1.0 THE NIANTIC RIVER AQUATIC ECOSYSTEM

The Niantic River is a shallow marine estuary that was formed when sea level was at an elevation high enough to flood the low lying coastal valley. The river has historically supported healthy populations of shellfish, crustaceans, and finfishes and also provides excellent bird habitat as ospreys, herons, kingfishers, and cormorants may be observed at various times throughout the year.

In recent times, changes in river ecology believed to be associated with nitrogen loading include the loss of commercially important shellfish species, in addition to eelgrass (*Zostera marina*) stands and indicate a need for further water quality protection. Measures to protect water quality include land use and development controls to help reduce the influx of non-point source pollution. Additionally, the designation of the river and near-shore waters of Long Island Sound as a No Discharge Area may help eliminate potential sewage discharges from vessels, and eliminate another source of nutrient enrichment. Without the continued maintenance of existing water quality conditions, or attempts to reduce non-point source inputs, the health of the Niantic River ecosystem will deteriorate further.

1.1 Objectives

This overview is intended to provide a general discussion of the Niantic River aquatic ecosystem, and as such does not test any new hypotheses. Rather, the overview will synthesize historical and current research in an attempt to characterize the relationship between nutrient enrichment and effects on the receiving waters. Aspects of the Niantic River that are addressed include the primary producers (e.g. phytoplankton) and upper trophic levels including invertebrates and fishes. In addition to an examination of broader trends in the community, individual species are also discussed. Individual species were selected given their (1) critical importance from a habitat perspective, e.g. eelgrass (*Zostera marina*); (2) properties as a control species, free from the effects of fishing and predation, e.g. the grubby (*Myoxocephalus aenaeus*), and (3) commercial significance, e.g. the bay scallop (*Argopecten irradians*). Of these species, eelgrass is considered a keystone species.

Where applicable, aspects of the Niantic River have been compared and contrasted with other nearby sites within Long Island Sound. The inter-site comparison was achieved with a 2001 – 2004 data set collected by the University of Connecticut under the auspices of Dr. Jim Kremer at five study sites. Sites investigated by the University of Connecticut included the Pawcatuck River, Mumford Cove, Ninigret Pond, and the Hammonasset River. Other data sets were culled from research conducted by the Millstone Environmental Laboratory over the 1976 – 2004 timeframe, which also facilitated an assessment of trends in species abundance with time. Although the approach used in this overview is largely qualitative, quantitative methods were employed and are described in the narrative where applicable.

2.0 PHYSICAL AND CHEMICAL PROPERTIES

2.1 Bathymetry and Bottom Sediments

A flood delta has developed within the Niantic River estuary, which extends from the narrow inlet slightly less than 1 mile up the river. Immediately upstream of the flood delta is a broad basin with typical water depths of 3.0 meters (m), although depths as great as 6 m are reached further northward in the west branch of the Niantic (Marshall, 1994). The maximum water depth in the river is 6.7 m, with channel depths typically ranging between 3 – 4 m (Marshall, 1994).

With respect to bottom substrate composition, bottom sediments mirror the hydrologic regime such that well-sorted sands are observed in the high energy environment of the river channel, while finer grained silts and clays are observed in the more quiescent portions of the estuary. Organic material deposited in the low energy environment of the river basins has resulted in a muddy bottom that is highly unconsolidated (Marshall, 1994).

2.2 Tidal Exchange

The Niantic River system forms an inlet of Long Island Sound, and is subject to the tidal dynamics of the Sound itself (Saila, 1976). Local tidal conditions in Long Island Sound are predominately semi-diurnal (two high tides and low tides per day) that have a mean and maximum range of 0.8 and 1.0 m respectively (Saila, 1976). The tidal range in the Niantic River is 0.77 m, which is 5 centimeters (cm) less than it is in the Bay. However, construction at the mouth of the Niantic River may have damped tidal oscillations and reduced circulation within the river (Marshall, 1994). The average tidal prism volume of the Niantic River estuary is approximately 2.7 x 10^6 m^3, and the volume of water remaining in the Niantic River at low tide is twice the total tidal prism (Marshall, 1960; 1994).

The residence time within the Niantic River is 25 days (Marshall, 1994), indicating high retention properties. As an illustration of this, a study that modeled winter flounder larvae transport out of the Niantic River in the 1970s predicted that 72% of the winter flounder larvae leaving the river at ebb tide would return to the river on the following flood tide (Saila, 1976). The long retention times within the Niantic River are attributable to the morphology of Niantic Bay, which is a semi-enclosed basin.

2.3 Freshwater Contribution

2.3.1 Surface Water

The Niantic River drainage area is small and the volume of freshwater entering the estuary is low compared to tidal inputs. Freshwater input is limited to three streams and surface runoff from the 78 km^2 watershed which collectively account for only 3% of the total tidal prism (Marshall, 1994). The main tributaries to the Niantic River include Latimer Brook and Oil Mill Brook.

[NEED MORE HERE]

2.3.2 Groundwater

The discharge of ground water containing nutrients has been identified as a cause of water-quality degradation (Marshall, 1994). Based upon equations from Mazzaferro (1979), it is estimated that about 50 percent of the water discharged to the Niantic River originates as ground water.

[NEED MORE HERE]

2.4 General Physico-chemical Properties

2.4.1 Flow

The general circulation in the Niantic River is influenced by surface water runoff, as well as tides, winds, and possibly density differences (Saila, 1976). Although tidal currents are reduced across the flood delta, currents are sufficient that a channel is maintained. Maximum current velocities within the Niantic system occur through the narrow mouth of the river and reach 1m/sec, while in the upper Niantic River the tidal current is weak and currents only reach a maximum of 5cm/sec (Saila, 1976). Within the upper reaches of the Niantic, wind speed can affect current velocity, although the influence of the wind is less pronounced at the inlet, where current velocities are more vigorous and any wind-related effects are restricted to the upper few centimeters of the water column (Saila, 1976).

Modeled current vectors during ebb and flood tides indicate that during the flood tide, flow occurs along two paths including (1) the Niantic River and (2) through the Bay and exiting past Black Point (Saila, 1976). During the ebb tide, water exits the Niantic River and flows along the eastern Niantic Bay shoreline (Saila, 1976).

2.4.2 Temperature

Over 28 years of sampling (1976 – 2004), water temperatures within the Niantic River averaged 12.0 ºC (Millstone Environmental Laboratory, 2005). The Niantic River exhibits wide variation in temperature with an overall mean annual minimum temperature of 8 ºC and a maximum of 23.8 ºC. The highest overall water temperature measured during the 28 year study period was 27.0 ºC, and was recorded during August, 1999. Since 1976, a significant and increasing trend was observed in mean annual water temperature (*p* 0.005) (Millstone Environmental Laboratory, 2005). Keser et al., (2003) demonstrated that from 1975 through 2000, a temperature increase of 1.0 ºC (based upon annual means) and an increase of 1.5 ºC (based upon daily means) was occurring in Niantic Bay.

Overall winter temperatures during the 28 year period sampled averaged 3.7 ºC; spring temperatures averaged 10.9 ºC; summer temperatures averaged 19.8 ºC; and autumn temperatures averaged 11.9 ºC (Millstone Environmental Laboratory, 2005) (Figure 2-1). Seasonal temperatures were most variable during the winter and least variable during the summer.

