratios might show a downward trend reflecting reductions in N and no change in P. It was surprising how well the TN/TP ratios correlated with TN loading using a 3-month offset (Figure 13). Checking the correlation between the two showed a strong correlation (Figure 14) that only improved when a 3-month moving average was used (Figure 15). Looking at the monthly trend of TN loading compared to TN/TP ratios at Station D3 surface shows how visually well the two parameters track one another (Figure 13). While the tracking of the two parameters may be simply a function of matching seasonal phasing of TN loads and TN/TP ratios, i.e., a coincidence, the similar downward trend observed for both suggests a relationship between reduced input of TN and a change in the TN/TP. This is an important observation and not only warrants additional analysis but may also relate to reductions in chlorophyll-*a* discussed earlier.

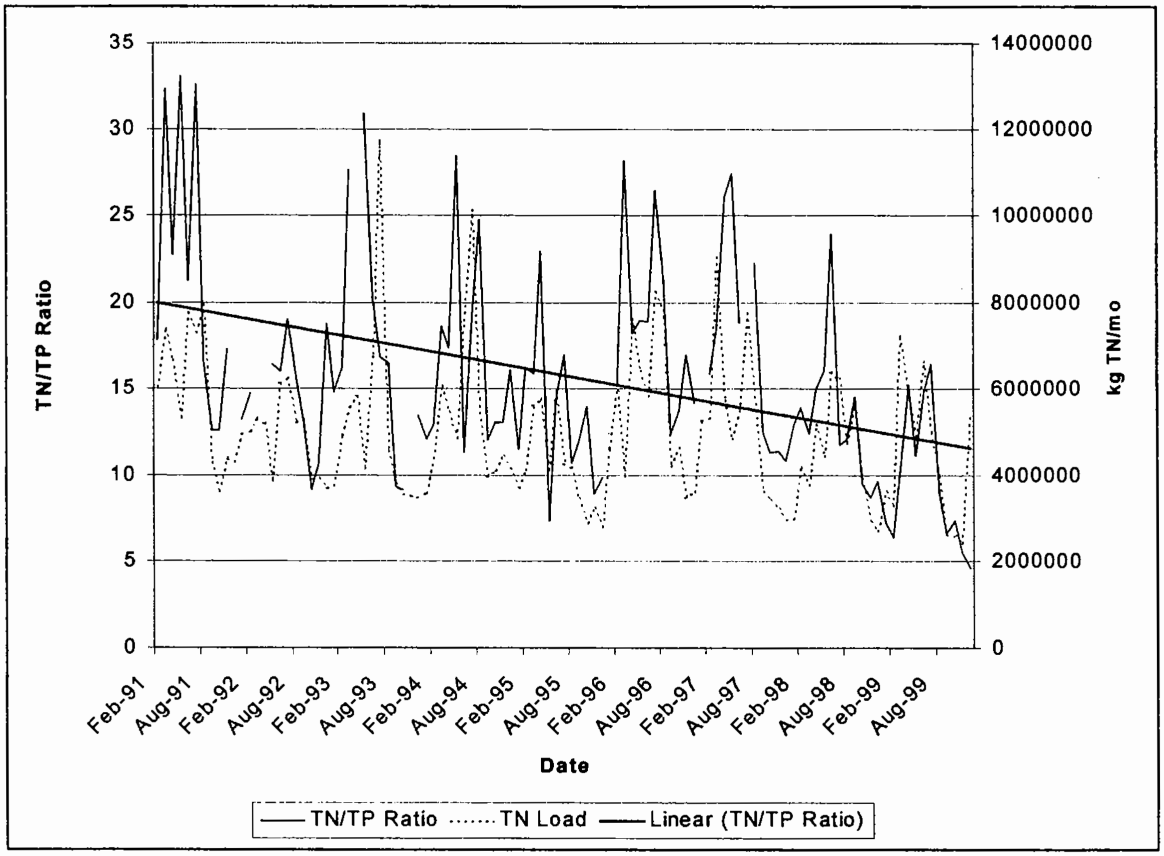

Figure 13. TN load (three-month offset) to LIS compared to TN:TP atomic ratios at Station D3 surface, February 1991-December 1999.

Summary and Conclusions

This preliminary analysis of the relationship between TN loads and effects on ambient TN, chlorophyll-*a* and TN:TP atomic ratios shows Station D3 in western LIS to be a good indicator location. While it presents the "best case" analysis of these relationships, it is not unique as other stations show similar trends. The main conclusions of this analysis are:

Trends

The rough estimates of Sound-wide loading identify a significant decreasing trend in TN loading over the period from October 1990 to September 1999. Planned refinements in TN loading estimates by USGS should be evaluated to ensure this trend is real.

Station D3 surface exhibits a significant decreasing trend in TN concentrations during the January 1991 to June 2000 period.

Station D3 surface exhibits a significant decreasing trend in chlorophyll-*a* concentrations during the January 1991 to June 2000 period.

No significant trend in TIN concentrations at Station D3 surface was observed.

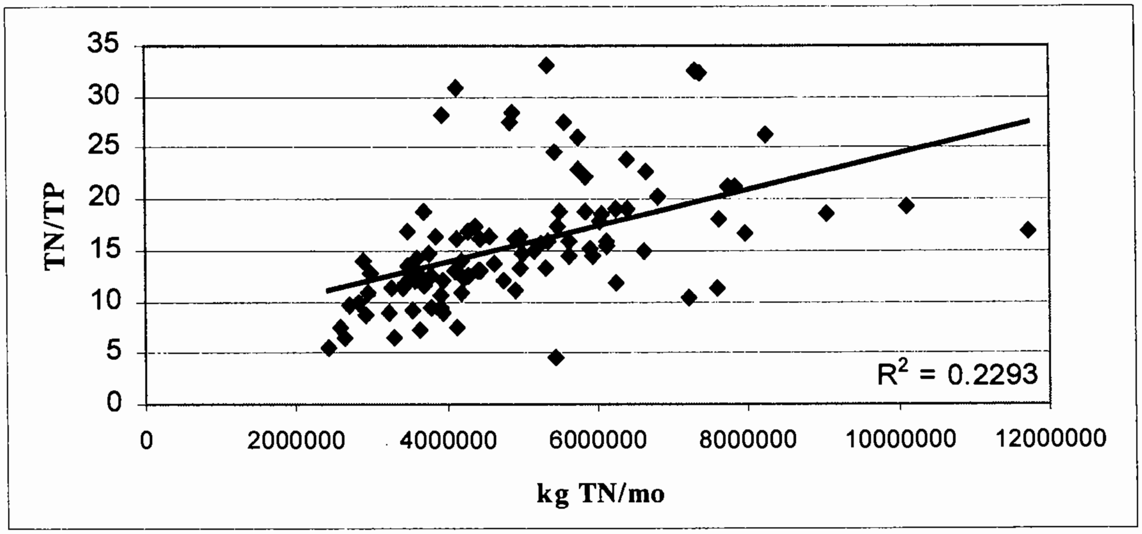

Figure 14. TN load to LIS correlated with TN:TP atomic ratio at Station D3 surface using a three-month offset.

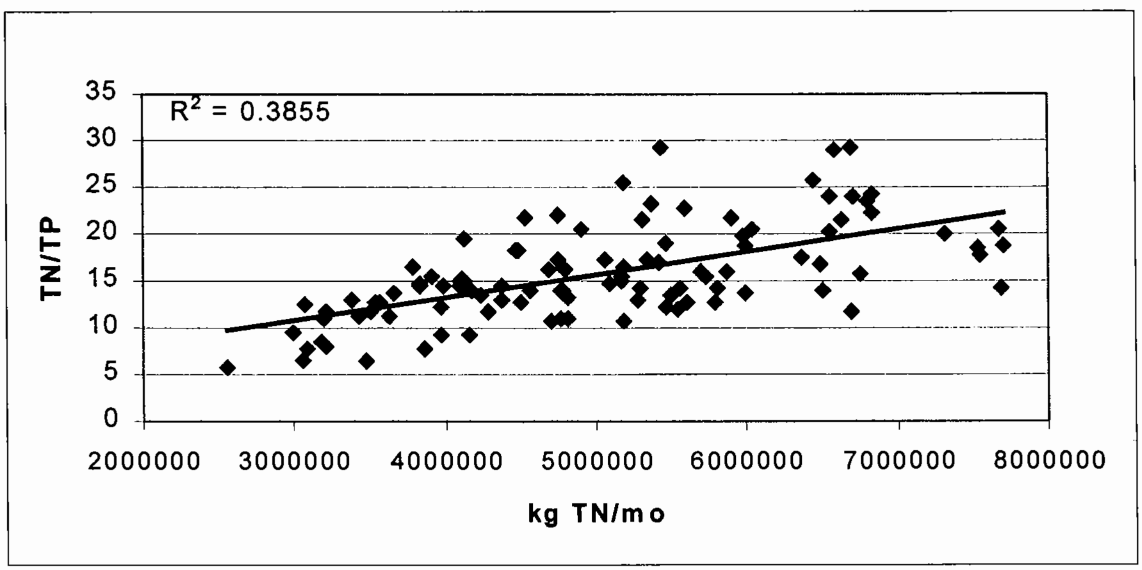

Figure 15. TN load to LIS correlated with TN:TP atomic ratio at Station D3 surface using a three-month offset with a three-month moving average.

Station D3 appears to reflect a general condition of TN, TIN, and chlorophyll-*a* trends observed at other stations in LIS, although an analysis of all stations has not been completed.

Relationships

Sound-wide TN loading and ambient TN concentration at Station D3 appear reasonably well correlated when a 3-month offset of loading is applied. Additional tests of covariance using a better loading database need to be applied to confirm this preliminary observation.

TN loading did not correlate very well with Station D3 chlorophyll-*a* and TIN concentrations. It appears that biological mediation, perhaps zooplankton grazing, interferes with these relationships.

Significant reductions in chlorophyll-*a* concentrations appear to be caused by other factors than reductions in TN loads to LIS, although load reduction may play a role. Additional analyses or studies of primary production might help resolve this question.

TN:TP atomic ratio trend was significantly downward at Station D3 surface and exceptionally well correlated to Sound-wide TN loads. Combined with the noted significant decline in ambient TN concentrations, this decline in the TN:TP ratio suggests that ambient TP concentrations have not changed. Additional analyses of TP data would help resolve this question.

Recommendations

Additional analyses of other stations, including bottom waters, should be undertaken to support preliminary analyses at Station D3 surface. It is likely that levels of enrichment will also relate to the Sound's response and yield different relationships from west to east.

Evaluations of other parameters, especially phosphorus and silica, could help define the changes observed in chlorophyll-*a* and TN:TP atomic ratios.

Studies of phytoplankton and zooplankton community structure and changes would help determine if observed reductions in chlorophyll-*a* are biologically mediated rather than driven by changes in TN load.

Primary productivity studies would provide a better indication of changes in productivity than chlorophyll-*a* observations and would be a better predictor of changes in hypoxia.

Acknowledgments

The LISMP and this analysis draw support from many cooperating agencies and people. The EPA LISS provides much of the funding for the LISMP. The role of CTDEP's Bureau of Natural Resources and the University of Connecticut's Environmental Research Institute (ERI) are critical to field and laboratory work. The U.S. Geological Survey's (USGS) East Hartford Office provides extensive river monitoring data throughout the state without which nitrogen loading estimates could not be made. Thom Haze and Iliana Ayala from CTDEP's Bureau of Water Management calculated nitrogen loading estimates from CT's sewage treatment plants and Phil O'Brien from New York State Department of Environmental Conservation provided data for New York's treatment plants. Supplementary monitoring data were provided by the Interstate Sanitation Commission and the New York City Department of Environmental Protection. Through the years, dozens of CTDEP employees and seasonal interns have worked to collect and refine the data and, while too many to name, are gratefully acknowledged. We also remember all the efforts of our friend and colleague, Nick Kaputa, and wish he could be here to enjoy the fruits of his labors.

Literature Cited

Capriulo, G.M. *et al.* 1996. Alteration of the planktonic food web of Long Island Sound due to eutrophication. Final Grant Report to CT DEP Long Island Sound Research Fund. 172 pp.

Welsh, B.L. and R. I. Welsh. 1992. Calculation of duration of hypoxia in western Long Island Sound. Final report to U.S. EPA Contract No. 68-C9-0029, Task Assignment No. BLW-2-209.

Settlement of Suspended Particles in Relation to their Optical Signatures

Karl-Heinz Szekielda
Department of Geography
Hunter College, City University
695 Park Avenue, New York, NY 10021

1. Introduction

Particles in an estuary have their origin from different sources and, accordingly, are composed of inorganic and organic products from *in situ* biological processes, decay mechanisms, bio-geochemical interaction between the dissolved and solid phases, and erosion. Transport mechanisms in tidal estuaries result in fractionation and interaction between the different particle sizes.

Advective transport is the dominant process for dissolved compounds and for small particles with minimal difference in density compared to water. Deposition and re-suspension of particles at a higher size class, on the other hand, are determined by turbulence and current velocity which determine their transport and pathway. The alternating cycles in tidal coastal water movements introduce particle sorting according to settling velocity, size distribution and chemical properties. Fractionation of particles, i.e. their dynamics with respect to turbulence, also changes the optical properties of water masses. Optical characteristics of settleable and non-settleable suspended matter can be better understood by sampling strategies either by conventional means or by more advanced techniques such as remote sensing.

Empirical algorithms to interpret ocean color monitored from space, in terms of chlorophyll, break down in near-coastal eutrophic waters with river discharge. This is partly due to the presence of chromophoric dissolved organic matter and inorganic particulate matter derived from biological production, coastal erosion processes or river discharge. In addition, varying plankton species carrying photosynthetic pigments, give varying specific spectral signature due to their reflectance properties and to physical configuration.

Riverine input, *in situ* production of colored dissolved organic and particulate organic and inorganic particles in coastal waters, may be considered as decoupled processes. Experiments were carried out measuring turbidity, oxygen, pH, temperature and salinity, to identify the behavior of particulate matter and their physical behavior in relation to water movements and settling properties.

Several experiments on settleable and non-settleable suspended particles have been carried out through fractionation of the suspended particles under laboratory conditions. As measurements on particle separation in a natural body are difficult to conduct, it is not surprising that our knowledge on separation of particles *in situ* by size and composition, is at an early stage. In order to contribute to a better understanding of the settling characteristics of particles in suspension, in relation to their spectral properties, research was conducted to study a large volume of water under natural conditions but at different stages of current velocity. The emphasis on this experiment was to gain more knowledge on the spectral changes of water masses during the tidal cycle. This work is a continuation of work reported earlier on analyzing satellite remote sensing data for a study on Long Island Sound (Szekielda, 1998).

