Chapter 3. Habitats and Habitat Quality (Brian Howes & Miles Sundermeyer)

A. Habitats

Research aimed at the identification of fish nursery habitats has become increasingly important to the management of both marine fishes and the coastal habitats themselves. The importance of this type of research has recently been emphasized by the adoption of Essential Fish Habitat (EFH) provisions by the U.S. Congress as part of the reauthorization of the Magnuson-Stevens Fishery Conservation and Management Act (Oct. 1996). Essential Fish Habitats are defined as "those waters and substrate necessary for fish for spawning, feeding or growth to maturity." The reauthorization of the Magnuson-Stevens Fishery Conservation and Management Act in 1996, therefore, has led to an explosion in research aimed at identifying fish habitats. The most rapid advances in this area have arguably been made towards defining habitats necessary for juvenile fish growth in estuarine habitats; less emphasis has been placed on identification of spawning habitats (Kneib 1997, Able 1999, Deegan et al. 2001).

Mt. Hope Bay is composed of many types of contiguous and trophically interconnected habitats. Classification of habitat types is somewhat subjective and dependent on individual perspectives, and can be based on geology, geography, dominant flora, or sediment types. Important broad habitat types include the open bay, salt marshes, freshwater marshes and rivers. The open bay habitats can be delineated into water column, benthos, shoreline and shoal habitats, each of which can further be delineated by sediment type, flora and hydrography (e.g., mud flats, sand flats, eelgrass and macroalgae beds). Salt marshes can be divided into tidal zones, salinity zones and dominant plant type.

Ongoing studies are currently beginning to map major habit type distributions in Narragansett Bay (Huber 1999, RIDEM 2001). The estimated total acreage of 14 broad habitat types for Narragansett Bay based on a preliminary summary of 1996 mapping data is provided in Table 3.1. However, other than eelgrass beds subtidal habitats are poorly represented because they are not well accessed with aerial photography. Aerial maps exist for Mt. Hope Bay, but were unavailable for our review and have not been specifically summarized to date.

Table 3.1. Summary of estuarine and marine habitat acreages for Narragansett Bay in 1996. (Adapted from Huber 1999.)

Habitat Type	Area in Acres
Open water	124,259
High scrub-shrub marsh	159
High salt marsh	2,709
Pannes and pools	46
Low salt marsh	443
Brackish marsh	428
Stream beds	<4
Dunes	43
Beaches	1,450
Rocky shores	573
Tidal flats	569
Eelgrass beds	100
Artificial jetties and breakwaters	23
Oyster reefs	9

Eelgrass habitat has long been known to be one of the most important fish nursery habitats (e.g., Heck and Thoman 1984), but is arguably the most endangered. Once extensive eel grass beds in estuaries along the entire east coast of the U.S. were decimated by a fungal blight in the 1930s which may have eliminated as much as 90% of the habitat (Thayer and Fonseca 1984, Short et al. 1993). Unfortunately, little recovery has occurred in most areas. Worse, in the last decade the remaining eelgrass beds on the East Coast have suffered further dramatic declines due to nutrient loading effects (e.g., Valiela et al. 1992, Short et al. 1996). Narragansett and Mt. Hope Bays have not been spared these impacts. Less than 100 acres of eelgrass beds remain in Narragansett Bay today (Figures 3.1 and 3.2). As evidence for the nutrient loading impact, all of the once-extensive beds in upper Narragansett Bay (Figures 3.1 and 3.2), including the entire Mt. Hope Bay, have been lost (Rines 2001 cited in PG&E 2001). Beds in the lower bays have also suffered serious declines. Eelgrass habitat has been largely replaced by open mud flats and macroalgae fields. The functional value of these habitats compared to eelgrass is unclear, though macroalgae may serve as a suitable replacement for some fishes such as tautog (i.e., *Ulva*; Sogard and Able 1991, 1992). The long-term impact of fragmentation and loss of eelgrass habitat to regional fisheries is unknown. Because of the importance of this habitat, several restoration projects have been conducted, are ongoing, or are planned for the future in Narragansett Bay. However, the long-term success of these efforts is doubtful unless the underlying cause of eelgrass loss is addressed.

Saltmarshes (including brackish marshes) are thought to provide major trophic support and nursery habitats for our fishery species (e.g., Kneib 1997, Able 1999, Deegan et al. 2001, Weinstein and Keeger 2001). But they too are greatly endangered in the Narragansett and Mt. Hope Bay systems. In general, it

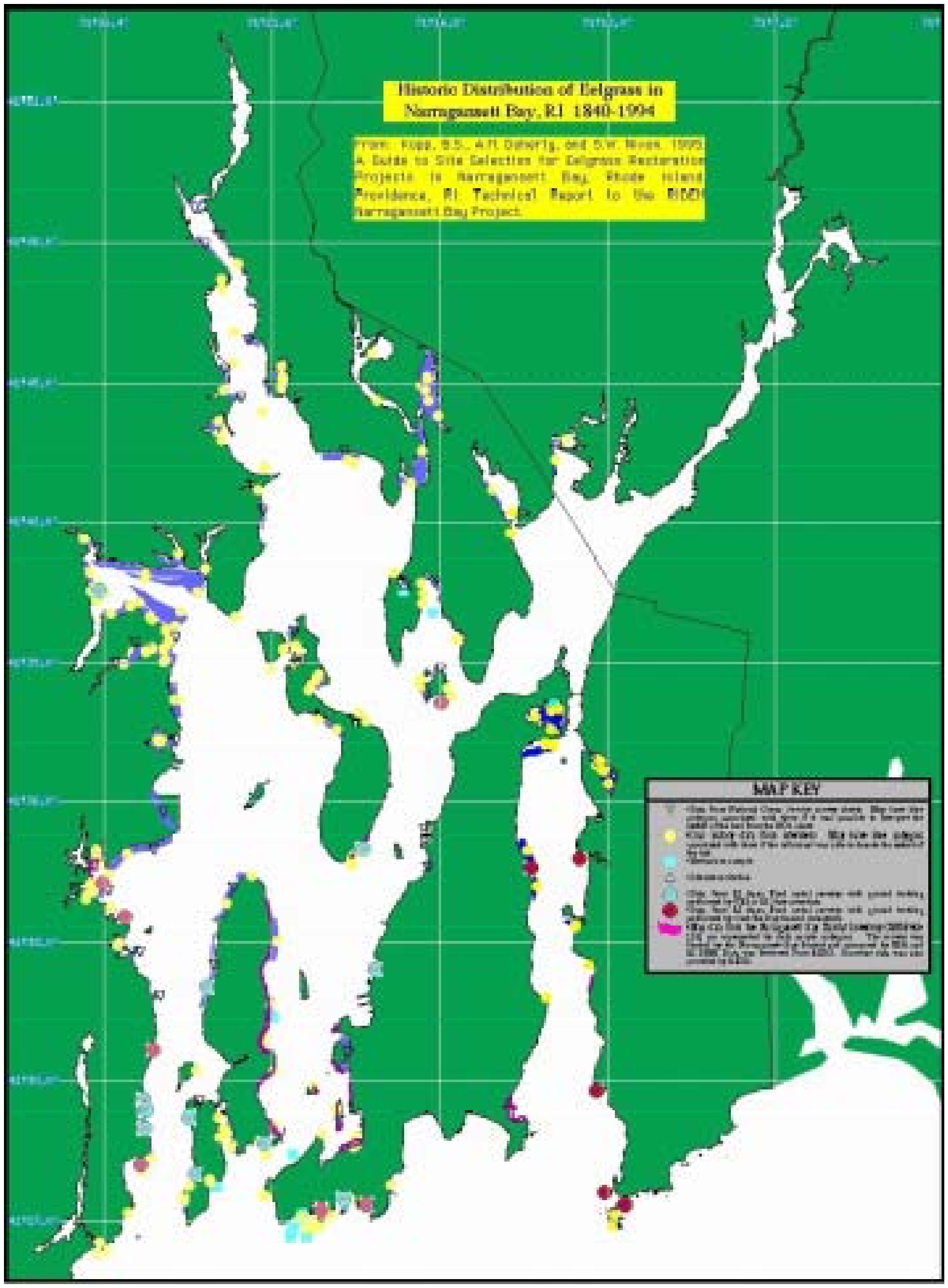


Figure 3.1. Historical distribution of eelgrass beds in Narragansett and Mt. Hope Bays. (Reprinted from Kopp et al. 1995.)