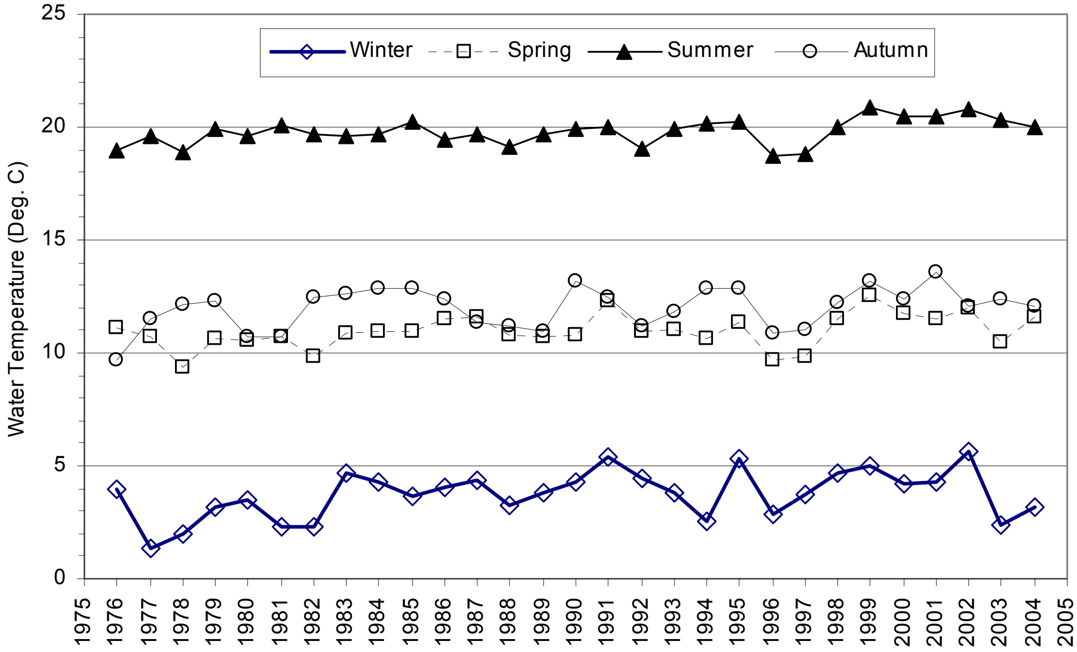

Figure 2-1. Seasonal mean water temperatures (1976-2004) calculated from mean daily water temperatures recorded in Niantic Bay (Millstone Environmental Laboratory, 2005).

2.4.3 Salinity

Although some reduction of salinity is evident in the upper reaches of the Niantic River, salinities in the river generally approximate those observed in Niantic Bay and Long Island Sound waters. Maximum salinity within Niantic Bay during the summer is 30 parts per thousand (ppt), which drops to 20 ppt at the surface during times of freshwater inflow during the spring and periods of heavy surface water flow following storm events.

Long term salinity data collected by Millstone Environmental Laboratory in Niantic Bay indicate that surface salinities ranged from 28.5 - 31.9 ppt over the past 26 years. Salinities of the bottom waters were slightly higher and ranged from 28.7 to 32.0 ppt. Long term trends in salinity indicate that a decline in both surface and bottom salinity has occurred (Millstone Environmental Laboratory, 2005).

3.0 BIOLOGICAL PROPERTIES AND ECOLOGICAL INTERACTIONS

3.1 Nutrients and Primary Productivity

In marine waters, nitrogen is typically the nutrient that limits algal primary production (Valiela, 1984). Consequently, the addition of nitrogen to coastal waters from anthropogenic sources can increase the growth and abundance of algae (Lapointe & O'Connell, 1989). Excessive algal production causes, either directly or indirectly, most of the adverse changes in coastal ecosystems (Costa et al., 1999). In general, the response of coastal ecosystems to nitrogen loading are most pronounced in systems with restricted water exchange, although stratified estuaries and estuaries where the photic zone extends to the bottom are also heavily impacted (Costa et al., 1999).

Primary producers have evolved different strategies to exploit heterogeneity in nutrient supply and exhibit marked differences with respect to the ability to retain nutrients (Worm & Sommer, 2000). Specifically, microalgae and filamentous macroalgae have a relatively high surface area to volume ratio, and as such, will uptake macronutrients and grow rapidly, yet possess low nutrient storage capacity (2-8 days for filamentous algae (Pedersen & Borum, 1996; in Worm & Sommer, 2000). Perennial canopy-forming macroalgae on the other hand, possess low surface area to volume ratios, and will uptake nutrients and grow slowly, yet exhibit higher nutrient storage capacities (weeks to several months) (Pedersen & Borum, 1996; in Worm & Sommer, 2000).

The differences in architecture will result in a variable response to nutrient inputs that may be apparent at fine spatial scales, e.g. embayment. Ultimately, the particular macroalgal assemblage at a site may mirror local conditions with respect to the return interval, duration, and concentration of the nutrient input.

3.1.1 The Macroalgal Community

The macroalgae data presented in this section were obtained from a raw data set collected by the University of Connecticut during May-November from 2001 to 2004 under the auspices of Dr. Jim Kremer.

A total of 39 species of macroalgae were identified and included a suite of Rhodophyta (red algae), Phaeophyta (brown algae), Chlorophyta (green algae), and three unidentified (UID) macroalgal species (Vaudrey & Kremer, in press). Of the sites investigated, the Hamonnassett site exhibited the lowest species richness (7), while the Pawcatuck site exhibited the highest (24) (Figure 3-1). The macroalgal community at the Niantic River site was represented by 15 species. In general, green and red algae dominate at all of the sites, with much fewer examples of brown algae, which were completely absent from the Ninigret site.

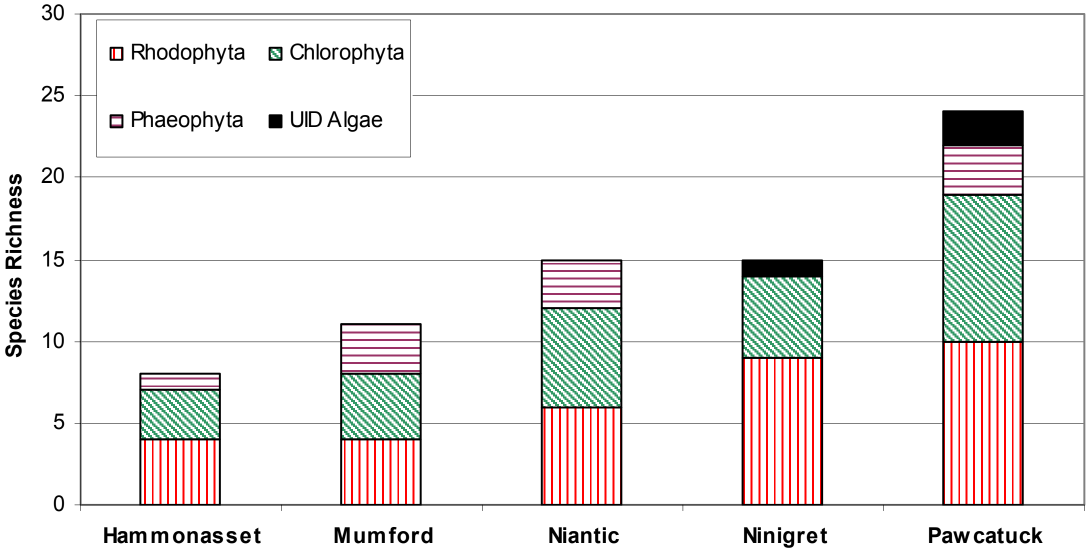

Figure 3-1. Cumulative species richness by phylum across each of the five University of Connecticut study sites.

The red algae exhibited the greatest species richness and were represented by 11 genera Table 3-1. *Ceramium, Agardhiella, Polysiphona* and *Gracilaria* occurred quite frequently, and were present at most of the five study sites. With respect to nutrient requirements and tolerance of nutrient enriched environments, *Gracilaria tikvahiae* is often found in areas undergoing eutrophication, and exhibits rapid growth, elevated nitrogen uptake rates, and high tissue nitrogen storage capacity (Lapointe & Duke, 1984). Furthermore, *Gracilaria tikvahiae* can tolerate the indirect effects of nitrogen loading, including anoxia (Peckol & Rivers, 1995). *Polysiphonia* is another commonly occurring genus that exhibits rapid growth and is an opportunistic species that displaces native algae (Maggs, 2003). Macroalgae with rapid nutrient uptake such as *Spyridia* are dominant in eutrophic environments with high nutrient supplies, but tend to be absent from low nutrient habitats. *Spyridia* can readily accumulate dissolved nitrogen, although accumulated nitrogen reserves decline quickly (McGlathery, 1992). *Spyridia* was observed at the Hammonasset and Ninigret sites.