Experimental conditions

The Shinnecock Canal of Long Island was selected as an ideal "natural tank" in an experiment to observe optical parameters and residence time of suspended matter in the water column, under different current speed and in periods during which turbulence is reduced. The principal function of the Shinnecock Canal and its operating lock system is to control the flow of water in one direction only from the Peconic Bay to the Atlantic Ocean through the Shinnecock Inlet. This prevents the flow of water with low salinity from the Shinnecock Bay to the Peconic Bay. As a result, the flow of saline water from the Peconic Bay to the Shinnecock Bay flushes through the Shinnecock gate with particle load originating in Peconic Bay.

The tidal range at end points of the canal, namely the Peconic Bay and the Shinnecock Inlet at the Atlantic side, is out of phase. High water at the Shinnecock Canal at Peconic Bay occurs close to the time during which low tide is observed at the Shinnecock Inlet, with an approximate difference in elevation of about 2.5 feet. A difference of about 2.9 feet is noted when low water is observed at Shinnecock Canal. During tidal change, the flow rate is controlled by the gates. Advantage was taken from the time period of about six hours during which the water flow is stopped. It allows the entrapment of a rather large water parcel from the Peconic Bay in the lock area for analysis and observations of the settling behavior of suspended matter.

The advantage of the tidal gates in this particular one-direction flow system, is that the canal and its gates permit the analysis of particle settling at different times and in different stages. These stages can be described at specific intervals, either as a plug-flow system, as a reservoir with reduced turbulence or as a basin in which re-suspension of settled material can be observed.

Observations

Hydrographic conditions were recorded over a lunar cycle, through continuous measurements of salinity, temperature, dissolved oxygen, turbidity and pH. The frequency of observations was set to five minutes, which was found sufficient as a minimum to resolve the spatial and temporal heterogeneity observed with a previous higher frequency rate of observations over a two-day period.

Based on the fluctuations in the hydrographic conditions, spectral properties ranging from 400 nm to 860 nm were measured as a function of solar irradiance and expressed in percent. Details of the results will be published elsewhere but the general conclusions will be incorporated in the following summary findings.

Experiments on settlement of particles at low turbulence showed that concentrations of settleable particles in near-shore water are around 30 mg/liter (expressed in montmorillonite-equivalent). Washload, which can be considered as the fraction with particle settling velocity < 0.001 cm/second, accounts in the average for about 12 mg/liter as can be seen in Figure 1. This amount of suspended matter stays in *quasi* permanent suspension. Advective transport can, therefore, be assumed to be the major transport mechanism responsible for the small size fraction of particles such as free bacteria and phytoplankton. This finding is in good agreement with results reported by Postma (1961) for the Wadden Sea having a background concentration of "permanently suspended" material of 15 mg/l, for the Chesapeake Bay of about 15 mg/l (Schubel, 1969, 1971) and the Ogechee estuary of about 11 mg/l (Alber, 2000).

The role of permanent suspended material can be demonstrated with the fact that at low turbulence, after four hour settling of suspended material in the closed gate, respiration indicates a fast biological oxygen uptake. Using the stoichiometrical ratio of plankton, the measured oxygen values relate to a respiration rate of about 0.2 mg C/liter/hour during the water's residence time of about six hours in the gate.

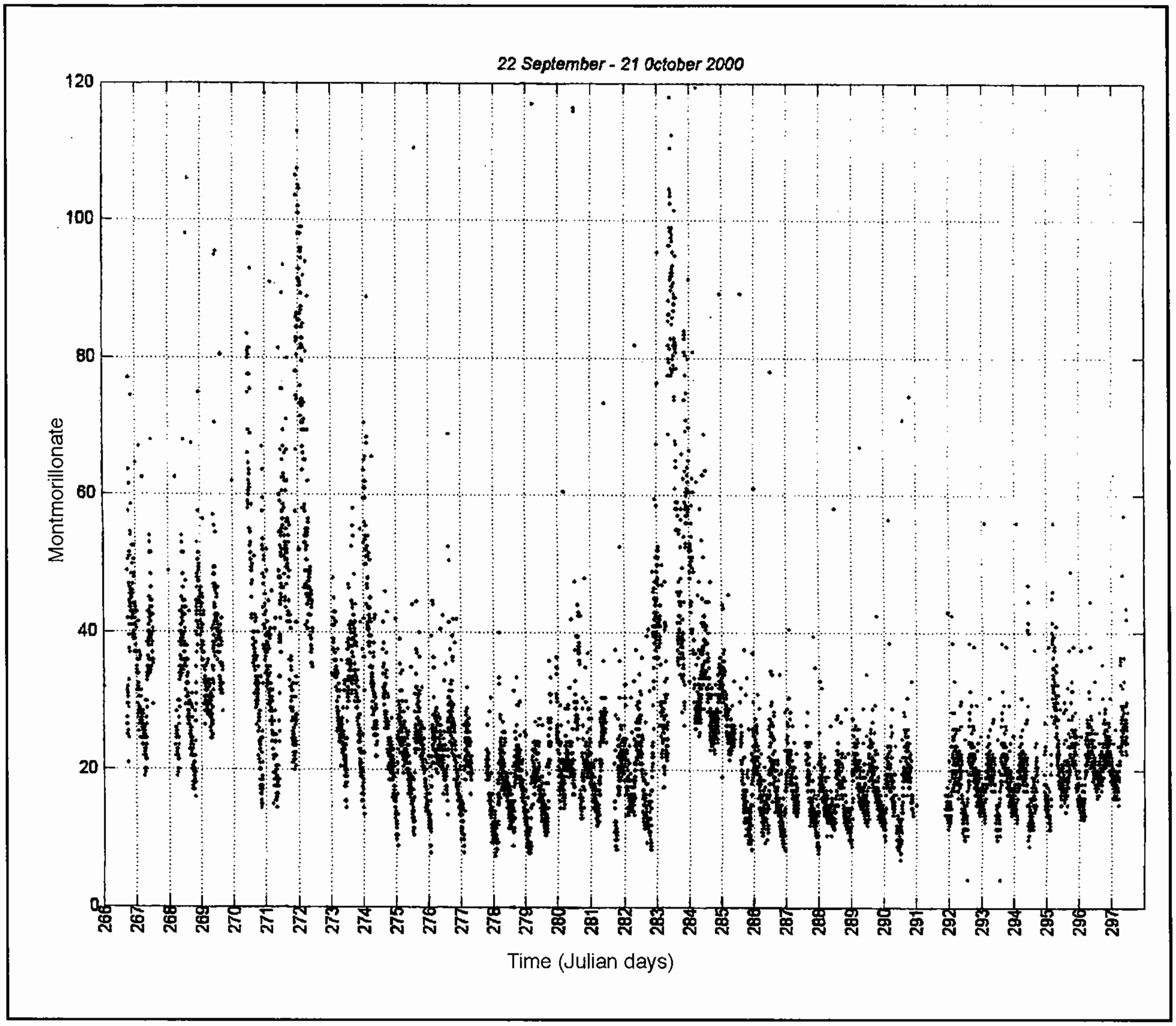

Figure 1. Turbidity measurements in the tidal gates of Shinnecock Canal covering the period 22 September to 21 October 2000. Time is given in Julian days and the vertical axis represents the concentration in milligrams measured against a standard montmorillonite suspension

This finding is in general agreement with rate constants used in dynamic ecosystem models of 0.01- 2 mg/day. Therefore, it can be postulated that the fractionation of particles enhances the decomposition of the organic fraction present either in dissolved or particulate form.

Spectral measurements of upwelling radiance confirm the fast settlement of particles during reduced turbulence while the water parcel is trapped during closed gates. Figure 2 represents reflectance spectra for different settlement times in the tidal lock. About 50% loss of spectral reflectance has been observed after settling of particulate matter in the entrapped water parcel as shown at wavelength between 550nm and 600 nm. In general, all spectra show that reflectance decreases with decreasing turbidity throughout the whole spectrum. It is noted that the broad low spectral response between 400 and 550 nm is due to the absorption of photosynthetic pigments, and that the second chlorophyll absorption band at around 660 nm is well-pronounced.

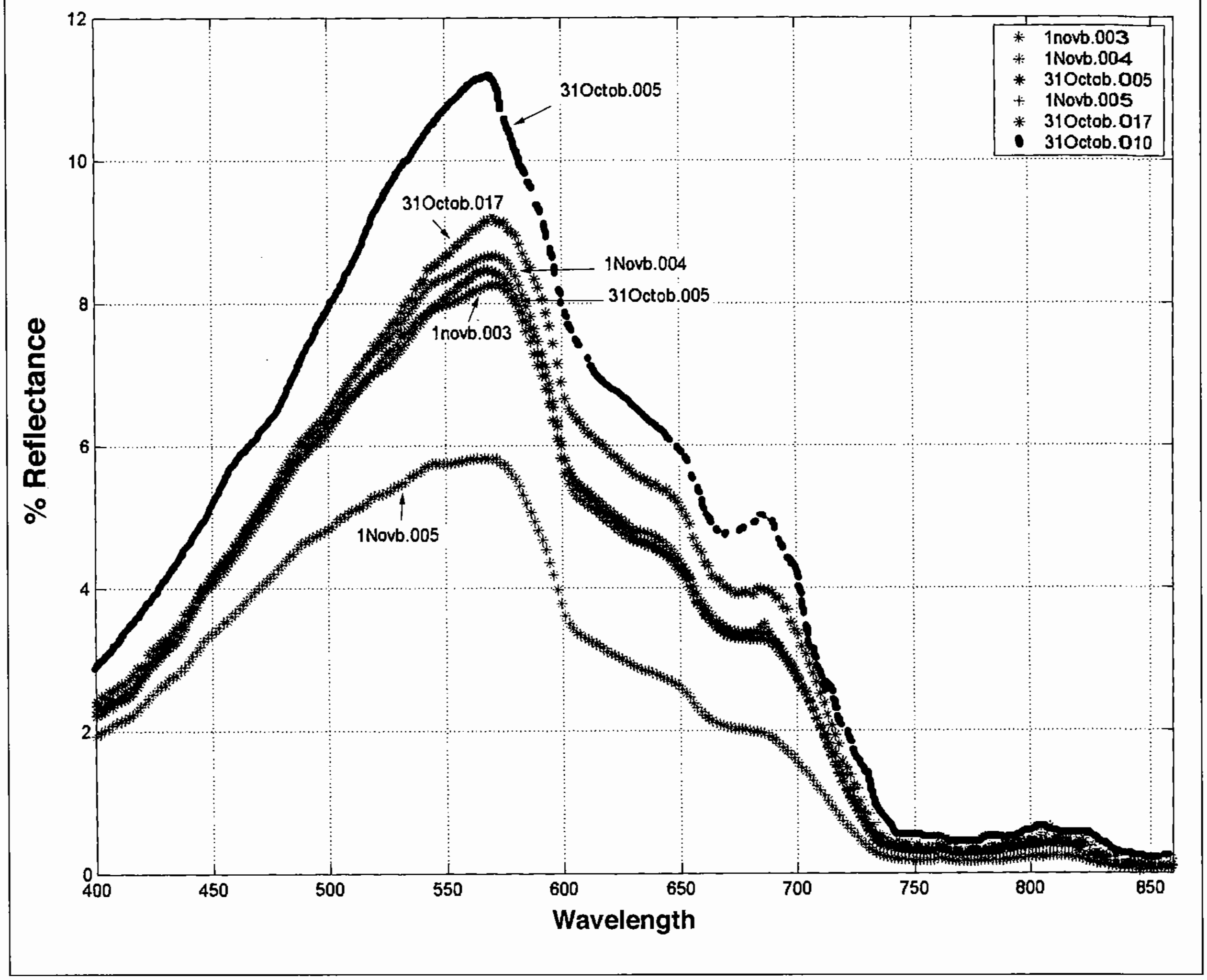

Figure 2. Spectral reflectance measurements in the Shinnecock Canal: 1novb.003 ≈ 40 minutes after opening the gates; 1nov.004 ≈ 40 minutes after opening the gates; 31 Octob.005 ≈ during opening of gates; 1 Novb.005 ≈ 4 hours 40 minutes of settling time in closed gate; 31Octob.017 ≈ 21 minutes after opening the gates; 31 Octob.010 ≈ 5 minutes after opening gates.

Conclusions

The reported measurements of turbidity and related spectral data represent the first data set in a controlled water parcel. In summarizing the presented observations in a well-defined water body, the following preliminary conclusions can be drawn:

1. Changes of turbulence as a function of tidal stage result in fractionation of the components in suspended matter, into a fraction with high settlement velocity andresidual suspended material, which is considered as a permanent fraction in the water column.

2. During the sedimentation of particulate matter, the spectral reflectance is reduced over the whole visible part of the electromagnetic spectrum (400–860nm). The resulting increased photon penetration depth increases the light intensities at deeper levels.

3. At reduced turbulence (current speed zero), the constituents of the permanent suspended fraction indicate high apparent oxygen utilization. This is an indication that the separation of particles according to their size, also determine the reactivity according to the tidal stage and related changes in turbulence.

4. For future research, it will be essential to decouple the bio-geochemical compartments in the different size fractions, especially in tidal influenced estuaries with respect to their optical properties and the fractionation of particle fraction according to size. This objective will be pursued in further analyses of the total data set collected under this project.

Acknowledgments

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References

Alber, (2000). Settleable and non-settleable suspended sediments in the Ogeechee River estuary, Georgia,U.S.A. *Estuarine, Coastal and Shelf Science* **50**:805-816.

Postma, (1961). Transport and accumulation of suspended matter in the Dutch Wadden Sea. *Netherlands Journal of Sea Research* **1**:148-190.

Schubel, (1971). Tidal variation of the size distribution of suspended sediment at a station in the Chesapeake Bay turbidity maximum. *Netherlands Journal of Sea Research* **5**:252-266.

Schuchardt, B. and M. Schirmer, (1991). Intratidal variability of living and detrital seston components in the inner part of the Weser estuary: Vertical exchange and advective transport. *Archiv fuer Hydrobiologie* **121**:21-41.

Szekielda, K.-H. (1998). Satellite monitoring of particulate matter in Long Island Sound, 95-105. In: *Proceedings of the Fourth Biennial Long Island Sound Research Conference.* State University of New York, Purchase, pp.170.

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Use of Photosynthesis Measurements in the Choice of Algal Species for Bioremediation

G.P. Kraemer[1], R. Carmona[2], T. Chopin[3], & C. Yarish[2]
[1]Department of Environmental Sciences, Purchase College
State University of New York, Purchase, NY 10577
[2]Department of Ecology and Evolutionary Biology
University of Connecticut, Stamford, CT 06901
[3]Coastal Studies and Aquaculture, Department of
Biology, University of New Brunswick
Saint John, New Brunswick Canada E2L 4L5

Introduction

Globally, finfish mariculture is a multi-billion dollar industry that continues to grow both locally and internationally (New 1999). However, an emerging problem of mariculture activities is significant loading of inorganic nutrients in coastal waters (Beveridge 1987). Effluent from fish farming operations contributes significant amounts of nitrogen and phosphorus to coastal waters (Persson 1992). Long Island Sound and areas of coastal New England already suffer from eutrophication-driven blooms of phytoplankton and weedy macroalgae, creating aesthetic problems, and contributing to the development of hypoxia in bottom waters, and the death or departure of ecologically and economically important biota.