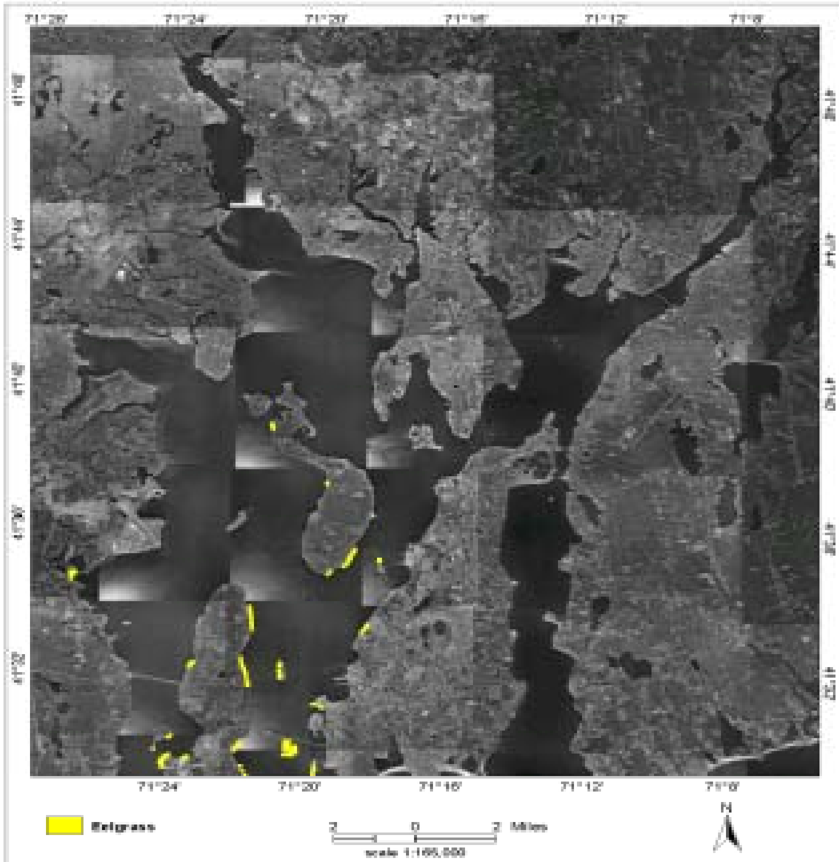


Figure 3.2. Eelgrass distribution in Mt. Hope Bay and upper Narragansett Bay. Eelgrass, shown in yellow, is absent from Mt. Hope Bay and is confined to shallow marginal areas within the lower western portions of Narragansett Bay. This system-wide distribution is typical of estuaries receiving significant nutrient inputs to the upper tributaries. Mt. Hope Bay has high turbidity and periodic low dissolved oxygen during summer, conditions not supportive of eelgrass beds. (Data provided by RIDEM–the Rhode Island Department of Natural Resources and Environmental Management.)

is thought that over half of the wetlands in the U.S. have been lost since colonial times (Dahl 1990, cited by the Massachusetts Coastal Zone Management Office (http://www.state.ma.us/czm/walossd.htm). In Rhode Island, 10% of the coastal wetlands were filled for development between 1955 and 1964 alone. In Narragansett Bay, as much as 70% of the remaining wetlands have restricted tidal flows and 60% are subjected to some amount of filling and dumping activity. In addition, drainage patterns of about 50% of the remaining marshes have been modified through mosquito ditching. To make matters worse, native plants are being replaced by the foreign invasive *Phragmites* in as much as 1/3 of the remaining marshes. Almost half of the brackish marshes in Narragansett Bay are now dominated by *Phragmites*. *Phragmites* replacement of native salt marsh plants is occurring at an alarming rate throughout the Mid-Atlantic Bight and New England region and has been the focus of much concern in the last decade. The degree of wetlands and salt marsh habitat loss and modification patterns are in Mt. Hope Bay are unknown. Although modification of tidal flood and drainage patterns in salt marshes may not seem to be of major importance, when one considers that most marsh nekton access the marsh's production through tidal movements (Rountree 1992, Deegan et al. 2000), any modifications to water flow patterns take on greater significance. In fact, tidal marsh creeks are thought to be a major access route to the saltmarsh for nekton (Rountree 1992, Rountree and Able 1992a, 1993, 1997), yet they are often subjected to development and modification. The consequences have not been addressed. Change in saltmarsh habitat coverage over the last four decades in Narragansett Bay is currently being quantified by the Narragansett Bay Estuary Program and their collaborators (RIDEM 2001), but is not currently known.

Other habitats - Little is known of the importance of other habitat types in Narragansett or Mt. Hope Bay; however, Save the Bay has summarized the coverage area of some of the other types of habitats (Table 3.1). There are over 46 acres of marsh pannes and pools in Narragansett Bay. The latter is an important habitat for resident marsh nekton, and may be an important wintering ground for some species (Smith and Able 1994, Smith 1995). This habitat is subject to adverse effects from marsh modification, especially through mosquito ditching. Tidal flats make up over 560 acres of Narragansett Bay. The importance of tidal flats has not been well documented, but it is known that tidal flats are important foraging grounds for winter flounder (Tyler 1971a, Wells et al. 1973). Shoreline beaches are a major habitat type in Narragansett Bay (1,450 acres), and are mostly dominated by irregularly flooded sand (47%) and regularly flooded sand and/or coble (48%). Rocky shores make up another 570 acres. Information on the importance of these habitats to winter flounder and other fishes is limited. Sediment types such as mud, shell, silt, clay, sand, pebble, etc., also constitute important benthic habitat types for the open bay system but have not been mapped or quantified to date.

Conspicuously lacking in the summary (Table 3.1) is an identification of macroalgae beds that have largely replaced eelgrass beds in many areas. Although macroalgae may not be the optimal habitat for many species, recent studies suggest it is an important habitat for some species (Sogard and Able 1991, 1992). A recent survey of Narragansett and Mt. Hope Bays concluded that macroalgae is the dominant vegetative cover and is an important nursery habitat for tautog (Dorf and Powell 1997). A survey of macroalgae habitat types and distribution in Narragansett Bay recently concluded that macroalgae habitats are extremely spatially variable and suggested that attempts to monitor macroalgae habitats should maximize their spatial coverage (Harlin et al. 1996). An indication of the effect of nutrient loading and pollution on benthic habitats dominated by shellfish is indicated by an examination of the closed shellfish areas for Narragansett and Mt. Hope Bays (Figure 3.3). Note that shellfish beds in the upper reaches of Narragansett Bay and most of Mt. Hope Bay are largely closed, suggesting potentially strong impacts on habitat quality.

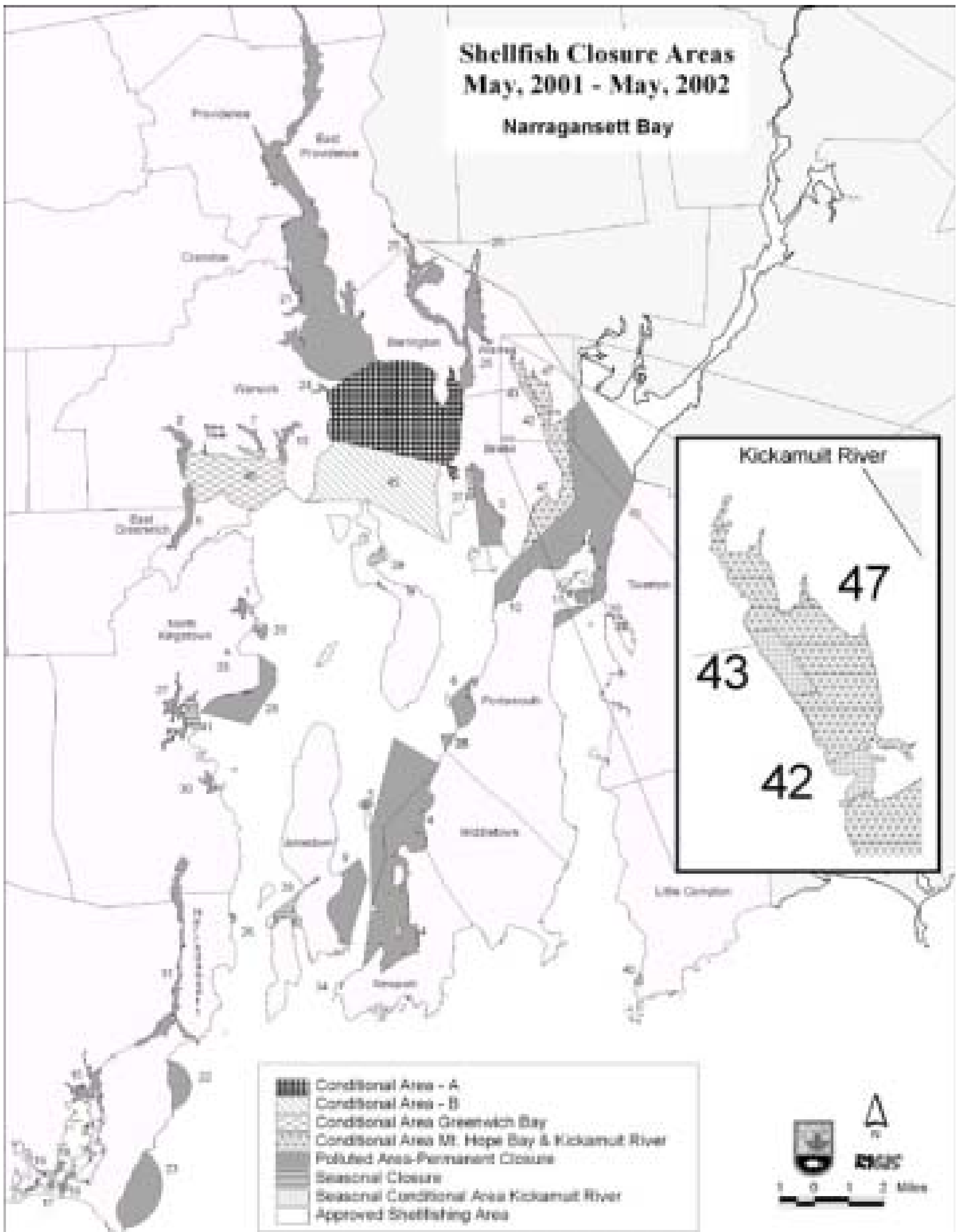


Figure 3.3. Evidence of the impact of nutrient loading and pollution on habitats and ecosystems depicted by closure of shellfish areas. (From www.state.ri.us/dem/maps/static/shellnar.jpg.)