Table 3-1. Summary of macroalgal occurrence identified during the 2001 – 2004 University of Connecticut study. (Data Source: Vaudrey & Kremer, in press).

Genus and Species	**Phylum**	**Hammonasset**	**Mumford**	**Niantic**	**Ninigret**	**Pawcatuck**
Desmarestia sp.	Phaeophyta		X			
Desmarestia viridis	Phaeophyta		X			X
Desmerestia aculeata	Phaeophyta			X		X
Ectocarpus silicularis	Phaeophyta			X		
Fucus sp.	Phaeophyta					X
Petalonia fascia	Phaeophyta	X				
Stilophora rhizodes	Phaeophyta		X	X		
Chaetomorpha melagonium	Chlorophyta					X
Chorda filum	Chlorophyta					X
Cladomorpha vagabunda	Chlorophyta					X
Cladophora sp.	Chlorophyta				X	X
Codium fragile	Chlorophyta		X	X		X
Enteromorpha intestinalis	Chlorophyta			X		X
Enteromorpha lingulata	Chlorophyta				X	
Enteromorpha prolifera	Chlorophyta	X				
Enteromorpha sp.	Chlorophyta			X	X	X
Laminaria agardhii	Chlorophyta	X	X	X		X
Laminaria sp.	Chlorophyta		X	X	X	
Ulva lactuca	Chlorophyta	X	X	X	X	X
UID	NA				X	X
UID (cord like/branching)	NA					X
Agardhiella tenera	Rhodophyta			X	X	X
Ceramium rubrum	Rhodophyta	X			X	X
Ceramium sp.	Rhodophyta	X		X		X
Champia parvula	Rhodophyta		X			
Dasya baillouviana	Rhodophyta			X		
Fine filamentous red algae	Rhodophyta					X
Gracilaria tikvahiae	Rhodophyta	X	X	X	X	X
Halosaccion ramentaceum	Rhodophyta		X			
Hypnea musciformis	Rhodophyta					X
Phyllophora sp.	Rhodophyta					X
Polysiphona denudata	Rhodophyta		X	X	X	X
Polysiphona filamentosa	Rhodophyta				X	
Polysiphona harveyi	Rhodophyta			X	X	
Polysiphona sp.	Rhodophyta				X	X
Rhodymenia palmata	Rhodophyta					X
Spyridia filamentosa	Rhodophyta	X			X	
UID red algae	Rhodophyta				X	

A total of 12 species of green algae were documented including the genera: *Ulva*, *Chaetomorpha*, *Enteromorpha*, *Cladophora*, *Chorda*, *Codium,* and *Laminaria*. Of these, *Ulva lactuca* was the most prevalent, occurring at all of the sites sampled although *Laminaria* also occurred frequently. *Ulva* as a genus is often epiphytic, thrives in nitrogen rich environments, uptake rates are particularly high, and the species grows rapidly (Kirby, 2001). However, *Ulva* has very little ability to store nitrogen in its tissues and is often out-competed by species that have longer nutrient retention times (Durkee et al., 1999). *Chaetomorpha* is light dependent, utilizes more nutrients, and also reduces nutrient flux. Additionally, water turbulence can benefit *Chaetomorpha* by increasing the amounts of available ammonium (NH_4+), nitrates (NO_3^-), and phosphates (PO_4^-). The occurrence of *Enteromorpha* is governed by the availability of nitrogen and the genus is presently being investigated for its uses as treatment of secondary municipal sewage (Bud & Pizzola, 2002). Accidentally introduced from Europe in 1957, *Codium* can be disruptive to ecosystems by displacing native algal species and smothering shellfish (Kennedy, 1997). When nitrogen is limited, *Codium* can appear sickly and bleached with a coat of fine hairs, that increase the absorptive area (Kennedy, 1997). This species can also utilize nitrogen in many forms such as nitrate, nitrite, ammonium, and urea, albeit at low concentrations.

Brown algae (Phaeophytes) were observed at four of the five study sites. Brown algae were represented by five genera including: *Desmarestia*, *Ectocarpus*, *Stilophora, Petalonia,* and *Fucus*. Of these species, *Ectocarpus* is present along the entire eastern coast of the United States and is tolerant of elevated metals concentrations.

With respect to mean macroalgal biomass observed at each of the sites (dry weight g/m^2), mean biomass is highest at the Pawcatuck site and lowest at the Hamonnasset site (Figure 3-3).

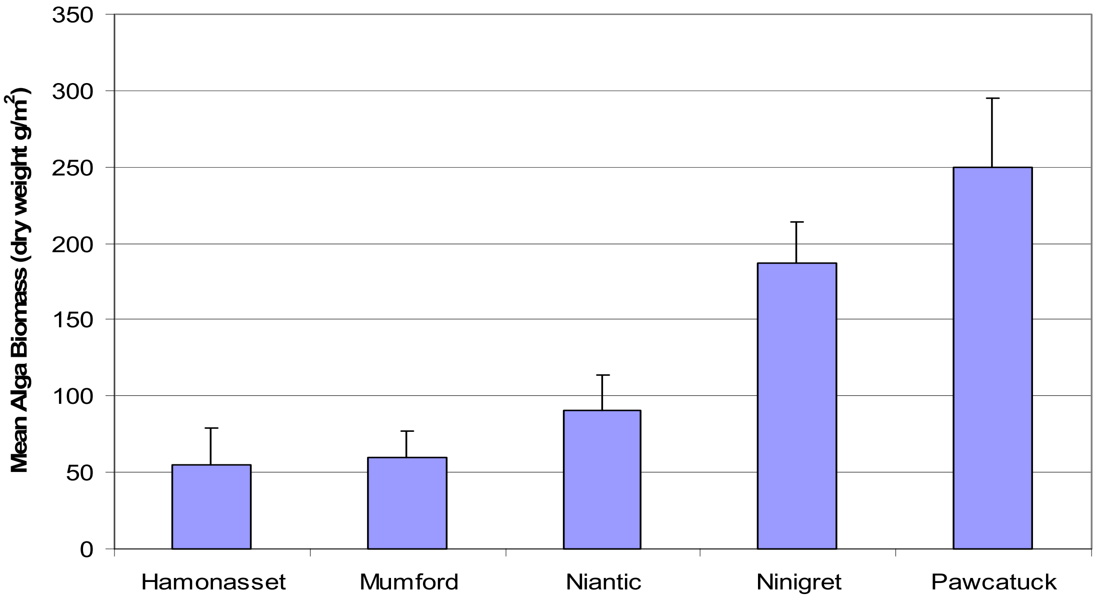

Figure 3-3. Summary of mean macroalgal biomass (dry weight g/m^2) ±1SE at each of the five study sites. Data Source : Vaudrey & Kremer, in press

3.1.3 Zostera marina (Eelgrass)

Eelgrass stands play a pivotal role in the maintenance of a healthy estuarine and coastal ecosystem. The stands form the basis of primary production that supports both epiphytic communities and species occurring at higher trophic levels (Short et al., 2002). Historically, Atlantic eelgrass stands within the Long Island Sound system have been reduced due to the episodic occurrence of a wasting disease, which was attributed to the slime mold *Labyrinthula* (Short et al., 1986). The effects of the wasting disease were first observed in the 1930s, with recurrences during the 1980s and 1990s along the eastern coast of the United States (Short et al., 1986). Eelgrass beds were extremely dense in the 1970s however (Short, 1988). Studies conducted during the 1990s suggest that the loss of eelgrass may be attributable to nitrogen enrichment (Short & Burdick, 1996), although competitive interactions with other macroalgae have been implicated as well (Short et al., 1991; Short & Burdick, 1996). Ultimately, the effects of nutrient enrichment serve to increase competition between eelgrass and macroalgae.