The reduction of nutrient leaching from fish food and trapping fecal matter can reduce nutrient loading (Phillips *et al.* 1993), but a more promising approach is to develop polyculture systems that integrate the culture of finfish or shellfish with macroalgae (Neori *et al.* 1996). Macroalgae are able to concentrate nutrients by as high as 10^5 (Chopin *et al.* 1990), removing excess nutrients from the effluent. Kautsky *et al.* (1996) integrated the agarophyte *Gracilaria* into salmon mariculture in Chile and reduced the release of nitrogen and phosphorus by 56% and 94%, respectively.

Worldwide, seaweed mariculture is also a multi-billion dollar industry. The red alga *Porphyra* (nori) is the most valuable maricultured seaweed, with an annual value of over $US 1.8 billion (Jensen 1993). It is primarily used as the wrapping around 'sushi' rolls, but also is a major source of taurine (controls blood cholesterol levels; Tsujii *et al.* 1983), and is rich in proteins, vitamins, trace minerals and dietary fiber (Noda 1993). *Porphyra* is a preferred source of the pigment, r-phycoerythrin, utilized as a fluorescent tag for biotechnological applications.

The relationship between photosynthetic rate (P) and irradiance (I) is a useful tool for evaluating primary production: (1) P-I relationships enable estimates of production under both light-saturated and

-limited conditions; (2) the short-term measurements do not suffer from tissue losses due to senescence and herbivory; (3) rapid estimates make possible measurements using many samples.

We present preliminary results that (a) compare production by several geographic isolates of *Porphyra*, and (b) examine the relationship between photosynthetic production and growth and measurement temperature, to help choose among the mariculture candidates.

Materials and Methods

Porphyra purpurea (New York strain), *P. purpurea* (Nova Scotia strain), and *P. umbilicalis* (Maine strain), were employed in this study. All are currently in culture at the Marine Biotechnology Laboratory of the University of Connecticut at Stamford. Gametophytes (blades) were grown from conchospores in von Stosch's seawater enrichment at defined temperatures and at approximately 50 μmol photons m^{-2} s^{-1} under a 12:12 L:D cycle. Samples of blade tissue were placed in 12 mL incubation chambers filled with filtered (0.22 μm), autoclaved seawater (30‰). Samples were incubated at temperatures ranging from 10-20°C. The chamber temperature was maintained (± 0.5°C) by a recirculating water bath.

Porphyra purpurea (NY) was also grown for 24 d in 1-L flasks (starting tissue density = 0.3 g FW L^{-1}) in a modified von Stosch medium (DIN (present as NH_4^+) = 300 μM). The culture medium was changed at three day intervals. Maximum rates of photosynthesis (P_{max}) were measured every six days. Growth rate (% d^{-1}; $100*\ln(\text{biomass}_t/\text{biomass}_0)/t$) was measured by weighing every six days, at which time tissue was removed to return biomass to starting tissue density.

Results

The rate of photosynthesis by *Porphyra* spp., measured under saturating irradiance, was a good estimator of growth rate over periods of six days (Figure 1). The relatively large error terms obtained during photosynthesis measurements derive at least in part from spatial variability in metabolic potential within the *Porphyra* thallus; rates of respiration and photosynthesis under both saturating and sub-saturating irradiances were ca. 30% higher in tissue at the thallus periphery than internally (Table 1).

Photosynthetic rates were dependent on light as well as temperature, the latter affecting maximum photosynthetic rates following typical Q_{10} kinetics (Figure 2). Blades of *P. umbilicalis* (ME) out-performed *P. purpurea* (NS) at 15°C and *P. purpurea* (NY) at 20°C in terms of P_{max} and or α (Table 2).

Table 1. Rates of oxygen consumption and production as a function of position within the thallus of *Porphyra purpurea* (CT4-1) grown and measured at 15°C (SD).

Irradiance (μmole photons m^{-2} s^{-1})	**Rate of Oxygen Evolution (μmol O_2 g^{-1} DW min^{-1})** Middle of Thallus	Thallus Periphery
0	-0.28 (0.03)	-0.36 (0.02)
37	2.04 (0.84)	2.559 (0.08)
315	2.96 (0.67)	4.27 (0.53)

Conchocelis P-I relationships were roughly similar to those of blades, though having maximum rates of photosynthesis and photosynthetic efficiencies only about 5% those measured for blade tissue (Table 2).

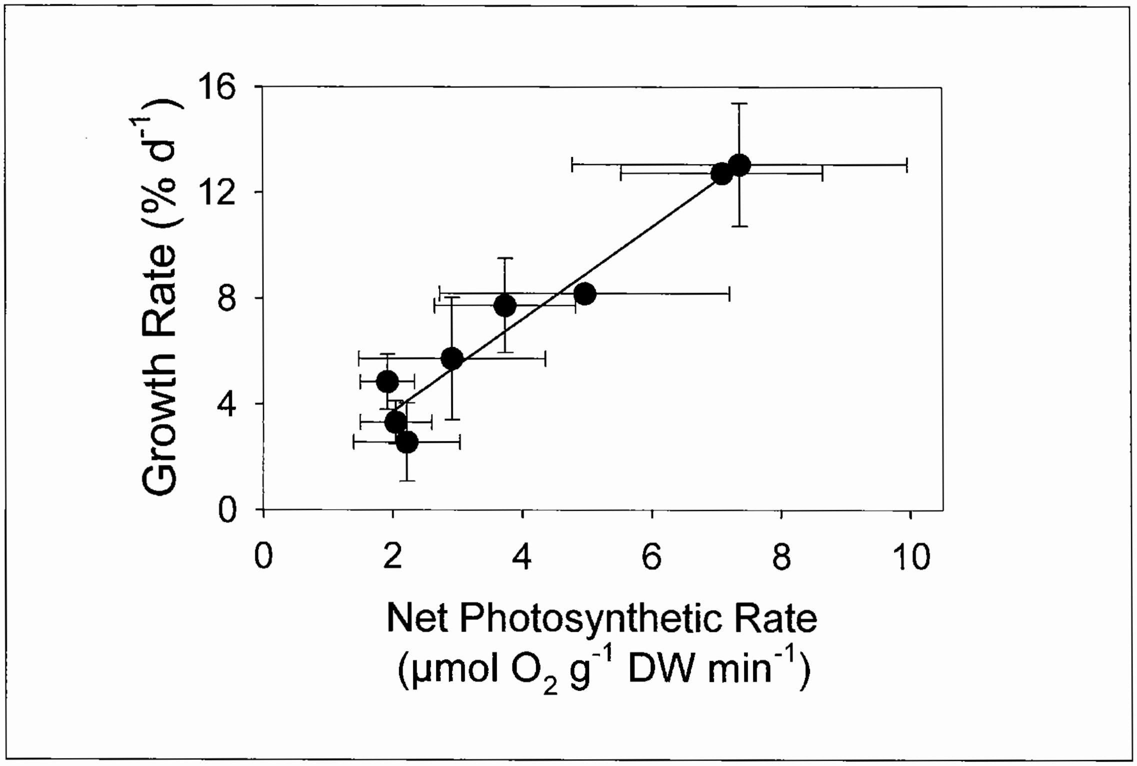

Figure 1. Relationship between maximum net photosynthetic rate and growth rate of *Porphyra purpurea*. Plants grown and measured at 15°C and saturating irradiances (290 µmol photons m^{-2} s^{-1}).

Table 2. Rates of oxygen production by various geographic isolates of *Porphyra* spp. (SD).
Origin codes: ME = Maine, CT = Connecticut, NS = Nova Scotia. P_{max} units = µmol O_2 g^{-1} DW min^{-1}, α units = (µmol O_2 g^{-1} DW min^{-1})(µmol photons m^{-1} s^{-1})$^{-1}$, I_k units = µmol photons m^{-1} s^{-1}. Photosynthesis measured at growth temperature. ND = not definable since oxygen production did not reach an asymptote even at irradiances as high as 300 µmol photons m^{-1} s^{-1}.

	Growth at 15°C			**Growth at 20°C**		
Species (Origin)	P_{max}	α	I_k	P_{max}	α	I_k
P. purpurea (CT)				15	0.19	82
P. purpurea (NS)	13	0.43	30			
P. umbilicalis (ME)	17	0.40	42	23	1.04	22
Conchocelis stage of *P. purpurea* (CT)	1.3	0.017	16	ND	0.0062	ND

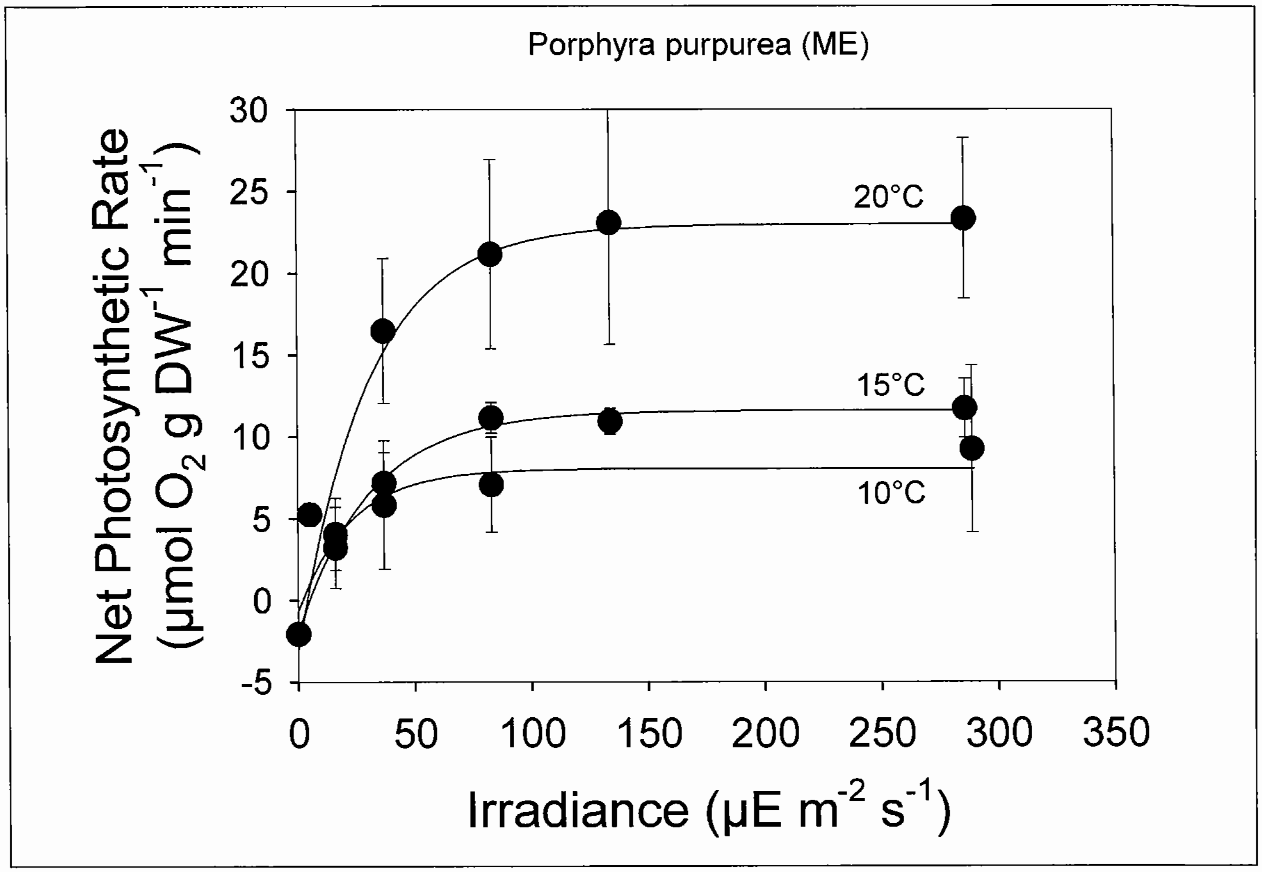

Figure 2. Effect of temperature on net photosynthetic rate of *Porphyra purpurea* (Maine isolate).

Conclusions

It is not surprising that measurements of P_{max}, the light-saturated (i.e., maximal) rates of photosynthesis, gave good estimates of growth. The *Porphyra* spp. used in this study are monostromatic; with no complex structural tissue, all of the biomass is productive. This makes the P-I approach useful in selecting from the long list of potential candidates for *Porphyra* mariculture. The relationship between P_{max} and growth rate does have inherent variability. Some of this variability in the measured photosynthetic rates is due to spatial heterogeneity in the thallus' metabolism. The periphery of the blades is more metabolically active, likely because this is the area of the thallus where active growth is occurring.

Growth of the conchocelis stage of the *Porphyra* life cycle is limited by photosynthetic potential. In mariculture applications, the growth of spore-generating tissue may seem limited by these lower rates of production. However, once a small mass of conchocelis filaments is generated, this may be maintained for relatively long periods of time, and the production of spores stimulated as needed.

From the initial work, it is clear that differences in photosynthetic and, hence, growth potential exist among the *Porphyra* isolates used in this study. There is accumulating molecular taxonomic evidence that the *P. umbilicalis* isolated from Maine is a geographic variety of *P. purpurea* (Neefus, personal communication). If this is supported by further study, the differences in the P-I characteristics observed here can be described as intraspecific geographic differences in performance.

Acknowledgments

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Literature Cited

Beveridge M.C.L. 1987. *Cage aquaculture.* Fishing News Books Ltd., Farnham, 352 p.

Chopin T., Hourmant A., Floc'h J.-Y. and Penot M. 1990. Seasonal variations of growth in the red alga *Chondrus crispus* on the Atlantic French coasts. II. Relations with phosphorus concentration in seawater and internal phosphorylated fractions. *Can. J. Bot.* **68**:512-517.

Jensen, A. 1993. Present and future needs for algae and algal products. In: A. R. O. Chapman, M. T. Brown and M. Lahaye (eds.), *Proc. Fourteenth Intern. Seaweed Symp.*, Brest, France, *Hydrobiologia* **260/261**:15-23.

Kautsky, N., Berg, H., Buschmann, A., Folke, C. and Troell, M. 1996. Ecological footprint, resource use and limitations to aquaculture development. *IX Congreso Latinoamericano de Acuicultura,* Book of Abstracts: **193**.

Neori, A., Krom, M.D., Ellner, S.P., Boyd, C.E., Popper, D., Rabinovitch, R., Davison, P.J., Dvir, O., Zuber, D., Ucko, M., Angel, D. Gordin, H. 1996. Seaweed biofilters as regulators of water quality in integrated fish-seaweed culture units. *Aquaculture* **141**:183-199.

New, M.B. 1999. Global aquaculture: current trends and challenges for the 21st century. *World Aquaculture.* **30**:8-14; 63-79.

Noda, H. 1993. Health benefits and nutritional properties of nori. *J. Applied Phycol.* **5**:255-258.