Habitat quality/suitability – A great deal of interest in quantifying habitat quality or suitability has been generated in the last two decades (Able 1999), partly because it represents a tangible unit for resource managers. The functions of habitats are varied, but each habitat can support fish and invertebrate secondary production in several ways: 1) direct use as a nursery (growth), spawning, predator refuge, environment refuge, and/or foraging ground, and 2) as the ultimate source of primary production supporting secondary production in another habitat or ecosystem (habitat linkage). Although many estuarine species appear to be prevalent in many types of habitats, each habitat is likely to contribute differently to the success of a given species (Figure 3.4). Attributes

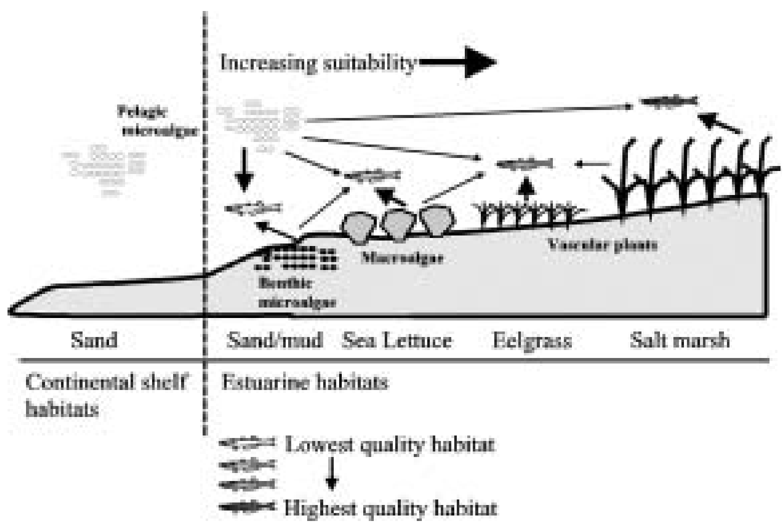


Figure 3.4. Although a species can be distributed across many types of habitats, variation in the habitat quality as measured by mortality, growth, fecundity, spawning success, etc., likely vary strongly among the habitats, such that some can be considered of higher "quality" than others.

such as growth, food availability, mortality, predator refuge capacity, spawning, and other factors can be used to quantify habitat quality. Although species may be capable of switching from a "higher quality" habitat to an alternate "lower quality" habitat, the consequence of habitat modification and loss is theoretically that of a reduced carrying capacity of the estuary, and hence a reduced population size. It is important to note that habitat quality can, and often does differ

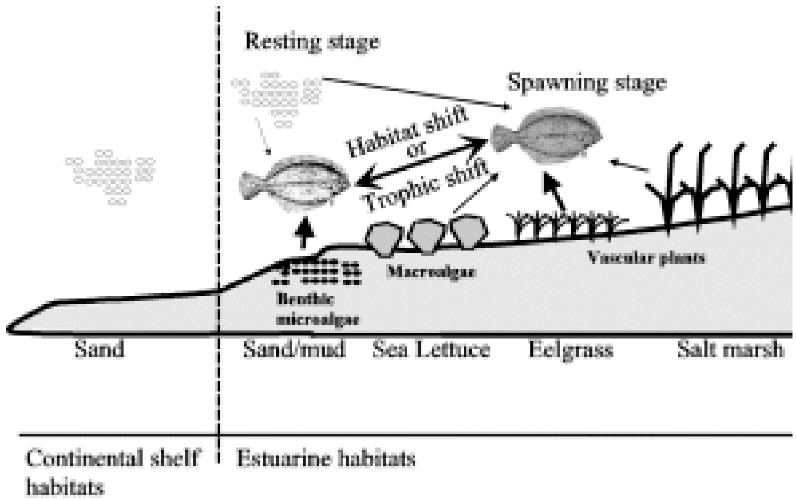


Figure 3.5. Habitat quality or suitability can shift among reproductive stages so that habitats optimal for spawning may not be optimal for other periods.

temporally (Figures 3.5 and 3.6). For example, habitats important during spawning may be different from those most important during resting and development stage (Figure 3.5). Similarly, habitat quality may shift among life stages, season, and even tidal and diel stages (Figure 3.6).

The importance of habitat linkages is crucial to understanding habitat quality and suitability for a given species, as often species may depend on habitats they do not directly utilize. For example, it is currently thought that the major pathway through which production originating in saltmarshes is transferred to open estuarine and coastal habitats is through trophic relay (Kneib 1997, Deegan et al. 2001). Trophic relay can be accomplished in many ways, but basically it is the

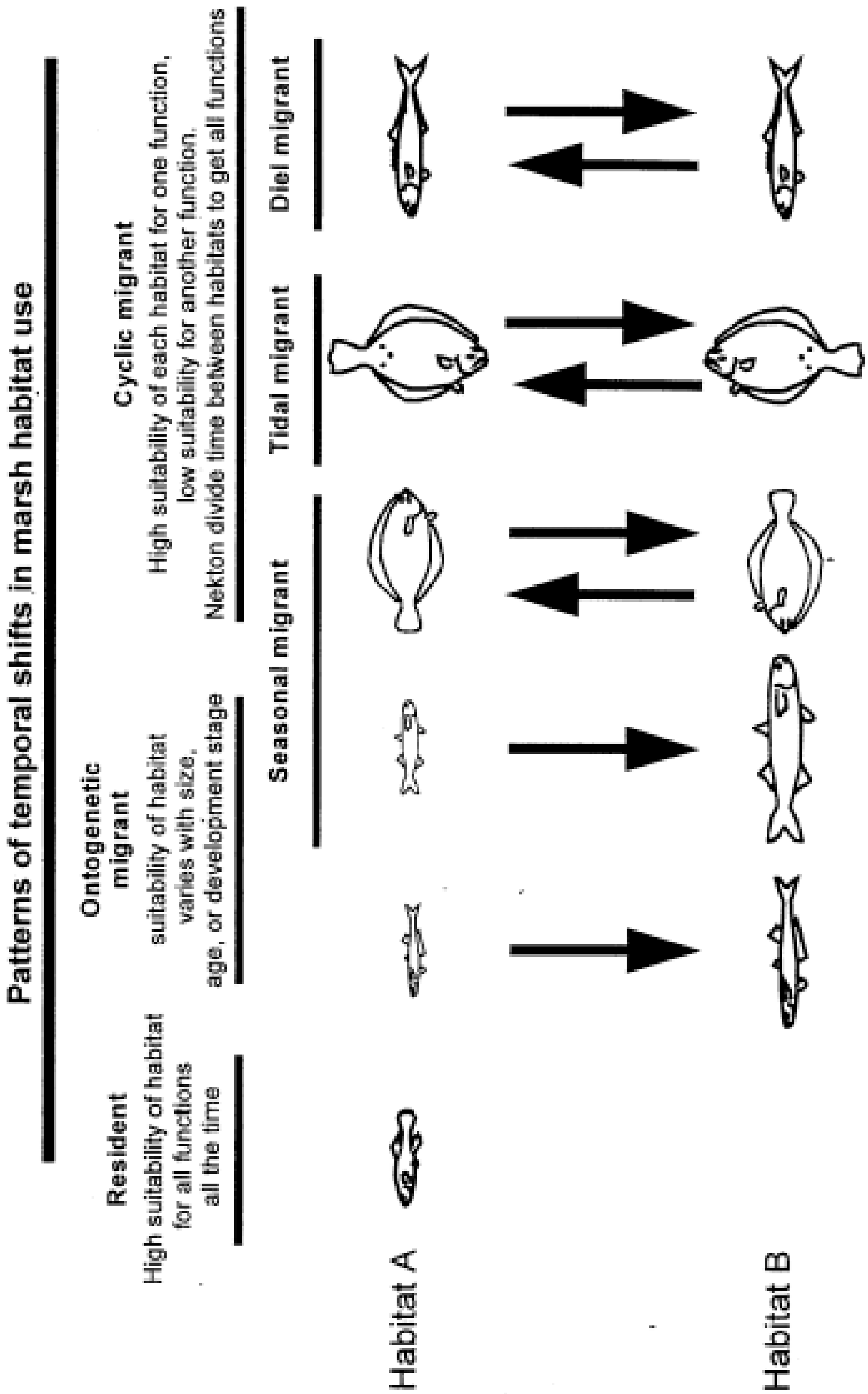


Figure 3.6. Estuarine habitats are trophically linked by nekton movements in a variety of ways, including ontogenetic, seasonal, tidal and diel migrations. (Adapted from Rountree 1992; permission pending.)

transfer of materials incorporated in living tissues through the movements of nekton between habitats. The most widely cited mechanism is through the emigration of nursery species from the saltmarsh (Figure 3.7). Materials

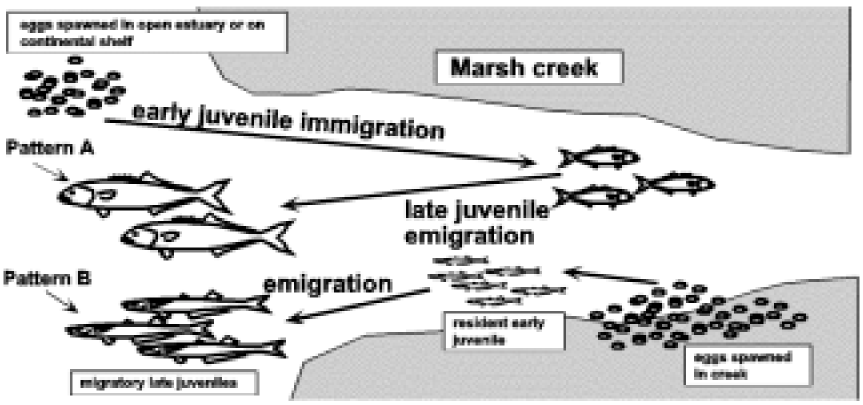


Figure 3.7. Primary and secondary production in saltmarshes and other shallow estuarine habitats supports secondary production in other habitats, sometimes far removed from them, through migration of nursery species. (Reprinted from Deegan et al. 2000; permission pend.)

incorporated into body tissues during growth are thus exported from the saltmarsh into coastal waters (e.g., Rountree 1992, Deegan et al. 2001). Less well known is the export of materials through tidal and diel foraging movements of nekton (Figure 3.8, Rountree 1992, Deegan et al. 2001). These processes result in the trophic linkage of habitats through a “chain of migration” (Figure 3.9), where primary production within important estuarine habitats such as saltmarshes and submerged aquatic vegetation (e.g., eelgrass and macroalgae) contributes to the secondary production of habitats that can be well removed both spatially and temporally. Loss of saltmarsh habitats, therefore, can have unforeseen impacts on nekton populations using other estuarine habitats.