Within the Niantic River, eelgrass stands have experienced frequent die-offs and the largest decline in population characteristics of any locality that presently supports eelgrass (Millstone Environmental Laboratory, 2005). Following a massive die-off in 1999, the Niantic River population exhibited a recovery in 2004, although the species is still under constant threat. Continued threats to eelgrass populations in the Niantic River include nutrient input from domestic septic systems, disease, increased turbidity, competitive interactions with macroalgae, and herbivory. In addition, local water temperatures have increased by as much as 1.5º C since 1976 (Millstone Environmental Laboratory, 2005). This trend may also be exacerbating unfavorable conditions for *Zostera marina*.

Autecology

Eelgrass spreads rhizomatously, with primary nutrient uptake occurring via sediment through the roots. Although nutrients within the water column may enter the plant via molecular diffusion across concentration gradients, this is a relatively insignificant pathway for nutrient uptake (**need citation**). Substrate requirements for eelgrass occur over a broad range of sediment particle sizes that include coarse sands/gravels and fine silts and clays. In a similar manner to many plants, this species exhibits a great deal of phenotypic plasticity, which allows it to persist in a wide variety of habit types. For example, it has been observed that eelgrass occurring in the wave mixed zone possess shorter, broader leaves, grow in dense stands and produce dense rhizome clusters, whereas plants growing in less turbulent environments are taller, have broader, longer leaves and are more widely spaced, with less dense rhizome networks (Costa, 1988). This pattern simply reflects the ability of eelgrass to overcome shear forces by anchoring in the sediment, along with altering its architecture to minimize turbulence.

The maximum depth at which eelgrass (and macroalgae) can grow is determined largely by light attenuation and spectral quality, which are mediated by absorption (by chlorophyll *a*) and scattering (by suspended solids, TOC etc.) (Spence, 1982). Light attenuation in perfectly clear waters is logarithmic with depth, although an increase in suspended solids and/or chlorophyll *a* concentrations will affect this relationship (Spence, 1982). The degree to which particles in the water column affect light attenuation is expressed as a vertical attenuation coefficient of "downwelling" light (K_d) (Spence, 1982). In extremely turbid waters, the K_d coefficient will be high, e.g. 2.0, yet will be low in very clear waters, e.g. 0.2.

The euphotic zone is the surface layer of the water column where photosynthetically active radiation (PAR) is sufficient to maintain phytoplankton populations (Spence, 1982; Hader et al, 1998). At high densities, phytoplankton can absorb more than 75% of PAR, and the absorption peak for chlorophyll *a* occurs at 665 nanometers (nm) (red wavelength) (Spence, 1982). In general, the blue and red wavelengths are the most used by chlorophyll *a*. The lower bound of the euphotic zone is that depth where gross daily photosynthetic carbon fixation balances phytoplankton respiratory losses over a single day and only 1% of PAR penetrates (Hader et al., 1998). Ultimately, the least absorbed wavelength by chlorophyll *a* (green) might be used to define the "bottom" of the euphotic zone and is represented by K_{min} (Spence, 1982). K_{min} also defines the maximum depth at which macrophytes can grow (z_c) (Spence, 1982).

Physico-chemical Environment

With regard to the physico-chemical environment, benchmark criteria for water quality parameters that would promote suitable eelgrass habitat within Long Island Sound have been developed. The suggested criteria were presented within the Eelgrass Habitat Restoration Technical Manual for variables including chlorophyll *a*, light attenuation, and total suspended solids etc. (Table 3-2).

Table 3-2. Suggested water quality criteria for eelgrass[a].

Parameter	Suggested Threshold
Light Attenuation coefficient K_d (m^{-1})	<0.7
Total Suspended Solids TSS (mg/L)	<30.0
Chlorophyll *a* (ug/L)	<5.5

Parameter	**Suggested Threshold**
Dissolved inorganic nitrogen (mg/L)	<0.03
Dissolved inorganic phosphorus (mg/L)	<0.02
Sediment Organic Matter (%)	<3.0
Secchi Depth (m)	>0.7

[a]: Parameters are based upon environmental data collected at three eelgrass sites in Long Island Sound over 18 months (Koch et al., 1994).

Based upon the data collected by the University of Connecticut, both the Niantic and the Mumford sites are below the suggested upper bound for K_d (0.7), the Ninigret site is at the upper bound, whereas the Hamonassett and Pawcatuck sites are above (Figure 3-4). With respect to chlorophyll *a* concentrations, the Ninigret site is the only location below the suggested upper bound (Figure 3-5).

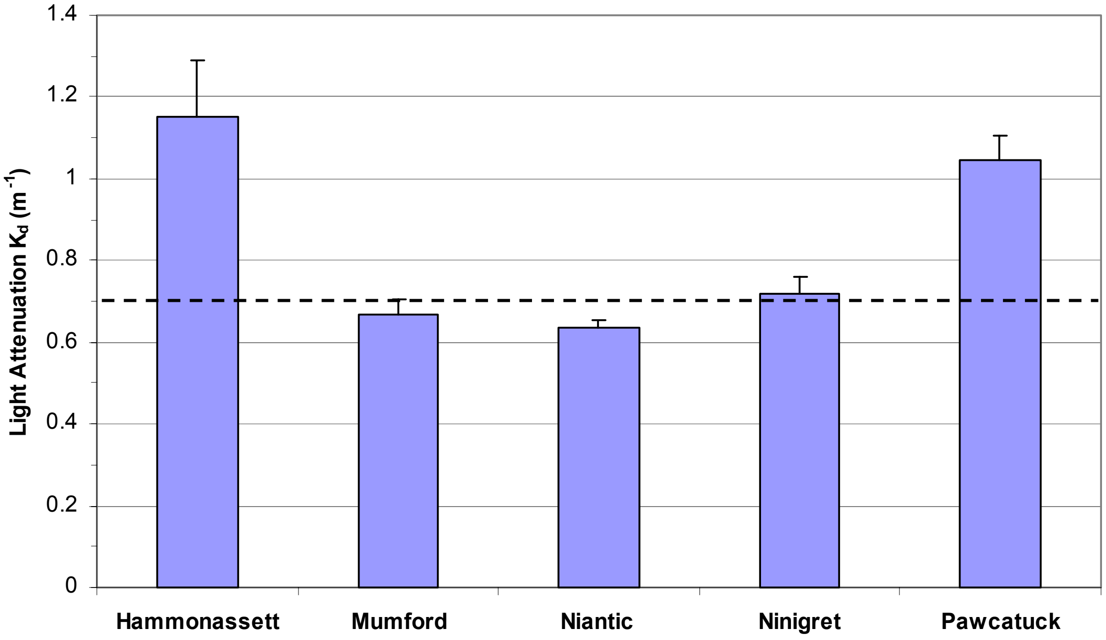

Figure 3-4. Summary of mean light attenuation (m^{-1}) at each of the five University of Connecticut study sites ±1SE. Data Source: Vaudrey & Kremer, in press.