Persson, G. 1992. Eutrophication resulting from salmonid fish culture in fresh and salt waters: Scandinavian experiences. *In* C. B. Cowey and C. Nu Y. Cho (eds.) *Nutritional Strategies and Aquaculture Waste.* :University of Guelph Press, Guelph, Ontario.

Phillips, M.J., Clarke, R. and Mowat, A. 1993. Phosphorus leaching from Atlantic salmon diets. *Aquacultural Engineering* **12**:47-54.

Tsujii, K., Ichikawa, T., Nakagawa, Y., Matusuura, Y. and Kawamura, M. 1983. Hypercholesterolemic effect of taurocyamine or taurine on the cholesterol metabolism in white rats. *Sulfur Amino Acids* **6**:239-248.

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Posters

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Microbiological and Physicochemical Aspects of Mercury Cycling in Waters and Sediments of Long Island Sound and its River-Seawater Mixing Zones

P.H. Balcom, C. H. Lamborg, C.-M. Tseng, C. R. Hammerschmidt, W. F. Fitzgerald and P.T. Visscher
Department of Marine Sciences
University of Connecticut
Groton, CT 06340.

Elemental mercury (Hg^0) cycling is a principal control on the aquatic biogeochemistry of Hg and the bioavailable Hg species (monomethyl mercury or MMHg). We have undertaken a comprehensive field and laboratory study to investigate reactions and processes controlling Hg cycling, speciation and bioavailability in the waters and sediments of Long Island Sound (LIS) and its watershed/coastal water interface (e.g., Connecticut River, East River). Extensive investigations of the air-sea partitioning of Hg are being conducted using an Automated aqueous Gaseous Elemental Mercury sampling and analysis System (AGEMS), designed for shipboard use, that allows direct analysis of Hg^0 in surface waters. The production and distribution of Hg^0 is related to the supply of reactant (e.g., ionic Hg) and in situ reducing agents (microbial activity and solar radiation). We are testing the following hypotheses: (1) The Hg^0 distribution in LIS is spatially/temporally variable and related to the supply of labile Hg (reactive; labile inorganic and organically associated Hg species); (2) Estuarine reactions (i.e., mixing of river-borne Hg species with seawater high in Cl^- and major cations) and direct wastewater treatment facility (WTF) discharges (sewage) increase the labile Hg fraction available for reduction, enhancing localized production of Hg^0; (3) Hg^0 formation reduces the availability of labile species for in situ biologically mediated production of toxic MMHg in coastal waters.

In situ Hg^0 production in the waters of LIS and emissions to the atmosphere are major processes (Rolfhus & Fitzgerald, in press) in the local/regional biogeochemical cycle of Hg. Hg^0 concentrations in LIS surface waters (60-600 fM) vary both spatially and seasonally, and are supersaturated with Hg^0 (75-1200 % relative to atmospheric equilibrium). LIS Hg^0 concentrations are correlated with sources of labile Hg (e.g., Connecticut River, where nutrient measurements typically indicate fresh water inputs), and influenced by biological production and mixing. For example, the Hg^0 distribution in March 2000 shows a maximum at the Connecticut River (eastern central LIS), while in May of both 1999 and 2000 the maximum was west of the Housatonic River (western central LIS). This illustrates that dramatic changes in Hg^0 distributions can occur between early and late spring. Hg^0 levels are generally highest in summer (enhanced photoreduction), typically show maxima in central LIS, and correlate with salinity during spring "high flow" conditions. The annual average calculated Hg^0 flux (Wanninkhof, 1992) from LIS agrees well between earlier (1995-1997; 334 p moles m^{-2} d^{-1}; Rolfhus & Fitzgerald, in press) and later (1998-2000; 316 p moles m^{-2} d^{-1}) surveys. General trends include increased Hg^0 flux at elevated Hg^0 concentrations during warmer months and at high wind velocities. Annual emissions (85-90 kg) indicate remobilization of approximately 35% of Hg inputs (230 Kg y^{-1}) to LIS (Fitzgerald *et al.*, in press).

Inputs of particular significance to LIS are the East River (large sewage loadings), and the Connecticut River (70% of the annual input of freshwater). Estuarine reactions (i.e., mixing of river-borne Hg species or sewage with seawater) increase the labile Hg fraction available for reduction. This physicochemical transformation results from shifts in speciation associated with the presence of in-organic complexing ligands (i.e., Cl^- ions) in coastal seawater and displacement of sequestered Hg by the increased activity and competition from cations such as Mg^{++}. The Connecticut River surface front (mixing zone) was sampled where it enters LIS, incorporating a wide salinity range (0.5–27 ppt) in the sampling design. Labile (reactive) Hg normalized to total Hg shows a strong positive correlation with salinity (both filtered and unfiltered samples), indicating a significant increase in labile Hg independent of the change in total Hg. We sampled surface waters at the site of the Ward's Island WTF (East River) effluent discharge, and sites to the east (increasing salinity) near LIS (Throgs Neck). Enhanced levels of labile Hg and Hg^0 were observed where WTF effluent mixed with polluted, higher salinity East River waters, and levels of both species decreased toward the east due to mixing.

Extensive and careful empirical documentation of the spatial and temporal variability of Hg in coastal waters can yield an indicator as to the status and trends of Hg pollution in the system. Since Hg^0 production and emissions are related to the supply of reactant Hg, then remedial measures should be reflected by a decrease in the Hg^0 distribution. This work is designed to increase understanding of *in situ* Hg^0 production and emissions and their role in the aquatic and atmospheric Hg cycles, and help constrain aquatic biogeochemical cycling and mixing models for Hg.

Future work will include: (1) Continued examination of Hg^0 distributions in LIS waters during spring and summer, including speciation analyses and vertical sampling in the water column; (2) Sampling of river-seawater mixing zones during both high flow (spring floods) and low flow (summer) conditions, with particular interest in labile Hg and Hg^0 production and distribution.

References

Fitzgerald W.F., Vandal G.M., Rolfhus K.R., Lamborg C.H. and Langer C.S., in press, Mercury Emissions and Cycling in the Coastal Zone. *J. Environ. Sci.*

Rolfhus K.R. & Fitzgerald W.F., in press, The Evasion and Spatial/Temporal Distribution of Mercury Species in Long Island Sound, CT-NY, *Geochim. Cosmochim. Acta.*

Wanninkhof R., 1992, Relationship Between Wind Speed and Gas Exchange Over the Ocean, *J. Geophys.* Res., **97**(C5):7373-7382.

Not Too Crabby: the Predator/Prey Relationship in the Mystic River

M.H. Canning
The Williams School
New London CT 06320

Since May of 1998, I have been researching marine fouling communities in the Mystic River under the guidance of Dr. James Carlton of Williams College. During one of my panel retrievals, I observed the sea squirt *Molgula manhattensis* growing on ropes and nearby floats, but not on the panels I had suspended close to the river bottom. I guessed marine predators such as crabs and fish had been feeding on my panels. I then raised the question: Is the biodiversity of marine life influenced by predators such as crabs and fish in an estuarine environment? I prepared an experiment with twelve plywood panels to be retrieved in pairs (one from each of two racks) every two weeks for 105 days. At each retrieval we took one panel from a caged rack and one from an uncaged rack. One rack was caged to eliminate predators. After the project was completed, we found that predators have a significant effect on the population of the species. The absence of the predator resulted in dominance by a single species, *Molgula manhattensis*. The presence of a predator resulted in the dominance of *Bugula turrita* for the first eight weeks of our test; and from then on, both *Molgula manhattensis* and *Bugula turrita* maintained shared coverage of the panel. While predation may have some control over which species dominates the panels, my data suggested that overall diversity is not controlled by predation. Twenty-nine species were observed on both sets of panels during the course of the study.

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Site Assessment of the Silver Sands State Park Debris Field, Milford, Connecticut

Cynthia R. Coron, Ken Becker, J, Cooper, David Lamoureux , Jess Priest,
Roger Rushworth, and Glenn Setkoski,
Earth Sciences Department
Southern Connecticut State University
501 Crescent Street, New Haven, CT 06515,
<coron@scsu.ctstateu.edu>

Summary

Silver Sands State Park is a 47-acre recreational beach and salt marsh facility along Long Island Sound in Milford, CT. The park project was initiated in the 1960's and developed and adopted by the State of Connecticut in 1991. The area had been a dumping site for local inhabitants since the 1920's and had been used by the town of Milford as an unregulated landfill since the end of WWII. The site was officially closed in 1977 and capped with fly ash beginning in 1990. Anecdotal information indicates that, in addition to regular household waste, hazardous materials including asbestos, lead paint, pesticides, oil, battery acid, freon, toluene, PCB's and radioactive medical waste were discarded at the site.

During restoration of the Fletcher's Creek tidal marsh system during late Summer 1999, channels were dredged to restore circulation. A boardwalk was constructed connecting parking lots, built on engineered fill at the landfill's base, to the beachfront. As a result of construction and clearing of *Phragmites*, debris was uncovered at the surface.

The debris field was mapped, refuse samples taken to be dated, and water samples were collected from tidal channels, pools and seeps within the debris field in Fall, 1999, and late Summer, 2000. The affected area was initially determined to be 242 meters south of the fenced-off landfill, extending 60 to 100 meters beyond the mapped '0' limit of landfill waste. The debris field as currently exposed covers an area of 3.72 square kilometers. Bedded debris exposed in channels occurs to an average depth of 2 meters. Dated materials exposed on the surface cluster between 1964 –1968.

A Cesium magnetometer survey of the debris field and surrounding area extended the limits of buried waste in a continuous line from the town landfill, passing under the parking lots and encompassing the exposed debris field, to within 150 meters of the beach.

Spectrophotometric analyses of water samples from the debris field and surrounding marsh areas indicate concentrations of heavy metals (including chromium, copper, iron, lead, manganese, nickel and zinc) elevated three to five times above the concentrations of metals in openly circulating tidal channels in the beachward part of the system.

1.0 Introduction

Silver Sands State Park is a 310-acre recreational beach on Long Island Sound in Milford, Connecticut, which includes the 47-acre partially-restored Fletcher's Creek Tidal Marsh. The Silver Sands State Park project was initiated in the 1960's due to concerns that the Connecticut coastline was becoming over-developed and was restricting inland residents from access to Long Island Sound. Public access to the Sound is very limited in Connecticut, since most of Long Island Sound shorefront is privately owned (Jacobsen and Associates, 1981). Connecticut ranks 49th in the amount of land owned by federal, state or local governments, with 0.096 acres per capita (State of Connecticut Council on Environmental Quality, 1991). The pressures of development have diminished tidal wetlands in recent decades and open space in general. The region that is expected to use Silver Sands State Park extends from Newtown in the west to Watertown in the north to Meriden in the east and to Bridgeport in the south. This region contains 29 towns, which had a 1960 population of 882,000 residents and increased 17% to 1,031,000 in 1990. It is expected to grow to 1,074,000 in 2000 (State of Connecticut, State Data Center, April 1991).

Milford was chosen for the site because it had more undeveloped shoreline property than surrounding communities and was centrally located between Sherwood Island State Park (Westport, CT) and Hammonasset State Park (Madison, CT). The project was developed and adopted by the State of Connecticut Department of Environmental Protection (DEP) in 1991. The state has currently used $9 million of a projected $27.1 million in the preliminary stages of development of the park.

The park design calls for the conversion of the former City of Milford landfill into a focal point at the park, which is designed to accommodate a peak visitation rate of 6,700 to 8,100 people. The summit of the landfill, which will have to be raised to 66 feet above sea level, will be utilized as a viewing vista looking into Long Island Sound. The summit will have a four and a half-acre level area for parking and viewing. The slopes have been capped with fly ash (an inert incinerated by-product of electric energy consumption) produced by United Illuminating at their Milford plant. The plan calls for two boardwalks stretching across Fletcher's Creek Tidal Marsh and one boardwalk running along the beach. Two 5706 square-foot bathhouse/concession buildings will be located on the eastern and western ends of the park. (DeVido *et al*, 1991).

To facilitate the main objectives of the park, swimming, picnicking, fishing and nature observation, the park design will also enhance or rebuild some of the natural features of the park. Stabilized sand dunes have been constructed between the beach and the tidal wetlands. An old seawall was removed and sand was deposited along the high tide mark in order to create a perched beach. The park will also encompass Charles Island an 18.7-acre area of metamorphic rock connected to the mainland by a tombolo 1000m long and 10.3m wide, which is exposed during low tide.

1.1 Environmental Site Characteristics

The three main parts of the original wetlands include Fletcher's Creek in the center, Great Creek to the east and Nettleton Creek to the west. These marsh areas were once connected, but construction of beach cottages (destroyed by Hurricane Diane in 1955) and the establishment of the landfill cut them off from each other. The marshes used to be salt-water estuaries, part of a mixed semi-diurnal tidal regime which replenished the nutrients necessary for aquatic life and which hosted a *Spartina*-based ecosystem on a muddy substrate. *Spartina* normally grows approximately 1 m high and allows more sunlight to penetrate the soil and enhance growth of salt marsh species. There are now two culverts that connect

Fletcher's Creek Tidal Marsh to Long Island Sound. They are composed of three 12-inch diameter metal tubes. Sand deposition due to wave action has clogged the culverts and cut off the marsh from the Sound, and as a result the water is now brackish. *Phragmites* now dominates the area, growing to an average height of 3 to 4 meters.

Indigenous to the area are the great egret, the snowy egret, and the northern harrier, all classified as threatened species. Other marsh inhabitants include the great blue heron, the black crowned night heron, and the osprey, which are classified as species of special concern. There are also two rare plants in the area that are considered threatened species or species of special concern: beach needlegrass and cursed crowfoot. (DEP Natural Diversity Data Base, 1991)

1.2 Municipal Landfill and Associated Debris Field

The park is located on a former landfill whose mapped acreage is 90 to 100 acres. The northern edge of the park is a small hill 450 m in diameter that was the main part of the landfill. The debris field, as currently exposed, occupies an area of roughly 3.72 square kilometers approximately 240 to 250 meters south of the main landfill, extending a minimum of 60 to 100 meters beyond the previously mapped "0" margin of the landfill. A 200 meter-long footbridge bisects the marsh and the main debris field. Its construction and the accompanying channel dredging to restore circulation throughout the marsh resulted in the debris being uncovered. The channel that is adjacent to the main debris field runs generally east west for approximately 250 meters and there is embedded debris along its entire course. A Cesium magnetometer survey of the debris field and its margins indicates buried debris extending in places to within several meters of the strandline. Bank exposures, dug trenches and augur holes indicate that the debris is bedded and occurs to an average depth of 2 meters. The debris includes cans, glass bottles (most dating from 1964-1968), plastic bottles, toys, plastic bags, wood, clothing, and miscellaneous auto parts (see appended photographs). The debris becomes less dense heading south and at the surface appears to be dominated by wood laths. These are probably remnants of the houses damaged during the 1955 hurricane and subsequently bulldozed. Anecdotal information indicates that, in addition to regular household waste, hazardous materials including asbestos, lead paint, pesticides, oil, battery acid, freon, toluene, PCB's and radioactive medical waste were discarded at the site of the main fill. Surface seeps and films are common in the channels.