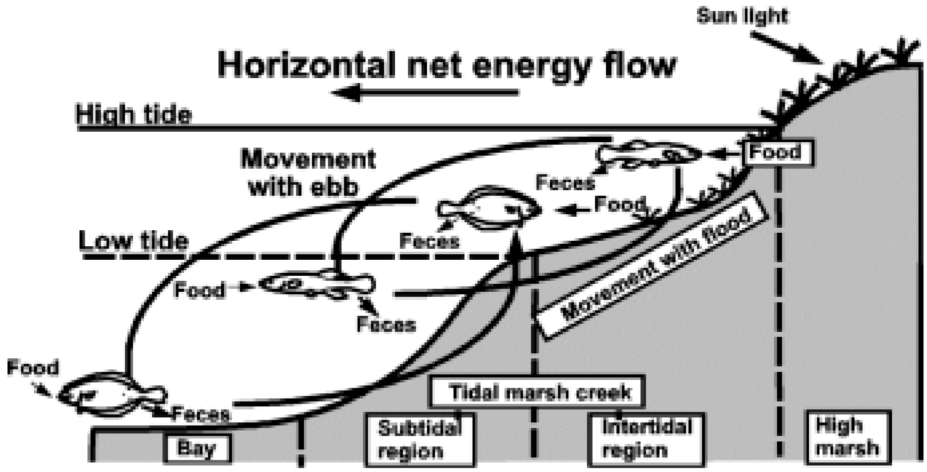


Figure 3.8. Saltmarshes and other shallow tidal habitats support secondary production in deeper subtidal estuarine habits through tidal and diel foraging movements of nekton (reprinted from Deegan et al. 2000; permission pending).

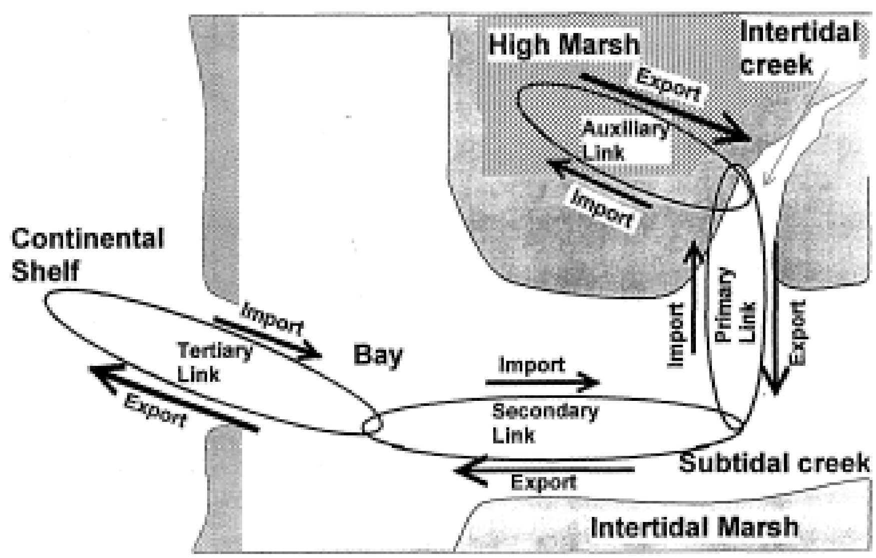


Figure 3.9. Saltmarsh and other shallow estuaries support open bay and coastal marine ecosystems through a chain of migration of nekton species resulting in the trophic relay of energy and materials. (Adapted from Deegan et al. 2000; permission pending.)

B. Watershed Inputs and Nutrient Related Habitat Quality

Mt. Hope Bay is one of the largest estuarine systems in Massachusetts and a major tributary system to Narragansett Bay. Like estuaries throughout the U.S., Mt. Hope Bay has become nutrient enriched as its surrounding watershed has become increasingly developed by the growth in regional population. At present about 1/3 of the total watershed area has been developed. The shift from forest to urban and residential development has enhanced nutrient inputs through wastewater, fertilizers and runoff.

The primary mechanism for watershed nitrogen to enter Mt. Hope Bay is through surface fresh water inflows. Mt. Hope Bay receives direct freshwater discharges from the Cole River, Lee River, Quequechan River and Taunton River systems. Of these, the Taunton River has the largest watershed and discharge. The Taunton River is the second largest river in Massachusetts and has a number of tributary river systems which contribute to its flow. In addition, there are two direct discharges of treated wastewater to the Bay (23 MGD) and five discharges directly to surface water tributaries to the Taunton River (30 MGD).

The primary nutrient related to the habitat quality and ecosystem functioning of Mt. Hope Bay is nitrogen. At present, the lower estuary appears to be receiving nitrogen inputs beyond its capacity to assimilate them without water quality declines. During summer the Bay periodically shows phytoplankton blooms (>30 μg chlorophyll-a L^{-1}) and low bottom water dissolved oxygen (<4 mg L^{-1}), indicative of eutrophic conditions. To assess the relationship of these parameters to the Bay's habitat quality requires analysis of the spatial and temporal extent of these key parameters relative to the animal and plant communities that have historically versus currently occupied this system.

A powerful approach to evaluating the key parameters which control the habitat quality of Mt. Hope Bay is through eutrophication or water quality modeling. A properly parameterized and validated eutrophication model could then be used to identify: (1) the nutrient sources controlling water quality, both within and external to the Bay; (2) the critical factors and physical conditions which control bottom water oxygen levels; (3) the relationship of oxygen conditions to organic matter production within the Bay versus entering the Bay from the watershed or via adjacent marine waters; (4) the areas where additional field data collection is needed; and (5) the potential for improvements in the health of the Bay through reduction of nitrogen sources or other key variables.

1. Key indicators of embayment "health"

The major ecological issue relating to habitat quality within Mt. Hope Bay is nutrient enrichment or eutrophication of Bay waters. Since eutrophication is the response to nutrients, the key indicators are (a) nitrogen concentrations, (b) chlorophyll-a (phytoplankton response), (c) light penetration (controls distribution of submerged aquatic vegetation–SAV), and (d) bottom water dissolved oxygen (primary ecological structuring parameter). Given the seasonal cycle of biological activity, the summer is the critical period for evaluating system health, and it is generally the period of annual minimum water quality. In addition, key ecological indicators include eelgrass and macroalgae distributions and dominant benthic animals, such as *Ampelisca*, *Mediomastus* and *Nucula*. A primary variable for predicting interannual changes in key indicators relates to volumetric discharge from the Taunton River and the frequency and duration of watercolumn stratification.

2. Watershed nitrogen loading analysis

The contributing land area to Mt. Hope Bay represents the second largest watershed in the State of Massachusetts (Figure 3.10). The watershed covers

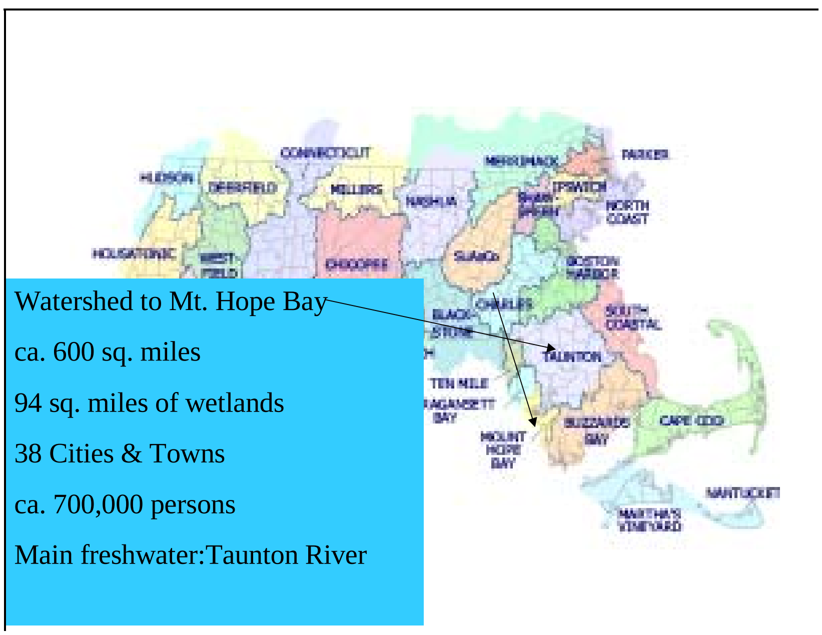


Figure 3.10. Land area contributing freshwater and nutrients to Mt. Hope Bay. The Bay's watershed is the second largest in Massachusetts. (Adapted from MassGIS and the Massachusetts Watershed Initiative.)

about 600 square miles and includes 700,000 people distributed among 38 municipalities. There are 94 square miles of wetlands and 24 major stream and river systems discharging to the Taunton River or directly to Mt. Hope Bay. The major freshwater discharge to the Bay is the Taunton River, which has estuarine waters in its lower reaches (Figure 3.11). The lower portion of the Taunton River is a major tributary system to Mt. Hope Bay Estuary. It is estimated that about 70% of the freshwater from the Taunton River discharges to Narragansett Bay at the Mt. Hope Bridge (Hicks 1959c).