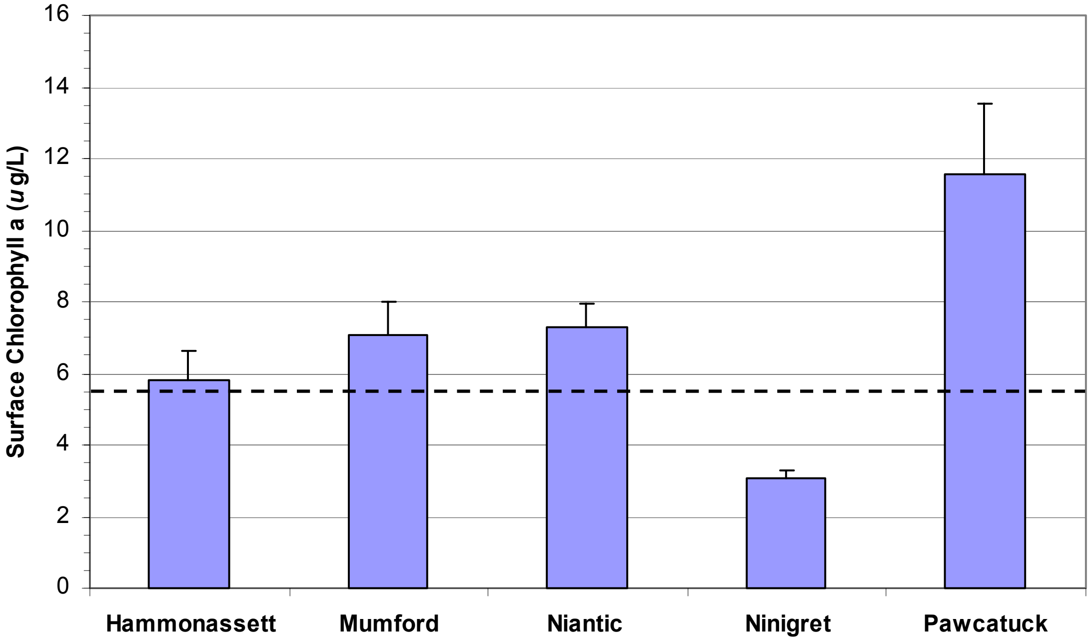

Figure 3-5. Summary of mean surface chlorophyll *a* concentrations (*u*g/L) at each of the five University of Connecticut study sites ±1SE. Data Source: Vaudrey & Kremer, in press).

In order to determine if chlorophyll *a* concentrations increased within the Niantic River during the 2001-2004 University of Connecticut sample period, a time series analysis was conducted with the non-parametric Mann-Kendall test for trend (*S*) (Gilbert, 1987) where *S* is calculated:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign\left(x_j - x_k\right)$$

The results indicate that mean chlorophyll *a* concentrations within the Niantic River system increased slightly over this time period (Figure 3-6) and that the increase in surface chlorophyll *a* is statistically significant (S = 6; $p = 0.042$), as is the increase in bottom chlorophyll a (S = 8; p 0.008).

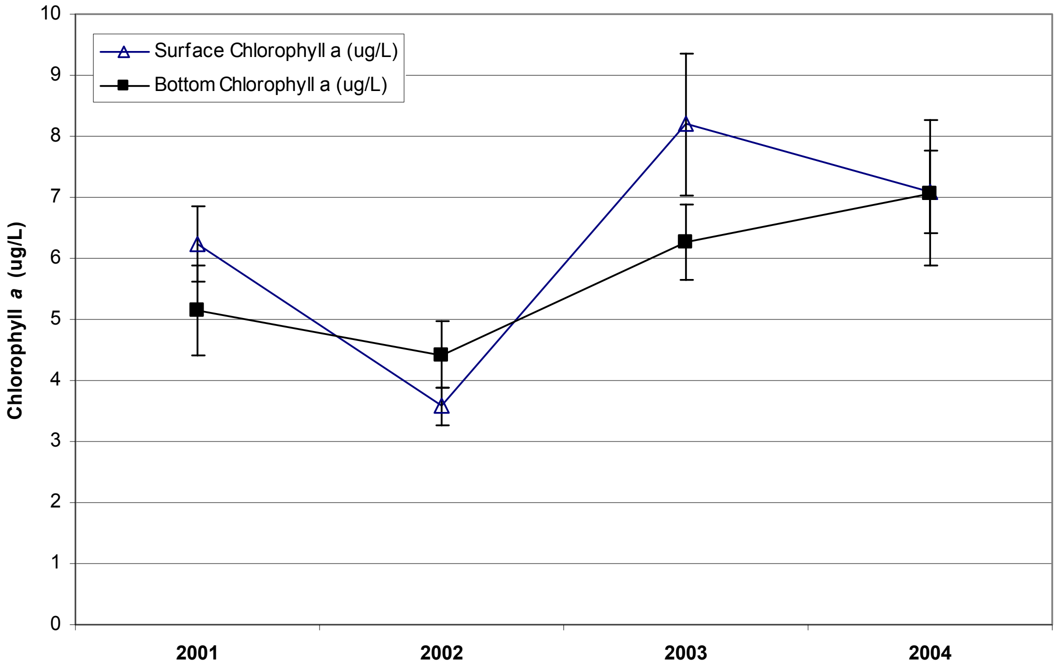

Figure 3-6. Mean surface and bottom chlorophyll *a* concentrations (*u*g/L) ±1SE over a four year period in the Niantic River system. Data Source: University of Connecticut (Vaudrey & Kremer, in press).

During the 1985 – 2005 time frame, the Millstone Environmental Laboratory has monitored aspects of eelgrass abundance in the Niantic River including shoot density, shoot length, and standing crop, in addition to sediment characteristics. Based upon the results, shoot density (no./m^2) has been largely static with time, although shoot length (cm) appears to have exhibited a slight decrease (Millstone Environmental Laboratory, 2005). Mean monthly standing crop (dry weight g/m^2) has also declined over the 20-year study period. With respect to the data collected by University of Connecticut during the 2001-2004 study of the Niantic and four other sites, mean *Zostera marina* biomass is highest at the Ninigret site, lowest at the Niantic River site, and is absent from both the Hamonasset and Pawcatuck sites (Figure 3-7).

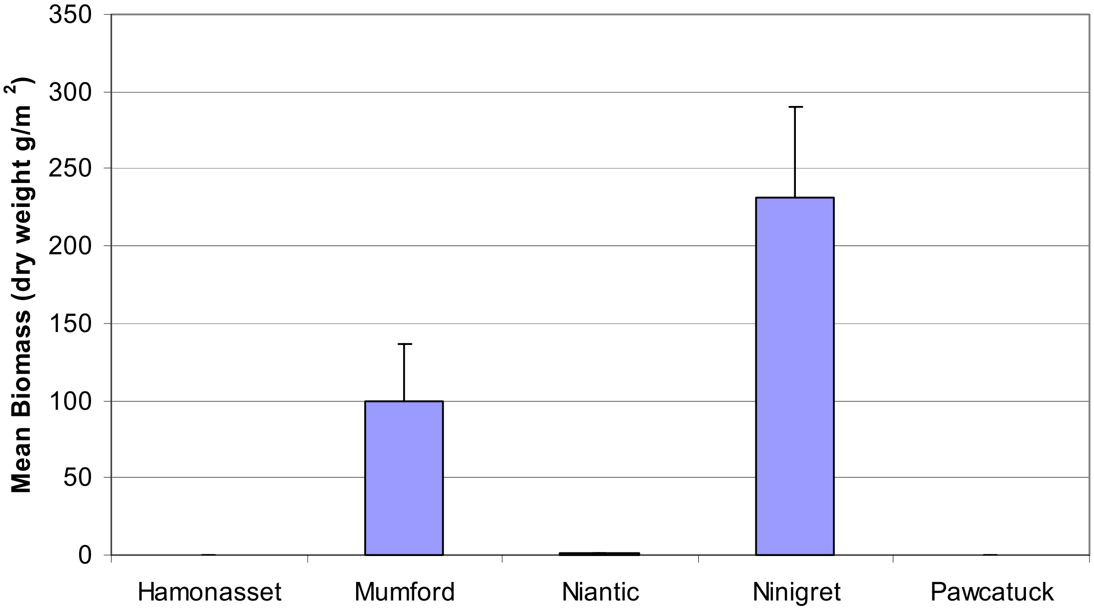

Figure 3-7. Summary of mean *Zostera marina* biomass (dry weight g/m^2) ±1SE at each of the five study sites. Data Source : Vaudrey & Kremer, in press.