2.0 Water Quality

The groundwater in the area is classified as GB, which means it is degraded and not suitable for human consumption. Groundwater quality under the landfill area was sampled during 1973 and 1977; iron and manganese were included in a listing of 'elevated constituents' at that time (Diversified Tech., 1993). The water table was adjudged to be very close to the surface and groundwater was thought to discharge into the northern, middle and southern ponds and into Fletcher's Creek and Nettleton Creek (Fuss and O'Neill, 1978). During the preliminary site mapping in November 1999, water samples from six locations within the debris field were collected, returned to the lab and analyzed using a HACH DRE 2010 Spectrophotometer. Though results for indicator heavy metals like copper and manganese were below maximum contaminant levels, sufficient levels in the channel waters appeared to warrant further investigation. Consequently, in March and in October 2000, thirty-three additional samples were taken from seeps and channels covering the extent of the Fletcher's Creek Tidal Marsh system. Results were consistent with those of the preliminary sampling site visit. These are contained in the following table:

	Concentration (mg/l)	
	Settled	Agitated
Chromium	0.01 – 0.40	0.01 – 0.16
Copper	0.01 – 0.52	0.61 – 1.48
Iron	0.47 – 3.21	1.09 – 3.25
Manganese	0.10 – 11.40	0.30 – 5.10
Zinc	0.00 – 1.12	0.00 – 1.17

Concentrations of heavy metals in open channels circulating at the base of the municipal landfill and through the exposed debris field were elevated three to five times above the concentrations of metals in openly circulating tidal channels in the beachward part of the system. The highest concentrations (two to four times higher) obtained occurred at the confluence of the east-west channel draining the debris field and the channel dredged south to Long Island Sound at the east margin of the marsh. Water from this channel passes through the culvert system directly into the sound. The only other comparably high site was in an isolated pool trapped within the debris field itself. The obvious conclusion to be drawn is that no hydrologic barriers exist between the municipal fill, the debris field and the tidal channels and that there is an apparent hydrologic connection between the landfill and the salt marsh. An aqueous particulate component of Pb, Zn and Cu in marsh sediments has previously been documented by Varekamp (1991) who was unable to pinpoint the sources contributing to the concentrations of Cu and Zn in the Connecticut River estuary and Long Island Sound marshes investigated. He did conclude, however, that the sources were likely anthropogenic. Heavy metal concentrations in the channels of the Fletcher's Creek Tidal Marsh system appear to mimic the proportions of heavy metals found in marsh sediments. There appears also to be an excess inventory of zinc relative to copper at about a 2:1 ratio. Zinc is a common component of both industrial and household waste products (Forstner and Whittman, 1983). Given the unique situation at Silver Sands, where debris is exposed at the surface and channels have been established through the debris field, a direct relationship between the source and its contributions to the heavy metal load is apparent.

3.0 Remediation Alternatives

There are four preliminary alternatives for remediation at the site. One, take no action, which means allowing the public to use the park as it is. Two, do not cap the exposed debris and close the park. Three, remove the debris, deposit the solid waste into a working landfill or trash-to-energy plant, clean the soil and let the public continue to use the park. Four, cap the exposed debris with soil or a geotextile (containment) and let the public continue to use the park.

Ideally, the chosen alternative would meet the state's goal of providing an outdoor salt water recreational area, provide a safe means of reducing possible health hazards generated by the landfill while minimizing destruction of the salt-water wetlands. The fourth alternative seems best suited to the needs of the public and of the state.

The capping of the landfill should have short-term negative impacts on the geologic, hydrologic and biologic conditions. The installation of a geotextile may disrupt the natural processes of the marsh and will reduce infiltration into the landfill. This will reduce the amount of leachate discharged into the tidal marsh, but will inhibit biodegradation of fill materials. The geotextile will have to be covered with wetland soil in order to make it look natural. This will have an impact on the water if this loose, un-vegetated soil erodes into the marsh channels. Erosion and siltation caused by natural processes or construction might affect shellfish beds in Long Island Sound.

Construction activities will have short-term negative impacts on the marsh. The trucks will introduce higher noise and dust levels. This may affect the birds in the area. Excavating for building foundations and parking lots may cause erosion into the marsh, and may load the fill, increasing the amount of leachate migrating into the marsh, which may produce long-term ill-effects and potential health hazards for members of the community.

3.1 Mitigating Measures

Proper erosion control measures should be taken during the placing of the geotextile and excavating. Silt fences should be placed on the channel banks to prevent erosion when the geotextile is covered with loose fill. The loose fill should be planted immediately with natural salt marsh vegetation. This will anchor the plants to the soil and reduce erosion. The plantings should be done when the normal growing season occurs for the particular plant.

Bioremediation (also known as phyto-remediation) measures should be taken to help reduce the concentration of metals and toxins in the soil and water. Certain plants are capable of utilizing the metals and toxins through bio-uptake into their cells. Air-sparging, a technique used to neutralize VOC's in the soils, should be implemented if volatile organic compounds (VOC's) are detected in water quality tests.

4.0 Conclusion

Silver Sands State Park was established on an unregulated landfill. There is debris embedded into the banks of the salt marsh as well as concentrations of heavy metals in the water. Debris extends well beyond the zero margin limit mapped for the municipal fill. This situation poses a health and safety risk to the public and puts complete restoration of the tidal wetlands at risk. Assessment of viable alternatives results in the conclusion that the best and most prudent solution would be to cap the landfill with a geotextile and/or soil cover, and attempt phytoremediation of the exposed debris field. Though remediation efforts will take time, select areas of the park may be opened to the public at little risk. Water quality monitoring efforts should be continued as restoration efforts proceed.

References

DeVido, A. Associates/Clark and Rapuano, Inc. 1991. Silver Sands State Park, Milford, CT: A Master Plan: Silver Sands Feasibility Study: New York, NY.

Diversified Technologies Corporation. 1993. Environmental Impact Evaluation, Silver Sands State Park Master Plan, North Haven, CT.

Forster, U. and G.T. Whittman. 1983. *Metal Pollution in the Aquatic Environment.* Springer, New York, NY, p. 485 .

Fuss & O'Neill 1978. Landfill Closing Plan, Silver Sands State Park, Milford, CT: Preliminary Design Report, Manchester, CT.

Goodkind & O'Dea, Inc. 1960. Plan of Development for Silver Sands State Park: New York, NY

——————— 1982. Silver Sands State Park, Milford, Connecticut: Capital Project Coordination Study, New York, NY.

Jacobsen, N. L. & Associates. 1981. Study of Shore Erosion and Shore Protection, Milford, Connecticut: Chester, CT.

State of Connecticut Council on Environmental Quality (1991) Connecticut Environment Review.

Varekamp, J. C. 1991. Trace Element Geochemistry and Pollution History of Mudflat and Marsh Sediments from the Connecticut Coastline: *Journal of Coastal Research*, Special Issue #**11**, p. 105.

Post-Larval Blue Mussel (*Mytilus edulis*) Densities in the Vicinity of Millstone Nuclear Power Station, Eastern Long Island Sound

J. Foertch
Northeast Utilities Environmental Laboratory
Waterford, CT 06385

The blue mussel (*Mytilus edulis*) is a common component of intertidal and shallow subtidal communities in New England. The mussels can settle and grow on a variety of hard surfaces (e.g., rock, piers, navigational aids), and occasionally on soft substrata (e.g., sand, macroalgae, eelgrass). Millstone Nuclear Power Station is particularly interested in monitoring mussel settlement, as the power plant draws in large volumes of seawater for cooling, and fouling of intake structures and piping could seriously degrade efficiency and reliability. The station uses several biofouling control practices (e.g., chlorination, thermal backwash), but tries to ensure that any maintenance on these antifouling systems is conducted when risk of mussel settlement is minimal. Since August 1991, weekly or biweekly entrained plankton samples (~200 m^3 of seawater that has been pumped through the condenser cooling water system and discharged into a 335-mm mesh plankton net) have been sorted for plantigrades (the settleable post-larval stage). The time-series of plantigrade densities show large seasonal and year-to-year variabilities; these patterns are compared to field observations of mussel settlement, abundance (as percent substratum coverage) on rocky shores, environmental variables, particularly water temperature.

Environmental Benefit Projects in Stephenson Brook, Westchester County, Aimed at Reducing Nitrogen Runoff from Non-point Source Pollutants into Long Island Sound

S. Hoeger,
Creative Habitat Corporation
White Plains, NY 10601

Dredging and wetland plantings in three basins within the Stephenson Brook watershed in New Rochelle, Westchester County, NY, were implemented in the late spring 2000 as a result of an agreement between NY state and the county to compensate for a prior accident involving a sewage treatment plant. The plantings were designed to improve sediment retention within the system and to increase the acreage of freshwater marsh vegetation with the state goal to improve nitrogen removal from the watershed. The projects varied in scope and size. Based on data from the literature an attempt was made to quantify the potential contribution to the reduction of nitrogen in the system.

Biogeochemistry and Contaminant Geochemistry of Marine and Estuarine Sediments

M.A. Kruge
Department of Geology
Southern Illinois University
Carbondale, IL 62901

G. Benoit
School of Forestry and Environmental Studies
Yale University
New Haven, CT 06511

The urbanized shore areas of Long Island Sound in the vicinity of New Haven, CT, have a long history of exposure to point and non-point sources of pollution having been one of the birthplaces of the industrial revolution. As an unintended consequence of such activities, the region's sedimentary systems have incorporated a complex mixture of organic and inorganic contaminants. With its long and varied pollution history and the multiplicity of sedimentary present in a compact geographical area, the region is ideal for field testing new contamination assessment techniques. The residents of this densely-populated region continue to exploit the local waterways for recreation and economic benefit, including the harvest of seafood. A comprehensive, systematic evaluation of organic and inorganic contamination thus also addresses public health concerns. New Haven harbor is an active terminus for international marine cargo. The tidally influenced Quinnipiac, Mill, and West Rivers empty into the harbor, the shoreline of which is the site of docking facilities, a petroleum tank farm, a power generation station, sewage treatment facilities, a busy interstate highway, housing and park land. The shipping channel leading into the inner harbor is maintained by periodic dredging. A series of shallow core samples were taken in open water, in the shipping channel, in the inner harbor, and at the river mouths. For comparative purposes, several additional sediment samples were taken in waters near Guilford, a residential suburb of New Haven with low density housing and a marina. For molecular organic analysis, we employed pyrolysis-gas chromatography/mass spectrometry using milligram quantities of dry, whole sediment. The compounds thus detected form a complex mixture of thermally extractable components, plus the products of the thermal decomposition of (bio)polymers present in the sample. The Py-GC/MS results indicate a predominance of aquatic organic matter (OM) in the open water sediment samples at both sites, as evidenced by the relatively high abundance of nitrogen compounds in the pyrolyzate. In contrast, estuarine samples show a larger terrestrial OM component. A subset of the samples from the river mouths and the New Haven inner harbor shows significantly higher relative concentrations of thermally extractable polycyclic aromatic hydrocarbons (PAHs) and petroleum-derived hopanes. The Guilford and open water New Haven harbor samples appear relatively uncontaminated by PAHs. Our analytical approach permits the recognition of biogeochemical differences indicative of the parent OM and the depositional environment, as well as potentially hazardous anthropogenic contributions to the sediment.

The Physio-Ecology of *Hemigrapsus sanguineus* in the Long Island Rocky Intertidal Zones

A.M. Languth and K.A. White
Killingly High School
Danielson, CT 06239

The purpose of our experiment was to investigate environmental factors that influence movement, feeding habits, species interaction, and population density of the Japanese crab, *Hemigrapsus sanguineus*, in Long Island Sound. Population density of the crab species were conducted at several intertidal locations along Long Island, NY, the Connecticut shore, and the Rhode Island shore to determine if this species had reached its maximum density throughout Long Island Sound. Transects were set along the rocky intertidal shorelines at all designated locations. Crabs were collected in 0.25 meter quadrats along the transect line from the high tide mark to the ocean. Total numbers of crabs, gender and size were recorded. Correlations between gender and size were made related to location. It was hypothesized if Japanese crabs are placed in a container and the speed in which they exhibit "wall behavior" (movement to the edge of the container) is recorded in both diurnal and nocturnal environments, then the crabs will exhibit the greatest rate of speed in the diurnal conditions. Crabs were placed in the center of a 0.15 meter container under both diurnal and nocturnal conditions, and the time it took the crabs to exhibit "wall behavior" was recorded. Correlations of size and speed and gender and speed were determined. It was hypothesized if crabs of varying ratios of gender and size were placed in a container with only one sheltered location, the male crabs, regardless of size, would exhibit the most dominant behavior in acquiring the sheltered location. Crabs were placed in a 30 cm square container with only one sheltered location. Pairs of crabs of varying gender and size were placed on the opposite side of the container. The speed at which the crabs acquired the sheltered location was recorded. It is hypothesized if crabs of varying ratios of gender and size are placed in containers with various types of food, the larger crabs regardless of gender will acquire the most food. If crabs of varying ratios of gender and size were placed in containers with various types of food under both diurnal and nocturnal conditions, the crabs in the nocturnal conditions consumed the most food. Crabs of varying gender and size were placed in tanks under diurnal and nocturnal conditions. The mass and type of food was varied. The type of food and the time in which the crabs consumed the food was determined. The results of this experiment was that *Hemigrapsus sanguineus* seem to move quicker in nocturnal conditions that in diurnal conditions. *H. sanguineus* consumed more food in a quicker period of time in diurnal conditions because they do not feel as safe. We also found that the percent of crabs under the rocks in much greater number in diurnal conditions because they again do not feel as safe. This species of crab is a scavenger and they prey in the nocturnal conditions.

Connecticut Department of Environmental Protection Long Island Sound Ambient Water Quality Monitoring Program in 2000: Our Tenth Year of Monitoring

C. Olsen, M.P. Gates and M.J. Lyman
Connecticut Department of Environmental Protection
Bureau of Water Management,
Hartford, CT 06106

Since 1991, the Connecticut Department of Environmental Protection (CT DEP) has been monitoring the water quality of Long Island Sound. The primary goal of this monitoring program is to develop a long-term data base from which the effectiveness of management actions to reduce nitrogen inputs to the Sound may be evaluated. Year-round monthly sampling at eighteen stations, from the Western Narrows to Block Island Sound, provides nutrient and chlorophyll *a* concentrations, and water column profiles of temperature, salinity, irradiance and dissolved oxygen. Additional biweekly summer sampling at 40 stations provides data on the recurrent low dissolved oxygen condition known as hypoxia. During 2000, in addition to continuing monthly and summer monitoring surveys as before, CT DEP expanded its sampling effort as part of EPA's Coastal 2000 program. This expanded effort includes sediment sampling and analysis for grain size, benthic infauna, chemical contaminants and toxicity. Coastal 2000 sampling has also expanded our monitoring into near-shore environments. A program-specific website was also started this year and will eventually provide users direct access to our data. The CT DEP encourages the research community to make use of the monitoring program and the resultant database as an aid to complementary research efforts in Long Island Sound.