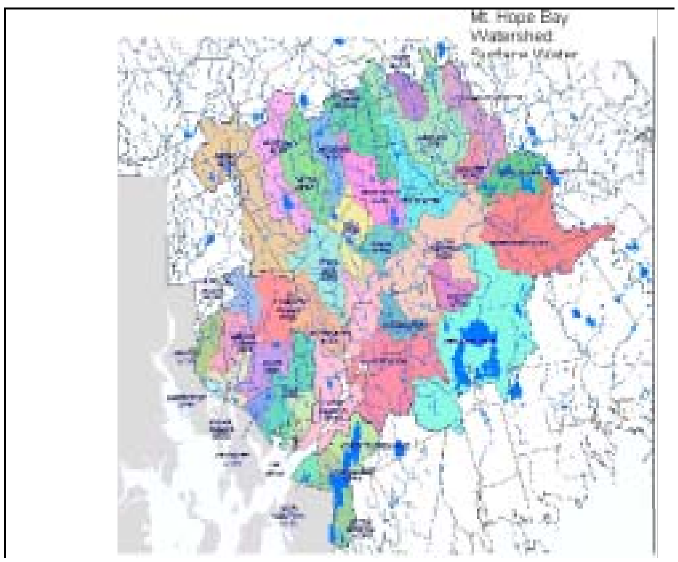


Figure 3.11. Map of the watershed contributing to Mt. Hope Bay via direct discharge or indirectly through the Tauton River. Major surface water sub-watersheds and freshwater streams and rivers are shown. (Map adapted from MassGIS; http//:www.state.ma.us/mgis/.)

The two major sources of nutrients to Mt. Hope Bay are from its watershed and the marine waters of Narragansett Bay. The magnitude of these inputs can be gauged (1) for the watershed, through land-use analysis and nitrogen load modeling for inputs transported by freshwater and (2) for the marine boundary inputs, through water quality modeling based upon nutrient levels and hydrodyanmics of the Bay. While transported by tidal flows rather than freshwaters, the "marine" organic matter and nutrient inputs are also primarily derived from the surrounding watershed (in this case to Narragansett Bay). A significant factor in the magnitude of these tidally transported nutrients to the total nutrient balance of Mt. Hope Bay, depends upon the extent to which tidal waters originate in the nutrient rich Providence River and are transported by tidal flows into Mt. Hope Bay (at the Mt. Hope Bridge) versus originate from the less nutrient enriched waters of the Sakonnet River. Quantifying these "marine" nutrient inputs would fill a key data gap that needs to be addressed in the creation of a nutrient balance/eutrophication model for the Mt. Hope Bay System.

3. Temporal trends in population and watershed nitrogen loads

The watershed to Mt. Hope Bay is functionally divided into an upper and lower region. The upper watershed discharges freshwater and nutrients to the freshwaters of the Taunton River System (ca. 20 tributary rivers plus the Taunton River) that discharges through the Taunton River the Bay (Figure 3.12). The lower watershed contributes its freshwater and nutrient loads directly to the estuarine waters of the lower Taunton River and Mt. Hope Bay (Figure 3.13).

There has been no comprehensive watershed nitrogen loading evaluation conducted for either the Taunton River System or Mt. Hope Bay. As part of the current review, we have begun this analysis. To determine the load of nitrogen from the watershed to Mt. Hope Bay it is necessary to determine the sources of

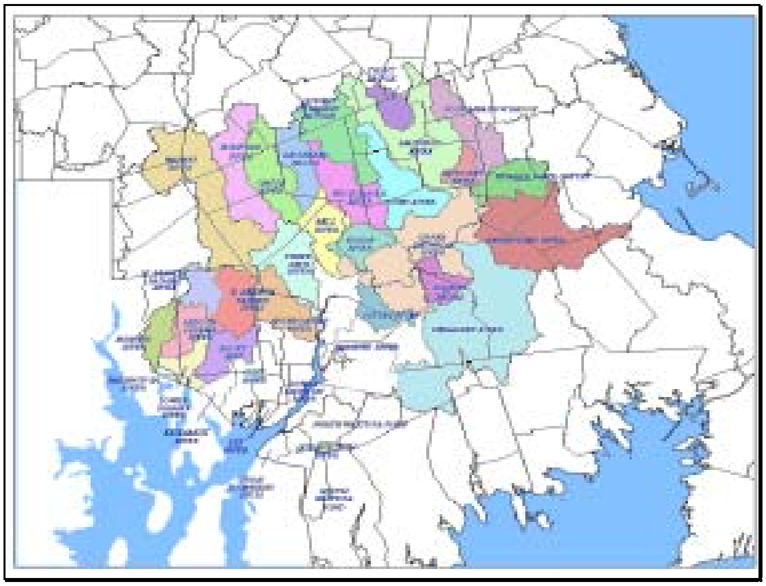


Figure 3.12. Upper watershed to Mt. Hope Bay showing sub-watersheds which contribute nutrients to the Bay via surface water discharges to the Tauton River. The Tauton River is the major freshwater source discharging to the Bay and the major conduit for the transport of nutrients from the upper watershed. (Map adapted from MassGIS.)

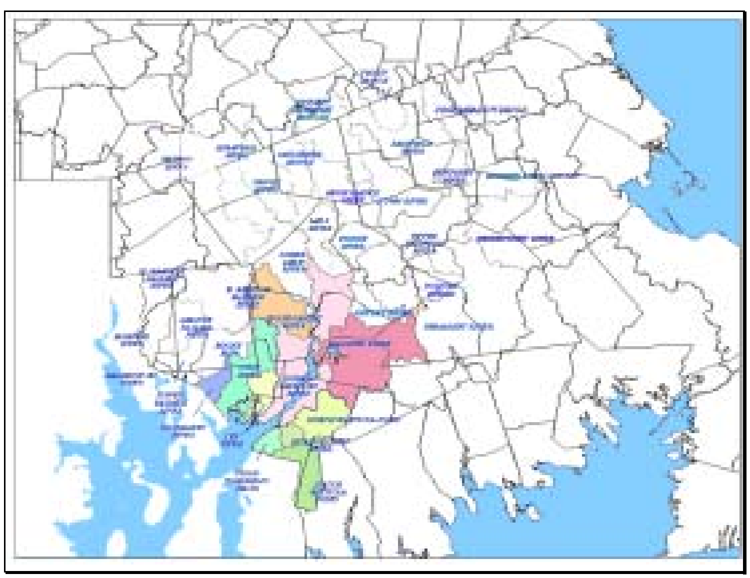


Figure 3.13. Lower watershed to Mt. Hope Bay showing sub-watersheds which contribute nutrients directly to the Bay via small tributary streams or direct groundwater discharges. (Map adapted from MassGIS.)

nitrogen, their magnitude and their spatial distribution. Each type of land-use has an associated nitrogen loading generally determined on an area or unit basis. If the land area is within the lower watershed, this nitrogen load will generally be transported to Mt. Hope Bay without loss or attenuation through natural processes of deposition or denitrification. In contrast, nitrogen transported from the upper watershed is generally attenuated during transport, with the magnitude of the attenuation being related to the specific characteristics of the surface water system through which is moves. Nitrogen attenuation within complex watersheds (e.g., containing diverse surface water systems) can exceed 60% of transported nitrogen. At this time it is not possible to determine the level of transport versus attenuation, since field data collection is required. However, determining the magnitude of attenuation of upper watershed nitrogen prior to entering the estuary is essential to eutrophication modeling and determination of future (and past) trends in habitat quality. This represents a major data gap.

At present, it is possible to gauge the recent temporal trend in nitrogen loading to Mt. Hope Bay based upon our initial watershed land-use analysis. This analysis examined both changes in population within the watershed over the past 40 years and the current pattern of specific land-uses. These data yield insight into both the magnitude of increases in nitrogen loading associated with population growth within the watershed and the extent to which future growth might occur. The major sources of land-use and population data were MassGIS and SRPEDD.

While a full population trend analysis is underway, a partial analysis was conducted which focused on the lower watershed (Figure 3.13). Unlike some areas in New England, the lower Mt. Hope Bay watershed has had a significant increase in population since 1960, with some areas growing 60%-80% (Figure 3.14). Some regions, particularly in urban areas, experienced small population declines (<10%); however, throughout the bulk of the watershed, population increased by 31%-60%. At present, it appears that an estimated average population growth of 30% for the lower watershed over the past four decades is conservative.

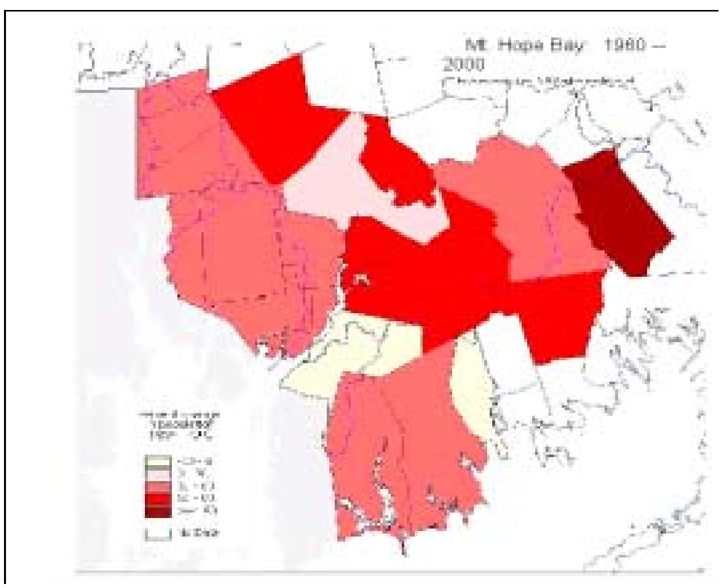


Figure 3.14. Population growth in the Mt. Hope Bay region between 1960 and 2000. Regional population has generally grown 30%-60% over this interval, while the urban (sewered) area has experienced a slight population decline. (Data from MassGIS and SRPEDD.)