With respect to competitive interactions with other macroalgal species, three, short-term declines in eelgrass shoot density and standing stock biomass at the nearby White Point in 1991 and 2004 were directly attributed to dense growth of the filamentous green algae *Cladophora*, which covered the entire eelgrass bed (Millstone Environmental Laboratory, 2005). Following the appearance of *Cladophora* in 1991, the few remaining eelgrass plants were observed by Millstone Environmental Laboratory researchers to be yellow (i.e. chlorotic). The eelgrass recovered from the invasion of *Cladophora* shortly after the 1991 die-off, only to be decimated once again by an algal bloom at White Point. Within the Niantic River itself, a 25cm thick mat of the rhodophyte *Agardhiella subulata* covered the sediment surface and the lower portions of the eelgrass beds shortly before the massive die-off of Niantic river eelgrass stands in 1999. Ultimately, the increase in algal decomposition induced anoxic conditions and elevated ammonium levels within the bed, which led to the gradual die-off. In spite of the frequent die-back, eelgrass populations within the Niantic River had rebounded by 2003, and by 2004 patchy eelgrass stands were once again established in the Niantic River (Figures 3-8 and 3-9).

Figure 3-8. eelgrass map

Figure 3-9. eelgrass map

The analysis of % carbon and nitrogen (CHN), in addition to stable nitrogen isotopes (δ^{15}N) in eelgrass and macroalgal tissue indicates that aquatic macrophytes in the Niantic River are experiencing what is referred to as the "luxury uptake" of nitrogen (Kremer & Vaudrey, 2006). The increased storage of N without a concomitant influence on biomass production is demonstrative of luxury consumption, and was mirrored in the higher than typical carbon:nitrogen ratios in Niantic River macrophytes (Kremer & Vaudrey, 2006).

3.1.4 Summary of Primary Productivity

The composition of the macroalgal community within the Niantic River indicates that species tolerant of both metals loading (*Ectocarpus*) and nutrient loading (*Ulva*, *Gracilaria*, *Enteromorpha* etc.) are present, albeit to a much lesser degree than other, more nutrient enriched sites such as the Pawcatuck River. As such, the Niantic River might be considered one of the least nutrient enriched sites included in the University of Connecticut study. Both surface and bottom chlorophyll *a* concentrations have increased over the 2001-2004 timeframe within the Niantic River, which is also somewhat suggestive of increased nutrient inputs. Ultimately, in the presence of increasing macronutrient concentrations, it is likely that the Niantic River macroalgal community will shift to increasingly favor those algal species that are more effective at macronutrient uptake and retention.

Based upon data collected by Millstone Environmental Laboratory over the past 20 years, complete die-offs/low abundance of eelgrass within the Niantic River occurred in 1985, 1986, 1988, 1992, 1994, and 1999, 2000, and 2001. The loss of eelgrass within the Niantic River has been observed to occur in response to smothering by epiphytic *Mytilus edulis* (blue mussels), pulses of sedimentation which coincided with the catastrophic 1999 die-off (Millstone Environmental Laboratory, 2005), and competitive interactions with macroalgae. Elevated water temperatures have also been implicated and were present during the 1999 die-off, the effects of which are heightened during concentrations of elevated inorganic nutrients in the water column (Millstone Environmental Laboratory, 2005). In summation, the eelgrass beds within the Niantic River are uniquely susceptible to the effects of macronutrient enrichment, i.e. nitrates, phosphates, ammonium, given the long residence times in the Niantic River, and the proximity to agricultural runoff and domestic septic systems.

3.2 Macroinvertebrates (bay scallop)

Over the last several decades, there has been a marked decline in the population abundance of bay scallop (*Argopecten irradians*) in nearshore waters and estuaries of the northeastern United States. Losses of habitat, deterioration of water quality, and harmful algal blooms have probably contributed to this decreased abundance (Goldberg et al., 2000). Apparently, bay scallops will generally only spawn once in their 18-22 month lifespan and this property increases the possibility of limited (and successful) recruitment when year-class survival is poor. From this, it is clear that even slight perturbations to habitat properties may have serious consequences for this sensitive species.

Very young scallops (<10mm) apparently cannot tolerate highly silted substrates and will attach themselves to epibenthic surfaces until reaching 11 millimeters (mm) and then drop to the bottom until most scallops are 31 mm in size (Garcia-Esquivel & Bricelj, 1993), a strategy that probably improves their survival rate. Beds of eelgrass are apparently preferred as settlement locations. Young bay scallops grow faster in slower moving currents, and since eelgrass beds tend to slow normal water currents (through increased surface area), availability of these plants may enhance growth rates. In instances where an eelgrass bed has become disturbed, bay scallops will emigrate out of the damaged eelgrass bed and re-attach to blades in adjacent and undisturbed beds (Garcia-Esquivel & Bricelj, 1993). The study also indicated that those bay scallops that emigrated remained in the adjacent beds, even after the damaged bed had recovered (Garcia-Esquivel & Bricelj, 1993). This response has also been observed in the Niantic River, whereby bay scallops were observed migrating out of Niantic River eelgrass beds that had become hypoxic as a result of thick mats of decomposing *Agardhiella subulata* (Goldberg et al., 2000; Millstone Environmental Laboratory, 2005).

In the case of the Niantic River, and the extremely patchy and stochastic nature of eelgrass biomass within the system, it seems probable that a population of bay scallops emigrating out of a disturbed bed might not actually encounter a suitable patch. In fact, the risk of predation by green crab (*Carcinus maenus*) for example, would only be increased as the small juvenile scallops move across broad expanses of unsuitable habitat, thus increasing mortality. During times of a low standing crop of eelgrass within the Niantic River, predation efficiency would most likely be increased (Prescott, 1990). Therefore, a decrease in eelgrass biomass even over a timeframe of a few weeks could markedly increase the mortality of small juveniles (Garcia-Esquivel & Bricelj, 1993).

Within the Niantic River, the abundance of bay scallops was at a peak in 1986, after which time the population plummeted (Figure 3-10). Presently, the species persists at low levels in the Niantic River and the small population size is mirrored in the low abundance of scallop landings over the past 10 years (Faber, Waterford East Lyme Shellfish Commission (WELSCO), pers. comm.; as cited in Goldberg et al., 2000).

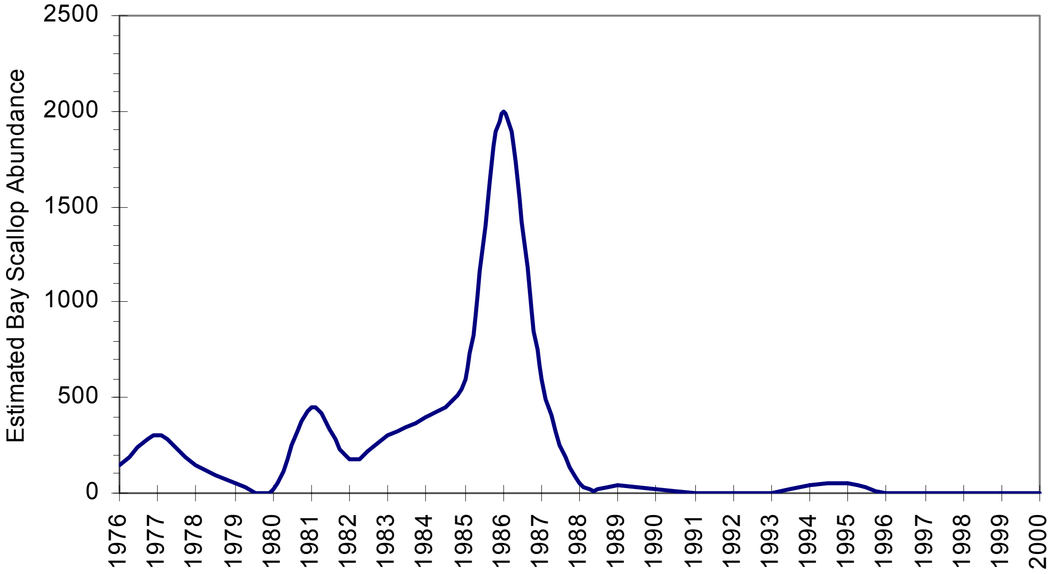

Figure 3-10. Niantic River bay scallop abundance taken from trawl data collected from 1976 – 2000. Data Source Millstone Environmental Laboratory, 2001.