Effects of *In Vitro* Exposure to Organochlorine Mixtures on Lymphocyte Proliferation in Marine Mammals and Mice

M.J. Levin, and S. DeGuise
Department of Pathobiology
University of Connecticut
Storrs, CT 06269

Non-point source pollution, such as metals and polychlorinated biphenyls (PCBs) from atmospheric deposition and sediment runoff, has been a major concern on the health of aquatic species living in the Long Island Sound. Though PCBs are nearly ubiquitous in all aquatic environments, the health affects of animals contaminated with these compounds have yet to be fully elucidated. In particular, the immunotoxic effects of PCBs on marine mammals warrant further investigation, since the immune system plays a central role in the overall health and disease management of an animal. Marine mammals may also reflect the overall health of an ecosystem as they feed at the top of the food chain, possibly bioaccumulating immunotoxic compounds in their tissues. Immunotoxicity of organochlorines has been demonstrated in laboratory animals but has not been proven in marine mammals. Exposure to individual PCB congeners has been previously studied in laboratory animals, but little work has been done with mixtures of organochlorines, which may act synergistically, additively, or antagonistically on immune functions. The present study is aimed at characterizing immunotoxic potential for mixtures of organochlorines compared to that of individual compounds, and compares the relative sensitivity of different species of marine mammals. Four PCB congeners, PCB 138, PCB 153, PCB 169 and PCB 180, as well as 2, 3, 7, 8-TCDD were tested. All combinations of PCBs and TCDD were tested with a final concentration of 5 ppm for each PCB congener and 10 pg/ml for TCDD. Two different mitogens were used to stimulate cell proliferation: lipopolysaccharide (LPS) and concanavaline A (ConA). Beluga whale and harbor seal peripheral blood mononuclear cells (PMBC) were tested. Murine spleenocytes were used in parallel with marine mammal cells to insure validity, reproducibility and quality control of the *in vitro* assays. Preliminary results in mice suggest that some of the mixtures of organochlorines reduce lymphocyte proliferation, compared to unexposed lymphocytes and cells exposed to individual organochlorines. Results of the present study will help to assess and manage the risk associated with exposure to mixtures of organichlorines.

The Effect of Disinfectant and Seed Color on the Germination of Eelgrass (*Zostera marina* L.) Seeds

Ruth Linden and Charles Yarish,
Department of Ecology and Evolutionary Biology

Suman Majumdar
Department of Statistics

University of Connecticut
1 University Place
Stamford, CT, 06901

Abstract

Effects of disinfecting the surface of different colored *Zostera marina* L. (eelgrass) seeds were tested in an ambient flow-through seawater tank system during a 20-month-long experiment. Two-way analysis of variance (ANOVA) of log-odds transformed data showed significant difference ($\alpha = 0.05$) for seed color and disinfecting seeds, but no significant interaction between the two variables.

Introduction

Previous methods and materials used to control seed decay prior to ambient seawater eelgrass seed germination experiments included running seawater (Orth and Moore, 1983; Moore *et al.*, 1993) and treating seeds with a Clorox® solution (Moore *et al.*, 1993). The effect of seed color on eelgrass seed germination has been tested only once in fresh water for 48 hours by Harrison (1991). In this paper, the long-term effects of disinfecting the surface of eelgrass seeds and the color of eelgrass seeds on eelgrass seed germination are presented.

Materials and Methods

During September, 1994, sand was collected and between 12 July and 9 August 1995, reproductive shoots were collected from an eelgrass meadow in Niantic Bay, Long Island Sound (41°19' N, 73°10'W), Waterford, CT. Seeds were shaken in Erlenmeyer flasks (15 min) to remove debris. Seeds to be surface disinfected were shaken for 20 min in a 1.3% solution of Clorox® bleach and sterile seawater (Churchill, 1992). All seeds were rinsed in sterile seawater, and all batches of seeds were sorted according to color and stored in the dark in sterile seawater (5°C, 33‰). Of the total number of seeds stored (N =12,244) 61.5% were green, 17.3% were black, 11.5% were tan, and 9.7% were white.

The 20-month germination experiment was conducted at the National Marine Fisheries Service Milford, Connecticut Laboratory at 25 cm depth in an ambient flow-through seawater tank in experimental containers constructed using polypropylene containers and tubes of nylon stocking material. Sample

N for each replicate (2) varied: disinfected surface (DS) seeds: white, 97 and 91; tan 74 and 96; green, 94 and 98; and black, 100 and 98; and not disinfected surface (NDS) seeds: white, 98 and 97; tan, 98 and 99; green, 96 and 96; and black, 100 and 75. Covers were constructed of PVC pipe and nylon stocking material and stretched across submerged experimental containers.

Each week containers were observed for seed germination, and the seawater tank system was cleaned. Ambient light was supplemented using two quartz floodlights. Statistical analysis consisted of two-way analysis of variance (Sokal & Rohlf, 1981) after a log-odds transformation of the original count data and an Anderson-Darling normal distribution test for ANOVA residuals (Anderson and Darling, 1954).

Results and Discussion

Temperature and salinity ranged between 0 and 25.5 ^{o}C and 21 and 28 ‰, respectively, between November, 1995, and June, 1997. Percentages of DS and NDS seed germination at the end of the 20 month-long experiment were 47.6% (N = 748) and 21.2% (N = 759), respectively, and total germination percentages (mean + SE) of DS and NDS eelgrass seed germination according to color were green, 67.5 + 16.6; black, 59.04 + 5.0; white, 35.5 + 11.8; tan, 25.2 + 5.0; and black, 56.5 + 0.5; green, 20.3 + 7.8; white, 8.2 + 6.2; and tan, 3.5 + 3.6, respectively. Sources of variation from a two-way analy sis of variance (ANOVA) of log-odds transformed data showed significance ($\alpha = 0.05$) for seed color ($p = 0.01$) and disinfecting the surface of seed coats ($p = 0.005$), but not for interaction between the two variables ($p = 0.3$). The Anderson-Darling normal distribution test provided a confidence level of 90.2 % for residuals.

Moore *et al.,* (1993) used a Clorox® bleach solution (1%) to prepare eelgrass seeds used in anoxic but not oxygenated germination experiments. They showed that almost two times and three times as many seeds germinated under light anoxic conditions than light oxygenated conditions and under dark anoxic conditions than dark oxygenated conditions, respectively. Since our results show a 2.1 times increase in germinated eelgrass seeds that were surface disinfected, Moore *et al.,* (1993) results may have been influenced more by treating eelgrass seeds under anoxic conditions with Clorox® (1.0%) than the anoxic conditions. From our results, we conclude that seed color and disinfectant treatment are two variables that should be considered when using eelgrass seeds for germination experiments and restoration projects.

Literature Cited

Anderson, T.W. and D.A. Darling. 1954. A test of goodness of fit. *J. of Am. Stat. Assn.* **49**:765-769.

Churchill, A.C. 1992. Growth characteristics of *Zostera marina* seedlings under anaerobic conditions. *Aquat. Bot.* **43**:379-392.

Harrison, P.G. 1991. Mechanisms of seed dormancy in an annual population of *Zostera marina* (eelgrass) from The Netherlands. *Can. J. of Bot.* **69**:1972-1976.

Moore, K.A., R.J. Orth, and J.F. Nowak. 1993. Environmental regulation of seed germination in *Zostera marina* L. (eelgrass) in Chesapeake Bay. Effects of light, oxygen and sediment burial. *Aquat. Bot.* **45**:79-91.

Orth, R.J. and K.A. Moore. 1983. Seed germinationand seedling growth of *Zostera marina* L. (eelgrass) in the Chesapeake Bay. *Aquat. Bot.* **15**:117-131.

Sokal, R.R. and F.J. Rohlf. 1981. *Biometry, the Principles and Practice of Statistics in Biological Research,* W.H. Freeman and Co., NewYork.

Tutin, T.G. 1938. The autecology of *Zostera marina* in relation to its wasting disease. *New Phyt.* **37**:50-71.

Accumulation of Cadmium and Chromium in the Sediments of Binney Pond and its Creeks Following Dredging

Lane Marmon
5 Arrowhead Ln.
Cos Cob, CT. 06807
(Greenwich High School)

Lane L. Marmon, a junior at Greenwich High School, used the excellent research techniques and information learned through her participation in the Bruce Museum Eagle Pond Science Research Project to develop her award-winning Connecticut. Science Fair 2000 project entitled: "Accumulation of Cadmium and Chromium in the Sediments of Binney Pond and its Creeks Following Dredging" as summarized below.

This research study was designed to determine the concentrations of cadmium (Cd) and chromium (Cr), following the expensive Town of Greenwich-funded dredging operation of Binney Pond and its creeks in 1997. Prior to the costly dredging, sediments of the creeks leading into Binney Pond (Cidermill Brook, Easterly Branch Binney Park Brook, Dinney Pond, Binney Park Brook, and the northern entrance of Greenwich Cove in Long Island Sound located in Old Greenwich, Connecticut) had accumulated pesticides, arsenic, lead, and a cadmium concentration as high as 9ppm and chromium concentrations from 15ppm to 178 ppm, both in 1 gram of dried sediment. Continual wastewater discharge from nearby industries and urban areas most likely contaminated this popular recreational area.

These levels surpassed the guidelines for "low effect level" established by the NYSDEC Division of Fish, Wildlife, and Marine Resources, indicating that sediment contaminant concentrations of these levels can elicit a toxic response or biologic response in test organisms. The build-up of polluted sediment was attributed to the continual waste discharge from nearby industries in Stamford, as well as from pollution from urbanized areas where concrete and other impervious surfaces do not naturally absorb or filter storm and road run-off water, therefore causing overflow pollutants.

Another source of pollution comes from the 1500-acre watershed for Binney Pond which extends as far west as Cos Cob, east to Stamford's Shippan Point, and north to Stamford's E. Gaynor Brennan Golf Course. Part of this watershed encompasses the industrial Commerce Road area of Stamford and feeds directly into Binney Pond's eastern tributary, the eastern brook that feeds directly into Binney Pond.

Methods:

Sediment samples 4 cm below the sediment surface were collected during low tide at 16 sites. Samples were prepared by nitric acid digestion and analyzed using ICPAES (Inductively Coupled Plasma Atomic.Emission Spectrophotometer). The concentrations of the metals were derived using this formula:

$$\text{ppm Cd / Cr per gram dried sediment} = \frac{\text{ICPAES measured concentration \{=g/L\} ALI(Volume Solution (mL)\}}}{\text{weight of sediment sample (g)}}$$

Results

Results showed cadmium concentrations as high as 6,466 ppm, and a chromium concentration as high as 195.582 ppm, both in I gram of dried sediment. Most of the test results for sample sites surpassed the guidelines for the low toxic effect level established by NYSDEC Division of Fish, Wildlife, and Marine Resources for cadmium and chromium (Figures 1 and 2)*. Approximately half of the chromium concentration test results surpassed the severe effect toxic level established by NYSDEC.

The results from the 1993 study of the Long Island Sound, together with the results of this study, provide information that this waterway contributes to recent increased accumulation of cadmium and chromium in the Western Long Island Sound. Future aggressive regulatory and prevention measures using planned bioengineering should be instituted to protect marine life and human beings in this popular recreational area. It is also vital to enforce laws regarding pollutants from all areas of commerce. A better understanding of the extent of toxic sediment on water quality, marine life, and human beings is needed. The author concludes that testing of this site should be continued on a regular basis under regulatory authority.

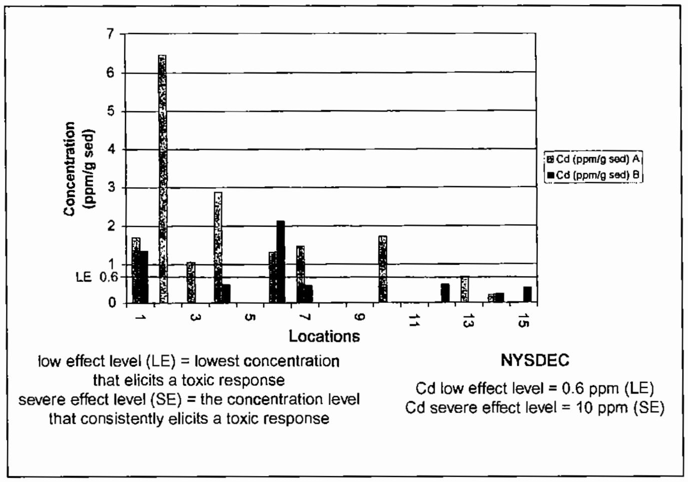

Figure 1. Cadmium concentration in sample sites.
(LE = 0.6 ppm; SE = 10 ppm)

Awards received for this project:

Connecticut Science Fair Awards: Second Honors
U. S. Army -$50 bond
Long Island Sound Foundation: Ist Place- $500 bond
CT. Audubon Society Award- $35 membership
Yale Science and Engineering Award
Trinity College Award -$100 bond
Mystic Aquarium Award. First Place Marine Science- $50 bond
Project Oceanology Environmental Lab Award- First Place
Boehringer Ingelheim Pharmaceuticals Award- $500 bond
American Electroplate & Surface Refinishers Award- $100

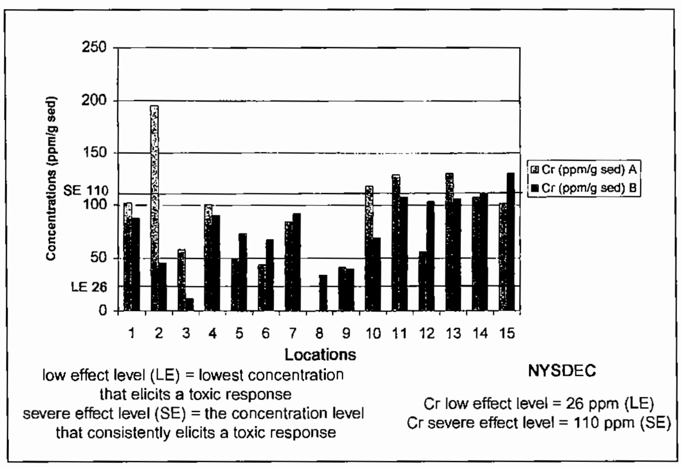

Figure 2. Chromium concentration in sample sites.
(LE = 26 ppm; SE = 110 ppm)

*** This summary is an excerpt from the original manuscript. For a full text of the project with tables, maps, full size figures, detailed conclusions, and references, please contact the author at the address on the previous page.**

Acknowledgments

The author thanks Ray Hamilton, chemistry teacher at Greenwich High School, Stanley E. Popielski, Senior Analytical Chemist at Cytec Industries (Stamford, CT), the Town of Greenwich Parks & Recreation, and Joseph Siciliano, Supt. of Marine and Facility Operations, Daniel S. Natchez & Assoc., of Mamaroneck, for their assistance, and his family for their encouragement.

The Role of Phytoplankton-Copepod Trophic Interactions in Hypoxia; Underestimated?