The increase in the watershed population almost certainly represents an increase in nitrogen loading to Mt. Hope Bay. However, the level of increase is not proportional, since much of the population has their wastewater processed by municipal facilities. These facilities have been upgrading their performance over the past decade, which has reduced the per capita nitrogen discharge to the Bay (Save the Bay 1997). However, as tertiary treatment is not in effect in the major facilities, it is likely that the nitrogen load through wastewater has and continues to increase. A full watershed nitrogen loading analysis will need to account for present and potential future changes due to population growth (increase) versus improvements in nitrogen removal by wastewater facilities (decrease).

At present there are seven major municipal wastewater treatment facilities that contribute nitrogen, organic matter and freshwater to Mt. Hope Bay. Two facilities (Fall River and Somerset) discharge their treated effluent directly to estuarine waters, while five facilities discharge directly to tributary rivers to the Taunton River, which then flows to the Bay (Table 3.2). Together these seven discharges contribute 1 metric ton of nitrogen and 52 million gallons of treated effluent per day. However, the wastewater treatment facilities discharging directly to the Bay account for most of the wastewater nitrogen input. It should be noted that this evaluation is based upon 1997 data, the most recent year for which synthesis data was available, and additional recent improvements have been made to the Fall River facility which would have to be included into any future modeling effort.

Table 3.2. Discharges from municipal wastewater treatment facilities during 1997. (Data from Save the Bay 1997.)

WWTF	**Flow** MGD	**Nitrogen** mg L^{-1}	**BOD** Mg L^{-1}
Taunton River watershed:			
Bridgewater	0.74	5.69	121
Brockton	19.1	5.31	98.9
Mansfield	2.04	0.67*	16.46
Middleborough	1.27	1.76	33.75
Taunton	6.4	7.84	190
Total =	10,782 MGY**	26.2 MT***	261 MT
Mt. Hope Bay:			
Fall River	20.0	106	277
Somerset	2.79	NA	224
Total =	8,322 MGY	352 MT	495 MT
* Data from 1994 ** MGY = millions of gallons per year *** MT = metric tons			

Inventory of current land-use within the upper and lower watersheds to Mt. Hope Bay was conducted with assistance from MassGIS (D. Pahlavan personal communication). The land-uses–as mapped from aerial photographs and processed by MassGIS–were partitioned by sub-watershed, and the number and/or area of each land-use type was determined. The data were then composited by upper or lower watershed region and the total number or area of each land-use type determined.

The upper watershed (115,283 hectares) is more than 3 times the area of the lower watershed (35,285 hectares, Table 3.3). However, the existing land-uses in both regions are virtually the same (Figures 3.15 and 3.16). Although it might seem that the lower watershed has a large urban area (Fall River), the upper watershed contains a number of urban centers as well. Residential and

Table 3.3. Land-use within the upper and lower watersheds to Mt. Hope Bay (data provided from MassGIS).

Mt. Hope Bay Land-use

Land-Use	Upper Watershed (Acres)	Lower Watershed (Acres)
Residential	65771	18249
Commercial	13526	4651
Agriculture	15875	5434
Open Space	18146	5892
Forest	148068	46089
Aquatic	21633	6466
Other	1845	408
Impermeable	23980	8578
Area (ha)	9705	3471
Total Area	284865	87189
Area (ha)	115283	35285

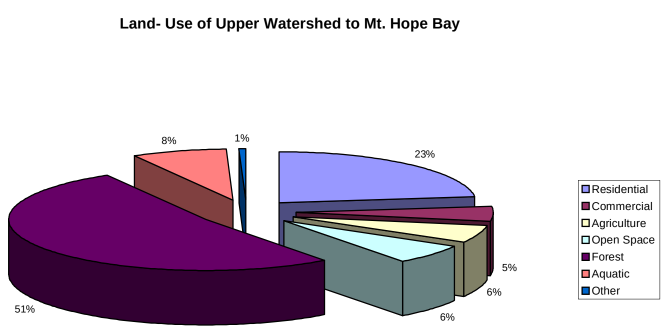


Figure 3.15. Distribution of land-uses within the upper watershed to Mt. Hope Bay (see Figure 3.12). Total land area is 115,300 hectares. (Data from MassGIS.)

commercial areas represent 28% and 26% of the upper and lower watershed areas respectively, with forest dominating both at 52% and 53%, respectively. The large remaining areas of forest in both upper and lower watersheds indicates the potential for continuing development and population growth. Based upon other

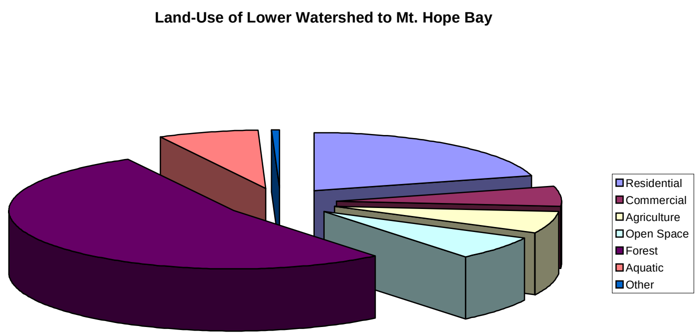


Figure 3.16. Distribution of land-uses within the lower watershed to Mt. Hope Bay (see Figure 3.13). Total land area is 35,300 hectares. (Data from MassGIS.)

Massachusetts land-use analyses, the future population of the watershed to Mt. Hope Bay could likely double over present levels. This would result in a potential doubling of present nitrogen loads, unless parallel improvements in wastewater treatment are instituted. Even if a fraction of this increase occurred, it would almost certainly have significant implications to the ecological health of Mt. Hope Bay.

4. Taunton River flow

The Taunton River is the primary surface water discharge to Mt. Hope Bay. The Cole and Lee Rivers also discharge directly to the Bay but are less than 4% of the Taunton River discharge. The Taunton River integrates numerous tributary streams and rivers throughout its 1153 km^2 contributing area, and it exerts a significant effect on the Mt. Hope Bay System both through the discharge of its nitrogen load and through its effect upon the salinity distribution and water column density field within the estuary. Freshwater discharge from the Taunton

River helps to create the vertical density stratification of Mt. Hope Bay, primarily due to salinity. Since bottom water oxygen within the Bay is related to water column stratification, the Taunton River plays a role in controlling this primary habitat quality parameter. In addition, the Taunton River gathers nitrogen from ca. 600 square miles of watershed and discharges it to the Bay waters. The overall result is that the river discharge serves both to increase the sensitivity of the Bay to nitrogen inputs (due to stratification) and to be a major contributor of nitrogen to the Mt. Hope Bay Estuarine System.

In order to assess potential seasonal and inter-annual variations in the effect of the Taunton River on water column stratification (and hence the sensitivity of the Bay to nitrogen loading), discharge measurements collected at the Taunton Gauge by the USGS from 1980-1999 were analyzed. As the gauge is located in the upper watershed, it does not capture the full Taunton River flow, but it does give important insight into the patterns of discharge.

The Taunton River exhibits a large degree of inter-annual variation in discharge. From the 1880-1999 data series, consecutive year shifts of 2 fold were common (Figure 3.17). It is not possible, at this time, to determine the effect of these large year-to-year changes in freshwater discharge to Mt. Hope Bay. At the lower river flows, however, it is likely that stratification of Bay waters may have been either less frequent or for shorter duration. This would likely result in higher habitat quality and possibly higher productivity of benthic animals in low flow versus high flow years. Understanding the relationship of freshwater discharge to bottom water oxygen levels is critical to determining inter-annual variations in

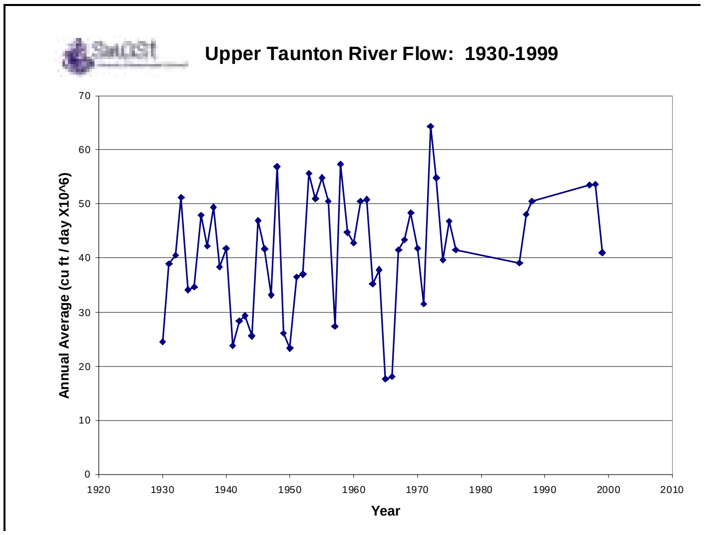


Figure 3.17. Long-term record (1930-1999) of flow in the upper region of the Tauton River as recorded by USGS. Note the 3-fold variation over the record and the frequent 2-fold variation in flow in consecutive years.

habitat quality. Determining this linkage would fill a major data gap and a critical gap in our understanding of the primary controls of annual variations in the health of sub-tidal regions of Mt. Hope Bay.

The Taunton River also exhibits a strong seasonal variation in discharge (Figure 3.18). The peak months of discharge occur in spring (March, April) and have been about 8 times higher than the summer minima (July-September). It appears that even during the low flow months, discharge (and temperature) can be sufficient to cause stratification of the Bay and consequent low bottom water oxygen conditions (see below). While the discharge measurements do not include all of the freshwater flow via the Taunton River to the Bay, it is still worth noting that the minimum discharge at the USGS gauge is 80-90 MGD compared to the total wastewater flows of ca. 50 MGD. It appears that a significant fraction of the freshwater budget of Mt. Hope Bay is associated with treated wastewater effluent.