Pilot studies directed at the restoration of bay scallop populations in the Niantic River have only met with mixed results, although these early attempts do show some promise (Goldberg et al., 2000). The overall conclusions of the study conducted by Goldberg et al, 2000 include the following:

1. The Niantic River bay scallop population appears to be recruitment limited, although habitat is such that a larger population could be supported;
2. Temperature affected the over-winter survival of bay scallops such that survival was higher at 8ºC or less. Total mortality occurred at water temperatures in excess of 19ºC;
3. Cages are a suitable method to over-winter and grow hatchery reared bay scallop seed.

3.2.1 Summary

The bay scallop has exhibited the most dramatic reduction in population size of the species examined and is most likely the least resilient organism to changes in habitat properties, e.g. eelgrass cover. Given the dependence of early developmental stages on eelgrass beds, stochasticity in the abundance of eelgrass, and the inability to locate suitable eelgrass patches may have increased the likelihood of predation. In addition to reduced recruitment in response to decreased availability of suitable habitat, the increase in predation may have at least partially contributed to the recent reduction in bay scallop.

3.3 Fishes

The analysis of the Niantic River fish community presented in this section is largely based upon a longitudinal demersal data set that spanned the years 1976 – 2001 (Millstone Environmental Laboratory, 2002) and an updated fish data set that spanned the years 1976 – 2004 (Millstone Environmental Laboratory, 2005). The data were collected within the Niantic River estuary channel by Millstone Environmental Laboratory researchers with the use of a triplicate bottom trawl tow equipped with a 9.1 m otter trawl with a 0.6 cm codend liner. The standard tow length was 0.69 km, although the tow distance was shortened in those instances where the net became fouled by macroalgae and detritus. The numbers of organisms (fishes and macroinvertebrates) caught with shortened tow lengths were standardized to 0.69 km and the catch adjusted proportionally. All catch data were expressed in units of catch per unit effort (CPUE).

For the purposes of this discussion, both species diversity and community evenness were used to describe the general health of the demersal Niantic River fish community over the 28 year period sampled. In this regard, the Shannon-Weiner diversity index (H) and an assessment of community equitability (J) were used. Species diversity is an expression of community structure, which varies with both species richness and equitability. For example, a community with many equally distributed species will exhibit high species diversity, whereas a community dominated by one or a few species will have low species diversity. The Shannon-Weiner diversity index is appropriate when dealing with a random sample and is represented by a single number that describes the diversity of a given community:

$$H = -\sum_{i=1}^{S} P_i \ln Pi$$

where P_i = the fraction of the total sample represented by species i; $\ln P_i$ = is the natural log of the species fraction P_i; and S = the total number of species (species richness). Equitability is represented by J, whereby J is calculated as a proportion of the maximum possible value H would assume ($H_{\max}$) if individuals were completely evenly distributed within the community ($H_{\max} = \ln S$) and ranges from 0-1.

In addition to the community level analysis, specific fishes examined within the Niantic river include *Myoxocephalus aenaeus* (grubby). The grubby was selected given its properties as a superb indicator species for natural variation (no fishing pressure and little predation).

3.3.1 Community Level Trends in the Niantic River

Over the entire 28 year period, a total of 129,649 individuals across 84 fish taxa were recorded in the Niantic River (Millstone Environmental Laboratory, 2005). Winter flounder was the most frequently captured fish taxon with 80,344 individuals collected. Overall, the top five taxa accounted for 81.5% of the total catch including: winter flounder (61.9%), silversides (7.4%), grubby (5.9%) windowpane (3.3%), and summer flounder (2.9%).

An increasing trend in both diversity and evenness becomes apparent starting in approximately 1987 (Figure 3-11). Prior to 1987, diversity cycled between a low of approximately 0.9 to a high of 1.6, with troughs occurring at five year intervals. From 1987 onwards, the pattern in H is random with an increasing trend (NEED TO TEST). The increase in H and J in recent times is occurring as a consequence of the reduced abundance of fishes that were dominant in the 1970s including the winter flounder and oyster toadfish. Furthermore, a wider variety of different species have increased in abundance in recent times, which has ultimately resulted in a more diverse and evenly distributed fish community. With respect to the distribution of species during times of low diversity in the early to mid-1980s, the winter flounder (*Pleuronectes americanus*) was the dominant species.

Species richness has more or less remained constant during the 1976-2001 period and has ranged from a low of 26 in 1978-1979 to a high of 42 species in 1990-1991 (Figure 3-12). The numbers of organisms caught in trawl samples has ranged widely, with peaks in 1982-1983 and 1988-1989. Numbers of organisms plummeted in 1993-1994 which appears to have coincided with an eelgrass die-off in 1992. Since 1992-1993, the numbers of organisms have remained low relative to the period of peak abundance noted in the 1980s.

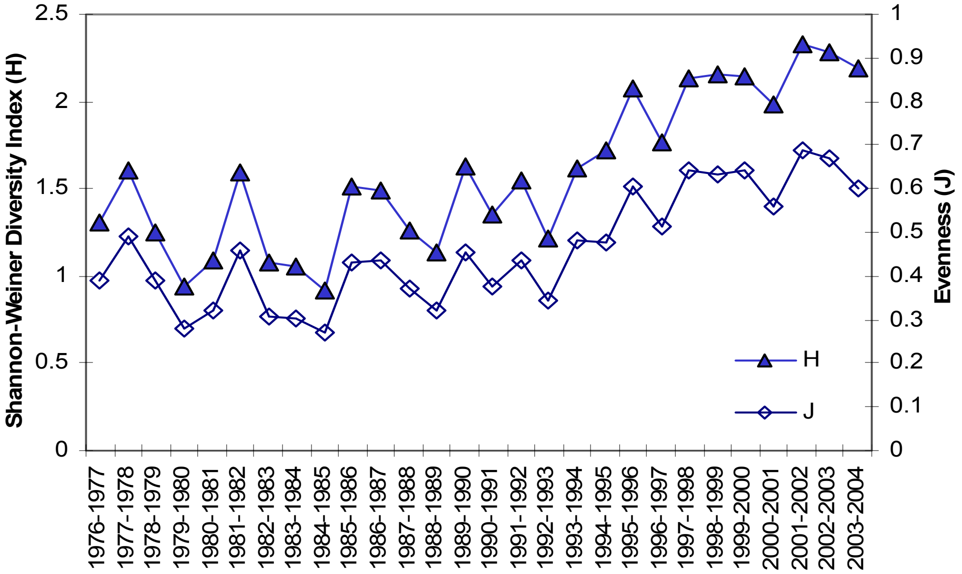

Figure 3-11. Trend in Shannon-Weiner diversity (H) and demersal community evenness (J) over 28 years of trawl sampling in the Niantic River.

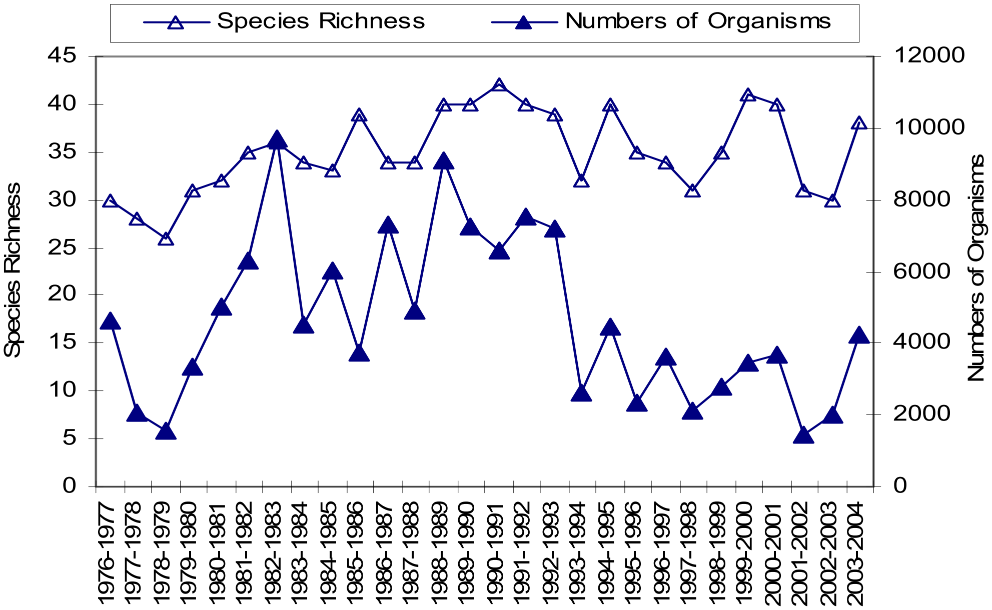

Figure 3-12. Trend in species richness and numbers of organisms over 25 years of trawl sampling in the Niantic River estuary (Millstone Environmental Laboratory, 2005).