Gary H. Wikfors
NOAA Fisheries, Northeast Fisheries Science Center
Milford, CT 06460

Hans G. Dam
Department of Marine Sciences, University of Connecticut
Groton, CT 06340

Trophic processing of phytoplankton primary production often is overlooked in hypoxia scenarios for coastal waters. Typically, the cause of benthic hypoxia is attributed to nutrient over-enrichment leading to phytoplankton production greater than can be assimilated by the grazing community. Uneaten phytoplankton then are thought to die and sink to the bottom where the biomass is decomposed by bacteria, thereby consuming dissolved oxygen. An alternative scenario can be constructed wherein hypoxia is a result of large zooplankton populations consuming nearly all primary production and delivering the unassimilated algal carbon beneath the pycnocline in rapidly-sinking fecal pellets. The rapid sinking of copepod fecal pellets minimizes decomposition in surface waters where oxygen is available, transferring more of the biological oxygen demand to bottom waters.

The following observations, from recent published and unpublished research, support a reconsideration of the importance of phytoplankton-copepod interactions in the biological and physical processes causing hypoxia in Long Island Sound:

1) Peak copepod abundances measured in the mid-1990's, particularly in summer and autumn, increased appreciably from the mid-1950's.

2) Sediment traps deployed near the mouth of the Connecticut River contained few single algal cells; the particle assemblage was dominated by copepod fecal pellets and aggregates.

3) Paired surface and bottom water samples collected from western LIS during September 1999, near the onset of lobster mortalities, revealed very low phytoplankton standing stocks in surface waters, but very large quantities of copepod fecal pellets in corresponding bottom-water samples.

Re-evaluation of biological processes mediating the nutrient-hypoxia link may have important consequences to management of Long Island Sound hypoxia. First, long-term (years to decades) nutrient control may not achieve anticipated improvements in hypoxic events that are controlled by biological processes occurring on the time scale of days to weeks. Further, changes in the community ecology of Long Island Sound, in addition to nutrient inputs, may need to be reversed for effective management of hypoxia. Trends in abundance of fish larvae need to be assessed to determine if a relaxation of predation, in addition to more abundant phytoplankton food, is responsible for increases in copepod populations. An unanticipated benefit of restoring fish populations may be mitigation of hypoxia.

Georeferenced Sea-floor Mapping and Bottom Photography in Long Island Sound on CD-ROM

L.J. Poppe,V.F. Paskevich, H.J, Knebel, E.L. Mecray, and M.R. Buchholtz ten Brink
USGS, Woods Hole, MA 02543

R.S. Lewis and M.L. DiGiacomo-Cohen., CT DEP, Groton, CT 06340

L. Lanbo, University of Connecticut, Storrs, CT 06269

E. Thomas and J.C. Varekamp, Wesleyan University, Middletown, CT 06459

R.N. Zajac, University of New Haven, New Haven, CT 06516

P.J. Auster, National Undersea Research Center, University of Connecticut, Groton, CT 06340

This CD-ROM, produced by the Coastal and Marine Geology Program, USGS, contains a digital archive of GIS data layers and bottom photographs from Long Island Sound. These data layers and galleries, which are intended to complement the databases and sidescan-sonar mosaics released in an earlier CD-ROM (Poppe and Polloni, 1998) and the research papers presented in a current Thematic Section of the Journal of Coastal Research on the Sound, were produced and compiled in cooperation with the Connecticut Department of Environmental Protection, the University of Connecticut, Wesleyan University, and the University of New Haven. The goals of this cooperative project are to define the variability of the sea floor, which is a primary control of benthic habitat diversity; to improve our understanding of the processes that control the distribution of bottom sediments, contaminants, and benthic habitats; and to provide detailed maps for future research and monitoring programs.

The GIS data-layer archive contains geo-referenced regional maps covering a range of topics including: shallow stratigraphy, free-air gravity, sedimentary environments, surficial-sediment attributes, trace-metal and *Clostridium perfringens* distributions, bathymetry, benthic-community structures, and benthic foraminiferal distributions. Each data-layer is provided as an ArcView shape file and (or) an ArcInfo coverage and displayed within an ArcView project file. ArcExlorer, a free ESRI mapping product, is supplied on the CD-ROM to enable users without access to ArcView to explore, query and display the data layers. The bottom photographs, supplied as stand-alone images, provide a pictorial survey of megafaunal interactions and sedimentary environments.

References

Poppe, L.J., and Polloni, C.F., Long Island Sound Environmental Studies: U.S. Geological Survey Open-File Report 98-502, CD-ROM.

Seasonal Distribution of DMSP Among Seston, Dissolved Matter and Zooplankton Along a Transect in the Long Island Sound Estuary

D. Rogers
Department of Marine Sciences
University of Connecticut
Groton, CT 06340

We studied the seasonal distribution of dimethylsulfoniopropionate (DMSP) among seston, dissolved matter and zooplankton along a transect in eastern Long Island Sound. The seston DMSP concentration (1 - 52 nM) was comparable to that reported for some estuaries. Most of the seston DMSP was derived from particles <10 mm. Seston DMSP concentration did not correlate with water temperature or salinity. Most of the seston DMSP appeared to have originated from phytoplankton. Both dissolved DM<SP and dimethyl sulfide (DMS) concentrations remained low (3 nM) and were highly correlated to each other ($r = 0.83$, $p < 0.01$). Assuming a steady-state condition, the conversion efficiency from dissolved DMSP to DMS was estimated to be 75%. On the other hand, seston DMSP concentration did not correlate with dissolved DMSP, implying that the accumulation of seston DMSP and dissolved DMSP were uncoupled. Four types of copepods, plus several other types of zooplankters, contained DMSP. The copepod *Temora longicornis* contained 2.8 nmol DMSP per individual, the highest among the zooplankters. For most of the year, zooplankton were a negligible component of particulate DMSP in the water column. However, in months when *T. longicornis* appeared in high abundances, zooplankton represented 14 to 72% of the total particulate DMSP. Estimated copepod body DMSP concentrations were orders of magnitude higher than seston and dissolved DMSP concentrations; thus, copepod bodies represent a sparse, but highly concentrated source of particulate DMSP.

Multi-Beam Bathymetric Survey of the Central Long Island Sound Disposal Site

H. Saffert
Science Applications International Corporation
Newport, RI 02840

The Central Long Island Sound (CLIS) Disposal Site, located 10.4 km south of East Haven, Connecticut, is one of the most active dredged material disposal sites managed by the New England District of the U.S. Army Corps of Engineers. The 2 nmi^2 site has been monitored repeatedly since 1977 as part of the Disposal Area Monitoring System (DAMOS). Sediments dredged from New Haven, Bridgeport, Stamford and adjacent coastal areas have been deposited at the site creating an extensive complex of disposal mounds. Single-beam bathymetric surveys have been used to document these mounds with respect to previous small-scale surveys and a large master baseline survey of the area conducted 14 years ago. Due to advances in technology and navigational positioning systems, a new 2100 m x 4000 m master bathymetric survey was performed over CLIS and will serve as the baseline relative to future surveys and depth difference comparisons. The surveys were conducted from the *R/V OceanExplorer*, a 60-foot survey vessel under long-term charter from NorthEast Marine Services of Portland, Maine. The *Ocean Explorer* was configured with SAIC's ISS-2000 Integrated Survey System, which includes a Differential Global Positioning System (GPS) and a RESON 8101 multi-beam sonar capable of high accuracy depth measurements over a swath of the bottom equal to five times the water depth. Since the sound velocity profile of the water column is a key factor affecting the accuracy of the depth measurements, SAIC has introduced a Brooke Ocean Technology MVP-30 Moving Vessel Profiler to the system. This unit allows the surveyors to acquire sound velocity profiles of the water column at any time while the vessel is underway thereby significantly increasing the accuracy and efficiency of the operation. The multi-beam survey has resulted in a much more detailed understanding of the complex topography of the Central Long Island Sound site than was possible with earlier single-beam surveys and will allow for more precise tracking of even small changes in bathymetry.

Impact of Landfill Leachate on a Restricted Tidal Marsh of the Sybil Creek Watershed, Branford, CT.

Eugene Slason and Cynthia R. Coron
Earth Science Department, Southern Connecticut State University
501 Crescent Street,
New Haven, CT. 06515

Abstract

Sybil Creek is a tributary of the Branford River, which discharges into Long Island Sound approximately five miles east of New Haven, CT. The watershed area of Sybil Creek at its Route 146 tidegate comprises 232 acres, most of which are glaciated uplands. Degraded tidal wetlands consisting of three interconnected marshes, the Central Marsh (6.4 acres), the North Marsh (14.2 acres), and the East Marsh (52.6 acres) are the subject of a Connecticut Department of Environmental Protection project (Milone and MacBroom, 1996) to reestablish tidal circulation to the restricted marshes by replacing or augmenting the present tidegate. The intent is to generate a higher tidal prism with more invigorated flow to encourage a natural succession of preferred salt marsh plants and animals in areas currently overrun with the freshwater-tolerant species *Phragmites australis*.

Lying within the North Marsh is an area identified as an old landfill (Figure 1). Thick, oily sediment discharges have been observed by the DEP at the road crossing at the marsh's southern boundary. Fieldwork during the summer of 2000 was designed to sample these discharges and to test the water quality of tidal channels and pools up-gradient and down-gradient from the landfill site. Samples were analyzed for heavy metals including zinc, manganese, chromium, iron, and copper. Analyses were conducted using a Hach® DRE 2010 Spectrophotometer. Results show heavy metal contamination of surface waters elevated well-above background levels. Flow through the site appears to be both discreet and diffuse. Reestablishment of open marsh circulation, while raising the pH of the waters sufficiently to encourage transport of heavy metals more easily, would also shorten the residence time of the contaminants and dilute the concentration of metals in the system with tidal influx.

The next phase of the study will be to determine whether the lithology and structure of the glaciated ridge which bisects the marshes will act as a hydraulic barrier to leachate coming from the landfill in the North Marsh.

Study Area

The study area comprises 73.2 acres of degraded tidal wetlands, part of the Sybil Creek watershed, that lie between Talmages Ice Pond and Route 146. The study area extends northward to approximately 1400 feet from the end of Waverly Road, most of which was used as unregulated landfill. Water samples were taken from tidal channels and standing pools from as far west as 1000 feet from the Route 146 tidegate along Sybil Creek.

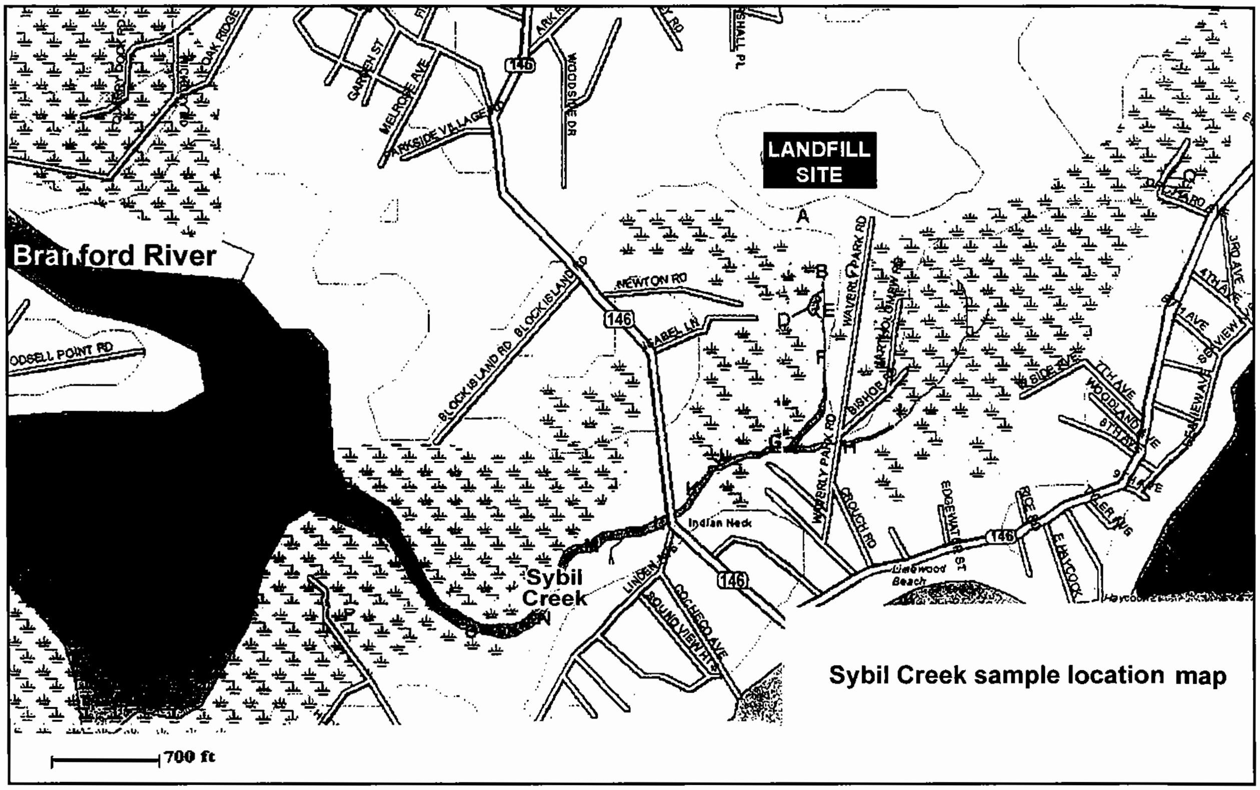

Figure 1. Location of Sybil Creek and landfill site.

Objective

The objective of this study was based on research and not reported hazards or contamination. This study was designed to assess the impacts presented by the landfill on the hydrology of the salt marsh. The results of this study are pertinent to the plans of the proposed salt marsh restoration, as concentrations of the contaminants tested could be altered by the augmentation of the tidegate and subsequent increase in the tidal range.