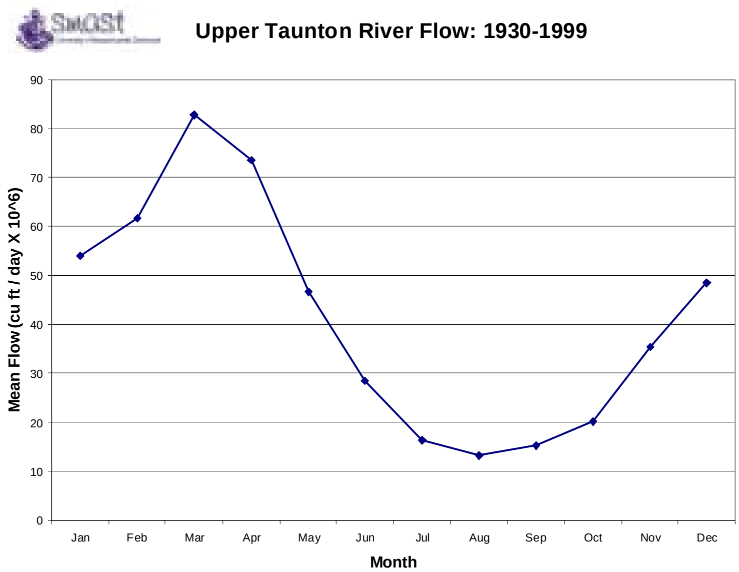


Figure 3.18. Average annual flow in the upper region of the Tauton River as recorded by USGS from 1930-1999 (see Figure 3.17). Note the strong annual cycle resulting from the annual distribution of rainfall and evapotranspiration within the watershed.

5. Assessment of nitrogen-related water quality indicators within Mt. Hope Bay

a. Historic values

While there has been an extensive amount of work on the fisheries, benthic animals, oxygen and chlorophyll levels within Mt. Hope Bay, there has been much less data collected on key nutrient species. In addition, chlorophyll-a data from 1985 to present is also sparse.

A variety of water quality indicators have been used to evaluate the “health" of coastal embayments. The specific water quality indicators selected change with the local ecological issue being addressed. The major ecological issue relating to habitat quality within Mt. Hope Bay is nutrient enrichment or eutrophication of Bay waters. Since eutrophication is the response to nutrients, the key indicators are (a) nitrogen concentrations, (b) chlorophyll a (phytoplankton response), (c) light penetration (controls SAV distribution), and (d) bottom water dissolved oxygen (primary ecological structuring parameter). Given the seasonal cycle of biological activity, the summer is the critical period for evaluating system health, and it is generally the period of annual minimum water quality.

Historical information on these key water quality indicators is limited. Chlorophyll-a levels have been were monitored in Mt. Hope Bay relative to the power facility discharge (MRI 1999), but annual data collection was relatively low after 1985. More recently, bottom water dissolved oxygen has been surveyed, particularly by MCZM and RIDEM, but these data are being finalized. Other indicators have been relatively undersampled. The most critical of these relates to water column nutrient concentrations. At present, we have found virtually no information on the nitrogen and phosphorus levels within Mt. Hope Bay or the lower Taunton River. There is some limited data on inorganic species (ammonium, nitrate, ortho-phosphate), but little on organic forms. Since most of the nitrogen and phosphorus is in organic form, these data must be collected both for assessment purposes and for the construction of water quality and eutrophication models. While the historical data set is not complete, it is sufficient to conclude that Mt. Hope Bay has been eutrophic for at least the past 3 decades. Chlorophyll-a levels in the early 1970’s were generally over 10 $\mu g\ L^{-1}$ and over 20 $\mu g\ L^{-1}$ for much of the spring and fall.

b. Present conditions

A variety of ongoing studies in Mt. Hope Bay are sampling water quality indicators (MCZM, RIDEM, EMPACT). Data from these studies support the contention that Mt. Hope Bay is currently exhibiting eutrophic conditions. In part, this results from the fact that Mt. Hope Bay can develop long periods (weeks to months) of water column stratification. This increases the Bay's sensitivity to nitrogen inputs by preventing ventilation of bottom waters. In organic matter rich systems like Mt. Hope Bay, ventilation is necessary to oxygenate bottom waters which otherwise become oxygen depleted due to high rates of respiration.

During the summer of 2001, the water column at a continuous sampling station in the western region of Mt. Hope Bay (SMAST Mooring) indicated periodic phytoplankton blooms (chlorophyll-a over 10 $\mu g\ L^{-1}$) and bottom water oxygen depletion (Figure 3.19). These data suggest that the ability of the Mt. Hope Bay System to assimilate nutrients without water quality decline has been exceeded.

Oxygen depletion was not uniform throughout the water column, but found primarily within the bottom waters (Figure 3.20). It appears that, for weeks (Figure 3.21) to months (data not shown), bottom water oxygen levels were rarely at atmospheric equilibrium. Oxygen depletion results from the uptake of dissolved oxygen in heterotrophic respiration in sediments and water column.

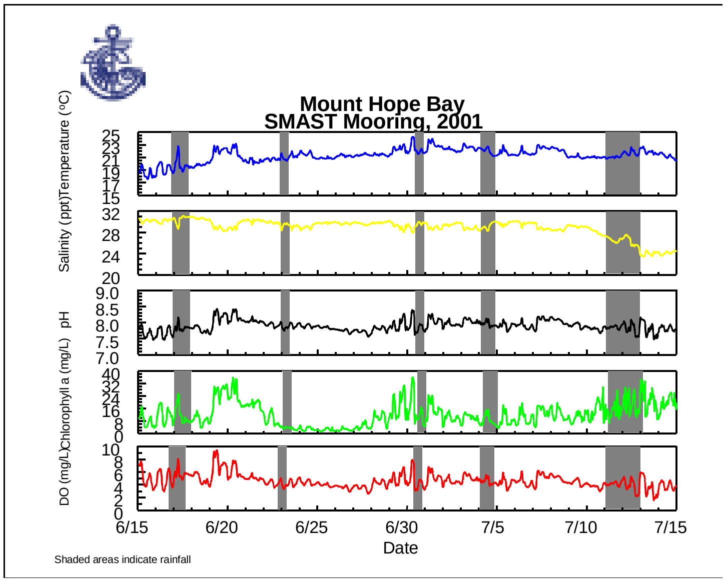


Figure 3.19. Key water quality data collected during mid-summer 2001 at the SMAST mooring near the channel at mid-Bay. (Data collection in collaboration with Narragansett Bay Commission and MCZM under EPA EMPACT Program.)

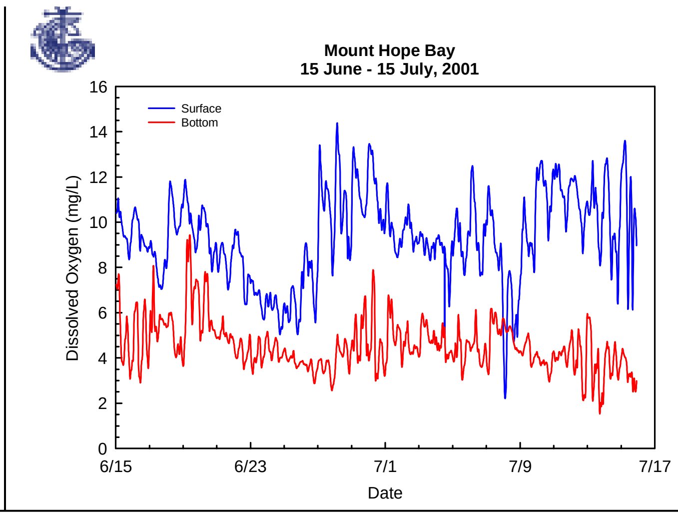


Figure 3.20. SMAST mooring in Mt. Hope Bay during mid-summer 2001. The oxygen levels at the surface are generally above and in the bottom water generally below atmospheric equilibration. This is indicative of eutrophic conditions, where ecosystem oxygen consumption is sufficient to exceed oxygen production through photosynthesis and ventilation. (Data collection in collaboration with Narragansett Bay Commission and MCZM under EPA EMPACT Program.)

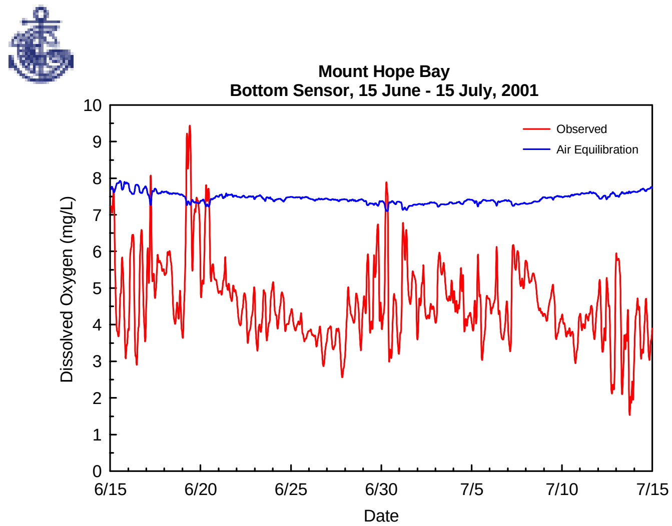


Figure 3.21. Bottom water dissolved oxygen levels and associated levels if at atmospheric equilibration for data interval in Figure 3.20.

Stratification of the water column isolates the bottom waters from reaeration from the atmosphere. If the waters are sufficiently turbid or deep that light does not penetrate below the pycnocline, then photosynthetic oxygen production is also eliminated. Both of these conditions are met within Mt. Hope Bay. The result is that organic matter degradation within the bottom waters and sediments consumes available oxygen and levels decline. Under long periods of stratification or where organic matter pools are large due to nutrient enrichment, large oxygen depletions can occur. Large oxygen depletions (to concentrations of <4 mg L^{-1}) are stressful to benthic animals and fish, and their communities tend to shift to more tolerant forms.