3.3.2 Grubby (Myoxocephalus aenaeus)

This section examines the trends in the behavior of benthic fishes that are known to utilize eelgrass beds during spawning and focuses specifically on the grubby (*Myoxocephalus aenaeus*) over the time period 1976-2004 (Millstone Environmental Laboratory, 2005). The grubby serves as an important link between benthic and pelagic foodwebs and is also free from the effects of fishing and to a lesser extent predation, thus rendering it an excellent control species with which to assess other disturbance types such as the loss of eelgrass stands. In fact, it has been asserted that the size of the grubby population could be, at least in part, linked with perturbations in spawning habitat such as the loss of eelgrass beds within the Niantic River (Keser et al., 2003). In addition, declines in other benthic fishes that favor eelgrass beds have been observed in the Niantic River including the winter flounder (Roseman & Tomichek, 2004) and the oyster toadfish (Collett & Klein-MacPhee, 2002). Unfortunately, the effects of fishing pressure on winter flounder populations in particular makes the process of isolating habitat related effects difficult.

The Millstone Environmental Laboratory grubby data collected from 1976-2004 indicate that there are greater numbers of grubbies in the Niantic River than in Niantic Bay. The grubby data were tested for normality with a Shapiro-Wilk test and were then subjected to a parametric *t*-test for independent samples. The *t*-test results indicate that the observed difference in grubby numbers is highly significant (n = 28; $t = 2.91$; p 0.005) (Table 3-3). This result is similar to the findings by Roseman *et al*., 2005. A comparison of the 95% confidence interval around mean grubby abundance by year indicates that there is much more variability in the numbers of grubby in the Niantic River per year than in Niantic Bay ($t = -3.07$; $p = 0.003$). This result indicates that it is harder to predict grubby abundance in the Niantic River than in the Niantic Bay on a year to year basis.

Table 3-3. Summary of mean grubby CPUE values in the Niantic River and the Niantic Bay (1976-2004). Data Source: Millstone Environmental Laboratory, 2005.

	Niantic River	Niantic Bay
Number of Samples	28	28
Range	0.4 - 8.1	0.2 - 4.9
Δ mean CPUE	3.45	2.05
Standard Deviation	2.26	1.14
Mean 95% Confidence Interval	1.47	0.81

In order to explore the possibility that variability in eelgrass biomass may partially explain the greater variability in grubby abundance within the Niantic River, abundance data were plotted against known eelgrass die-off events. Based upon data collected by Millstone Environmental Laboratory over the past 20 years, die-offs of eelgrass occurred in 1985, 1986, 1992, 1994, and 1999 (indicated by dashed lines), while low abundance events occurred in 1988, 2000, and 2001 (Figure 3-13). Grubby abundance fluctuates a great deal during this period around the die-offs of *Zostera marina*. Although there are other factors that might possibly regulate grubby abundance, such as summer flounder predation (Tomichek & Roseman, 2004), the grubby is a short-lived species that matures in one year, so a fairly acute response to changes in habitat properties might be expected. Unfortunately, eelgrass biomass data do not exist prior to 1980, so the low grubby abundance noted in 1976-1977 can not be accounted for.

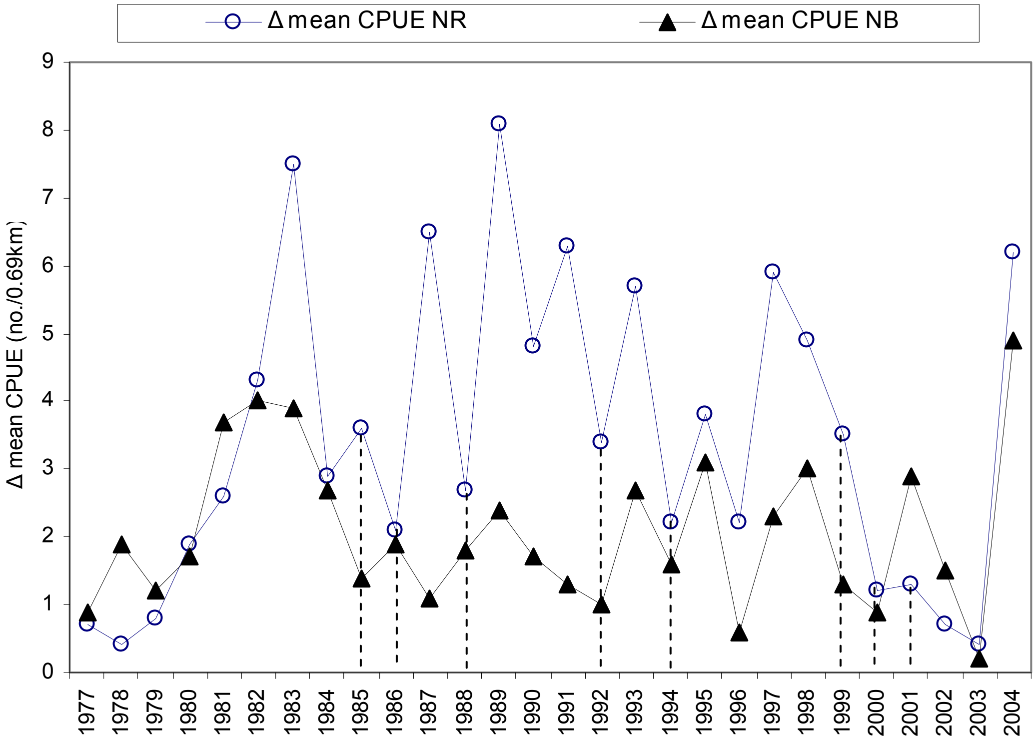

Figure 3-13. Annual Δ mean grubby CPUE within the Niantic River and Niantic Bay (1976-2004). Data Source: Millstone Environmental Laboratory, 2005.

3.3.3 Summary

The diversity and evenness of the fish community has increased dramatically in recent times. Unfortunately, the increase in diversity has come at the expense of fishes that were once numerically dominant including the winter flounder and the oyster toadfish. Furthermore, the numbers of species has increased in recent times, although the overall numbers of fishes have decreased.

The grubby is an excellent control species to use in an assessment of a response to variability in habitat properties. Based upon the evidence at hand, the grubby population size is more variable in the Niantic River than in Niantic Bay. A qualitative relationship between grubby abundance and eelgrass is suggested by alternating depressed grubby numbers during times of low eelgrass abundance and die-offs, followed by a rebound in grubby numbers as the eelgrass becomes re-established. This relationship needs to be explored more thoroughly.

Based upon research conducted by Roseman et al. (2005), grubby may be using the Niantic River preferentially to spawn. This relationship is based upon the fact that larger, more reproductively mature grubby were observed in the Niantic River. Under the assumption that the grubby use eelgrass beds preferentially during spawning, it might be expected that the abundance and total length of grubby within the Niantic River during times of low eelgrass abundance may decrease.

3.4 Literature Cited