Water Quality

Two sets of samples, totaling nineteen in number, were taken along the reaches of Sybil Creek at high and low tide. Standing water close to the landfill was also sampled. Samples were subjected to spectrophotometric analyses for select heavy metals using a HACH® DRE 2010 Spectrophotometer. Ranges for the indicator metals currently run are as follows:

	Concentrations (mg/l)
Copper	0.02 - 1.61
Manganese	0.0 - 2.1
KMnO	0.0 - 6.0
MnO_4	0.0 - 4.5
Iron	0.0 - 3.26
Chromium (Cr^{6+})	0.01 - 0.14
$NaCrO_4$	0.02 - 0.45
CrO_4^{2-}	0.02 - 0.32

Ranges for High Tide Samples
Concentration (mg/l)

Copper	0.02 - 1.61
Manganese	0.0 - 1.6
KMnO	0.0 - 6.0
MnO_4	0.0 - 4.5
Iron	0.0 - 2.69
Chromium (Cr^{6+})	0.01 - 0.14
$NaCrO_4$	0.02 - 0.45
CrO_4^{2-}	0.02 - 0.32

Ranges for Low Tide Samples
Concentration (mg/l)

Copper	0.11 - 1.33
Manganese	0.0 - 0.1
KMnO	0.0 - 0.2
MnO_4	0.0 - 0.1
Iron	1.70 - >3.26
Chromium (Cr^{6+})	0.01 - 0.08
$NaCrO_4$	0.02 - 0.24
CrO_4^2	0.01 - 0.32

Discussion of Results

Numerous recent studies (Varekamp, 1991; Buchholtz ten Brink and Mecray, 1998, among others) have detailed concentrations of heavy metals in marsh sediments along the Connecticut coast. Buchholtz ten Brink and Mecray (1998) dredged samples from shore and along a bottom transect of Long Island Sound in the general vicinity of the Sybil Creek watershed. Concentrations in these samples range from 15 to 80 micrograms/gram (ppb) copper, from 65 to 150 ppb zinc, and from 18 to 46.7 ppb lead on shore or close to shore. Heavy metals are sequestered in the fine-grained sediments of the marshes (NOAA, 1988) and under certain conditions are flushed out into the tidal channels. Reported concentrations of metals in marsh sediments are up to three times greater than pre-industrial background levels (Buchholtz ten Brink and Mecray, 1998), and even higher in mudflat areas (Varekamp, 1991). Anthropogenic sources are often inferred but not determined. In the case of Sybil Creek, concentrations of the indicator metals tested in the hydrologic system are higher than those observed in marsh sediments elsewhere, but lower than observable mudflat values. In the North Marsh at Sybil Creek, the landfill at the site is indicated as a proximal contributor.

In an attempt to identify trends among the Sybil Creek water samples, though, one might expect tidal dilution effects to be significant; this is apparently not the case. Concentrations of heavy metals are roughly equivalent along the reaches of Sybil Creek during low and high tides. It is possible, however, that heavy metals are being contributed by the Branford River, equilibrating in the estuary, and are influencing the high tide values. It is probably not coincidental that the highest concentrations of heavy metals occurs at the tidegate (Sample A). This is also one of the sites at which oily sludges have been reported previously. Exceptionally high concentrations also occur at Sample Point R, which is a standing pool on the west slope of the landfill. Iron and copper appear to be ubiquitous throughout the system. Manganese appears to be concentrated in the lower reaches of Sybil Creek, and, if it were not for high values on the fill at R, a second source might be suggested. Given the current distribution, manganese may just be more mobile within the system than expected. Of particular concern are the high concentrations of chromium throughout the study area. High values are present in standing water at Q but not at R, which may suggest a directional component to transport. Besides high chromium concentrations at the tidegate, Sample Points I and H appear to be unusually high. Hexavalent chromium, a known health hazard, is 0.11 mg/l at the tidegate which backs up to a residential community, as does the marsh site at which P was taken. This may also indicate a secondary source (one other than the landfill) coming from the direction of the Branford River estuary.

Sampling within the watershed will continue in an effort to further delineate metal sources within the system, and marsh sediment samples will be analyzed for comparison in the near future.

Literature Cited

Buchholtz ten Brink, M.R and Mecray, E.L., 1998, Regional Accumulation of Contaminated Sediments in Long Island Sound, *Proceedings of the Long Island Sound Research Conference*, State University of New York, pp. 1-19.

Milone and MacBroom, Inc., 1996, Sybil Creek Salt Marsh Restoration, Branford, Connecticut, Preliminary Design Report, Connecticut Department of Environmental Protection, 58 pp. and maps.

NOAA, 1998, A Summary of Selected Data on Chemical Contaminants in Sediments Collected During 1984, 1985, 1986, and 1987, NOAA Tech. Mem. NOS OMA 44, Rockville, MD.

Varekamp, J.C., 1991, Trace Element Geochemistry and Pollution History of Mudflat and Marsh Sediments from the Connecticut Coastline, *Journal of Coastal Research*, Special Issue # 11, pp. 105-125.

Responding to a Lobster Fishery Disaster and Ecosystem Enigma in Long Island Sound

Margaret Van Patten[1], Nancy Balcom[1], Richard A. French[2], Paul Focazio[3] , and Carl Lobue[4]
[1]Connecticut Sea Grant, UCONN, 1084 Shennecossett Rd., Groton CT 06340;
[2]University of Connecticut, Department of Pathobiology; [3]New York Sea Grant Institute, SUNY Stony Brook, [4]New York DEC.

Abstract

A massive die-off of the lobster fishery in western Long Island Sound occurred unexpectedly in the fall of 1999. The U.S. Department of Commerce declared the fishery a disaster in January 2000, and the problem continues today. With landings down 99% in some areas, LIS lobstermen suffered large economic losses and in some cases went out of business. Although a UCONN pathobiologist successfully identifed a parasitic paramoeba in the dead and dying lobsters, researchers and lobstermen believe that the dieoff indicates a stressed ecosystem and that complex environmental factors may be affecting animals' immune systems. Meanwhile, shell disease is infecting large numbers of lobsters in the eastern LIS and elsewhere in New England. A Lobster Health Symposium organized by the CT and NY Sea Grant programs was held to link researchers in diverse fields, oceanographers, state and federal agency managers, and lobstermen. The participants developed an action plan to set research priorities, from the synthesis of pooled observations, ongoing research and ideas. Federal funds ($6.6M) have now been allocated to begin tackling the research priorities, but it will take effective synergy between state and federal agencies, universities, and the fishing industry, and the compilation of information from many sources. Sea Grant outreach efforts have provided a Lobster Information website, a lobster listserve, and fact sheets to explain the problem to the public. This presentation will provide an overview of what has happened and where we go from here.

Introduction

The lobster resource in Long Island Sound (LIS) supports a bi-state fishery which some estimates value at $45 million. In New York, lobsters are the most economically important marine species harvested, while in Connecticut, lobsters are second only to oysters. A commercial license moratorium was put into place in the mid-1990's and in 1999, slightly more than 1,000 commercial lobster licenses were issued by the two states combined.

A number of factors over the past decade led to the overcapitalization of the fishery. Regulations have reduced dragging in many parts of the Sound, an important competitor for bottom space. The use of wire traps, nearly 475,000 in 1998, have reduced the time lost to maintenance. New electronics enable fishermen to retrieve traps that previously would have been lost and to fish in areas previously inaccessible due to the heavy boat traffic. Lobster abundance also increased during the 1990's, peaking in 1997. However, more than 90% of the lobsters landed in LIS are landed within the first molt group of legal size. This abundance, coupled with a stable market price, few alternative target species and the license moratorium, resulted in an increase in the total capital invested in the fishery by fewer fishermen. Bi-state landings in 1997 topped 11 million pounds, tailing off slightly to 10 million pounds in 1998. In both years, there were a few reports/rumors about dying lobsters, but not in great numbers.

In 1990, the lobsters in western LIS were reported dead or dying and traps and subsequent tests indicated the presence of *Gaffkemia*. In 1998, there were some reports of lobsters dead or dying in traps but the tests were negative for *Gaffkemia*. The 1999 lobster fishery began typically. The spring run was fairly normal. The region experienced a severe drought during the summer. However, beginning in August and continuing throughout the fall, the state agencies were deluged with reports of high numbers of dead and dying lobsters in traps, holding cars and dealers' tanks, concentrated in the western part of Long Island Sound. Other than appearing limp in some cases, the lobsters had an outwardly healthy appearance. Nevertheless, it is estimated that up to 11 million lobsters died.

Water quality tests were conducted to determine if a spill from a sewage treatment plant or industry had occurred. Concerns were raised about the coincidental spraying for the West Nile Virus and whether the chemicals used to kill mosquitoes were also killing the lobsters. Lobsters were tested for toxins and pathogens, but nothing unusual was initially found. In Fall 1999, pathobiologists from the University of Connecticut conducted full necropsies on the lobsters, discovering parasitic amoebae or paramoebae in the nervous tissues of all dead and dying lobsters from western LIS. The organisms apparently breached the immune system of the lobsters and were engulfing and destroying the nervous tissue. It was unclear, however, whether the paramoeba was the primary cause of the lobster deaths or whether other factors were involved.

While the fishermen from the western part of the Sound completely lost their fishery, the rest of the Sound was also negatively affected. Local and regional markets for LIS lobsters evaporated; Canada refused to import lobsters from south of Massachusetts. In eastern LIS, fishermen were reporting much higher than usual incidences of shell disease or shell rot, which rendered a larger proportion of their catch unacceptable for the lucrative live market. This was also true for lobsters harvested from Narragansett Bay, Rhode Island and Buzzards Bay, Massachusetts.

In January 2000, at the request of the Governors of Connecticut and New York, Secretary of Commerce William F. Daley declared the LIS lobster fishery a marine resource disaster. Developing a model for collaboration and coordination of effort, two state agencies, three federal agencies, lobstermen's associations, and university researchers pooled their limited resources to address the problems affecting this key bi-state industry and natural resource. This collaboration is beginning to make progress toward its goal–determining the cause(s) of the massive LIS lobster die-off.

Methods

A lobster health planning committee was established, with representation from the Connecticut Department of Environmental Protection (CT DEP), the New York State Department of Environmental Conservation (NYS DEC), the National Marine Fisheries Service (NOAA), the U.S. Environmental Protection Agency, Connecticut and New York Sea Grant College Programs, the University of Connecticut, and the State University of New York at Stony Brook. The two state agencies mailed surveys to lobstermen in October 1999 and January 2000 to solicit their observations regarding the lobster die-off. The committee convened a two-day lobster health symposium in Stamford, Connecticut in April 1999 that linked researchers in diverse fields, oceanographers, state and federal agency managers, and lobstermen. The purpose of the symposium, which drew more than 250 participants, was to share information on the fishery, pathological, climatic, environmental and anthropogenic factors that may have played a role in the lobster deaths. Working groups of invited experts pooled observations, research and ideas, culminating in a plan of action to set priorities for research and economic assistance.

The draft plan of action includes the need to:

1. Develop a timeline of key events leading up to and during the 1999 die-off.
2. Identify common stressors that may have affected lobster health.
3. Set up an information network and database.
4. Coordinate monitoring and research efforts.

Results

Despite limited financial and personnel resources available in 1999 and 2000, some progress has been made, although no definitive cause for the massive die-off has been identified. A timeline of events including rainfall events, mosquito control efforts, and lobstermen observations has been drafted and circulated. From the experts attending the April symposium, an extensive list of potential stressors and factors has been developed, including climatic factors such as warmer than average water temperatures, water column structure, and Tropical Storm Floyd; environmental and water quality factors such as resource overcrowding, quality of food, other species affected, hypoxia, and ammonia and sulfur in the sediments; anthropogenic inputs such as the chemicals used for mosquito control, chlorine from sewage treatment plants, bait and exposure to pesticides or toxic contaminants. There were also numerous questions raised related to lobster pathology, the paramoebae and interactions with various stressors that need answers.

To facilitate communication and rapid sharing of information, a listserve (LOBSTR-L) was established by Connecticut Sea Grant, and two fact sheets were produced. A website was constructed and maintained by New York Sea Grant, providing access to various documents, fact sheets and news reports generated by the lobster resource disaster. Follow-up annual lobster health symposia are planned for 2001-2003. CT DEP and NYS DEC strengthened their previously coordinated lobster resource monitoring and assessment efforts by increasing the number of sea sampling trips taken with commercial fishermen and devising a uniform means for identifying the presence and extent of shell disease in conjunction with state managers from RI and MA. Monthly lobster samples from five zones within LIS are collected during these trips and provided to the Pathobiology Department at the University of Connecticut for full work-ups. Additional water and sediment quality tests are ongoing. Some lobstermen are being funded to fish in western LIS to help resource managers assess the status and condition of the lobster resource there. Researchers and resource managers are asked to utilize the listserve to alert others to ongoing efforts, in order to facilitate an efficient combination of resources and effort.

Financial resources available in 1999 and 2000 to address this disaster have been piecemeal and limited, leading to great frustration on the part of the agencies, researchers and industry alike, particularly since the problem has continued into 2000. Those involved have worked hard to piggyback efforts and information gathering to maximize the limited financial and personnel resources available from Sea Grant, EPA and the states. To date, nearly two years after the onset of the event, no financial assistance has been received by the lobstermen devastated by the die-off and a significant number have left the fishery to seek other employment to offset personal debt and economic losses.

UPDATE: The financial picture is looking much brighter now due to recent Federal emergency appropriations and bond funding by the State of Connecticut. NOAA/NMFS has now budgeted $2.6 million in federal research funds. The Connecticut and New York Sea Grant programs have called for proposals from researchers throughout the United States to investigate the Long Island Sound lobster mortalities as well as shell disease syndrome. An additional $1 million will be awarded from the State of Connecticut's Long Island Sound Research Fund, by the Connecticut Department of Environmental Protection, for a total of $3.8 million. Preliminary proposals are presently under review.

Discussion

The LIS lobster resource disaster devastated the lobster population in western LIS, caused financial ruin for a significant number of fishermen, and most frustratingly, its cause remains a mystery. In 2000, the LIS lobster fishery was non-existent in western LIS, moderate in the deeper waters off the central part of the Sound, and exacerbated by shell disease in eastern LIS. The market for LIS lobsters has been severely curtailed and may take a long time to recover, particularly in the absence of a definite cause(s). To date, research funds have not reached the level that supports a thoughtful, stepwise, thorough examination of all potential factors to rule out most and focus attention on the few that could reveal the cause of the die-off. It may well be that the true cause of the die-off may never be fully understood. However, as the LIS lobster resource problem continues, the promise of substantial research support within the next 6-8 months raises hopes that more progress will be made to uncover the cause and effects of the lobster health problems. The ultimate goal is to restore the lobster resource and fishery in LIS to a sustainable level, while using the information gained to help other Northeast states and Canada determine the risk their lobster stocks face, if any, of a similar die-off.

One of the brighter sides to facing this resource disaster has been the ability of numerous state and federal agencies, university researchers and industry to combine talents and resources to address this problem together. It hasn't been an easy task because of the inherent differences in the responsibilities and modes of operation of the different agencies and organizations involved. By staying true to the mutually agreed-upon commitments of determining the cause and restoring the resource and fishery, the group has been able to combine and coordinate expertise, resources and personnel to continue to make progress on this important lobster health issue.

Conclusions --too early for conclusions on lobster mortalities, but we've learned:

- Resource mortalities on such a massive scale as the LIS events probably don't have a single cause. They may involve multiple complex factors acting synergistically, and need to be addressed at the ecosystem level.
- Even in a total fishery collapse situation that is a federally declared disaster, funds to conduct research and provide relief to individuals losing their livelihoods is hard to find and a *long time* coming.
- Short term emergency funds from granting entities such as Sea Grant can initiate research more rapidly but can only begin to address such a huge undertaking.
- Industries, resource users and harvesters, universities, state and federal agencies, and environmental organizations must combine resources as well as data, and work together quickly and efficiently, putting aside special interests and turf battles, to solve ecosystem issues on such a large scale.
- Including fishermen in monitoring undertakings can help them utilize their boats and personnel during hard times and greatly increases the pool of observations.