The proximate cause of low dissolved oxygen within Bay bottom waters is the long periods of stratification that can occur in summer (Figure 3.22). The ultimate cause is the organic matter, produced from nitrogen inputs from the watershed and marine boundary, which supports oxygen consumptive processes.

At present, these factors are producing summertime oxygen levels that should be stressful to many marine organisms.

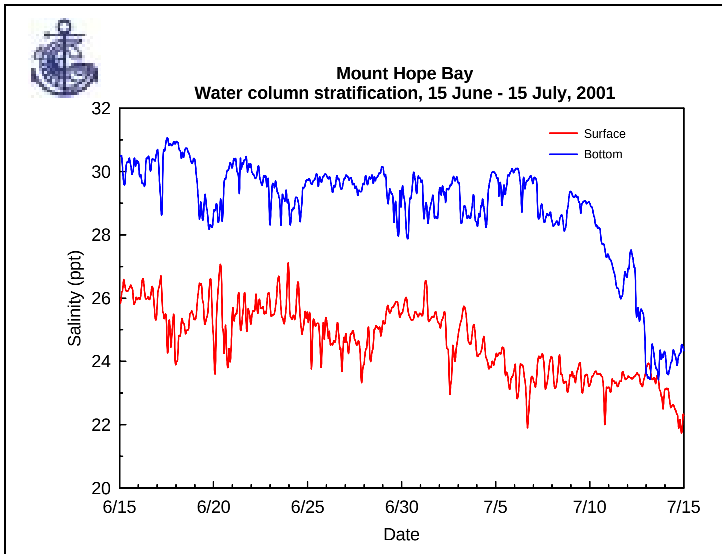


Figure 3.22. Salinity of surface and bottom waters at the SMAST mooring during mid-summer 2001. Note the strong salinity stratification, which is consistent with the low dissolved oxygen observed during this interval. (Data collection in collaboration with Narragansett Bay Commission and MCZM under EPA EMPACT Program.)

Available information supports a conceptual model of nutrient and organic matter cycling within Mt. Hope Bay that is driven by inorganic nutrients entering from the watershed primarily via the Taunton, Cole and Lee Rivers, and from the lower watershed wastewater discharges. These nutrients support high rates of phytoplankton production (MRI 1999), which likely exceed 600-800 g C m^{-2} y^{-1} (calculated from MRI data). These rates are indicative of nutrient-rich estuaries and coastal upwelling areas (Whittaker 1975). It appears that the high apparent rates of respiration within Mt. Hope Bay Estuary likely result from in situ production and decomposition. However, it appears from the inorganic N and P data collected in 1997-98 (MRI 1999) that even these high rates of production are insufficient to consume all of the available nutrients within the Bay waters, and the system remains nutrient-replete, possibly year-round. The nutrient levels within the Bay are consistent with observations that primary production within this system is generally light-limited (i.e., there is insufficient light to support photosynthesis by 1-2 meters depth). It appears that Mt. Hope Bay is likely a net contributor of inorganic nutrients and organic matter to greater Narragansett Bay.

c. Benthic animal communities

Benthic animals (animals living in the bottom sediments) are good indicators of system health. These animals are resident within the Bay and tend to integrate, over time, the environmental conditions in which they live. For this reason, benthic animals are typically used as bioindicators of system stability or stress (nutrient, oil, organic contamination, etc.). Benthic animal communities are being monitored by MRI as part of the Brayton Point Program. Samples are collected near the Brayton Point Power Station and near mid-Bay, off Spar Island (Figure 3.23).

We have used the Spar Island sampling station (station F) and the station 1+ km from the power plant (station C) to evaluate the general conditions within the central region of Mt. Hope Bay. At present these stations are dominated by *Ampelisca abdita,* and *Mediomastus ambiseta,* with lesser numbers of *Nucula annulata*. These species are indicative of an organic-matter-rich (somewhat stressed) environment, but do not indicate the highest level of stress (as, for example, would *Capitella*). These species are typical of areas of organic enrichment such as Boston Harbor or at distance from sewage outfalls. They do represent a food source for demersal fish and crustaceans.

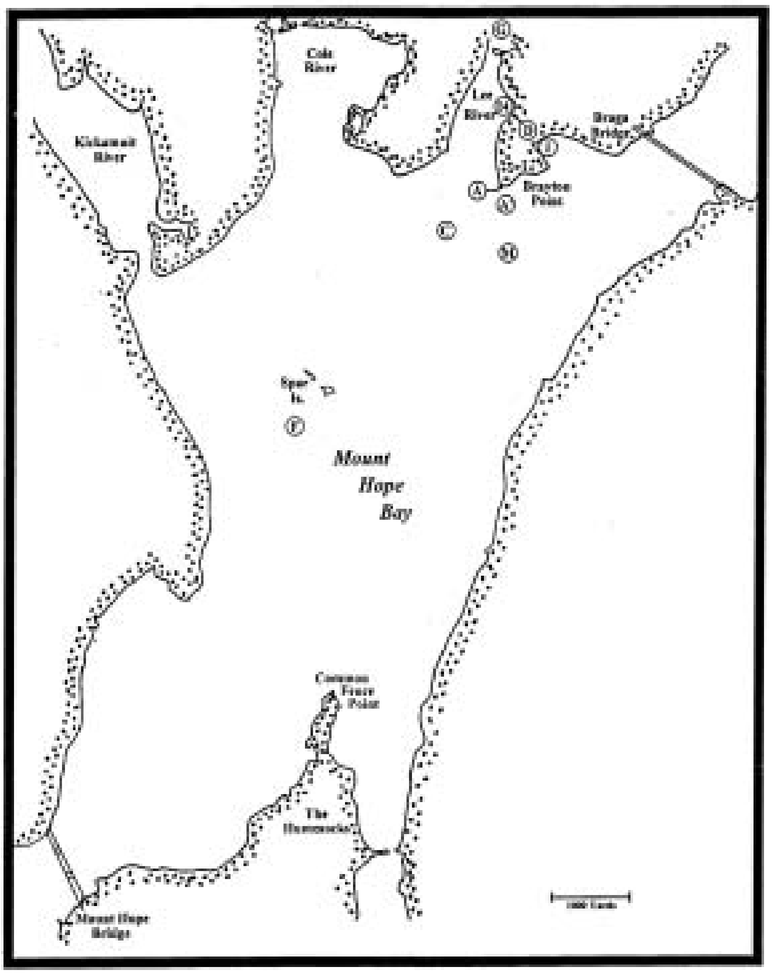


Figure 3.23. Location of benthic sampling (MRI 1999).

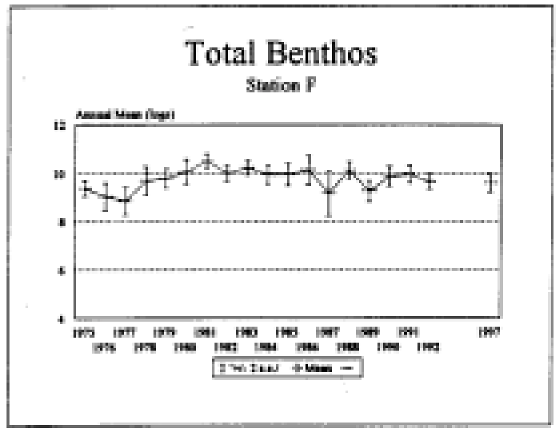
Overall, the Spar Island site tended to support between 5,500 and 36,900 total animals per square meter distributed among 17-36 species (Table 3.4). These data indicate a Phase II community as defined by Rhoads and Germano

Table 3.4. Benthic infaunal species and numbers within upper and mid-Mt. Hope Bay at Stations C, F, and I#4, March 1997-February 1998 (adapted from MRI 1999).

	C		F		I#4		Total	Mean
Date	Spec.	Indiv.	Spec.	Indiv.	Spec.	Indiv	Indiv.	Indiv.
March 10	16	5250	26	11350	28	59925	76525	25508
April 3	20	3300	24	5450	23	23300	32050	10683
April 23	17	4650	26	15325	28	39725	59700	19900
May 17	14	8850	33	19050	23	29400	57300	19100
June 4	23	10175	29	13375	19	10550	34100	11367
June 24	17	7275	26	29850	28	25625	62750	20917
July 16	18	4175	18	6100	27	14775	25250	8350
August 5	18	3075	27	15700	23	19300	38075	12692
August 26	18	3800	17	10625	19	9900	24325	8108
September 17	24	9475	17	11625	35	106550	127650	42550
October 10	29	9800	19	22975	39	119150	151925	50624
October 29	21	4575	22	17300	33	136600	158475	52825
November 20	26	11650	26	10650	41	151775	174075	58025
December 10	24	9000	24	9000	42	236750	254750	84917
December 24	31	19175	32	34325	42	135050	188550	62850
January 15	28	23750	30	35850	43	118425	178025	59342
February 3	21	10100	36	28250	41	177925	216275	72092
February 27	21	4900	28	24950	43	155000	184850	61617
Yearly Average	21		26		32		113591	37859
Indiv. Range		3300-		5450-		9900-	24325-	8108-
		23750		35850		236750	216275	84916

(1982). Phase II communities are represented by shallow burrowers which are typically deposit feeders (rather than filter feeders) and sediments which have limited oxygen penetration and a redox discontinuity layer near the surface. The species tend to be relatively short lived. Given the trends in watershed inputs, it is likely that these communities are transitional over the long term, and are moving towards smaller, shorter-lived species.

It appears that over the past 20 years there have been no dramatic shifts in the benthic animal community at mid-Bay. Total animals has remained nearly constant 1978-1992 and 1998 (Figure 3.24). Similarly, specific species, such as



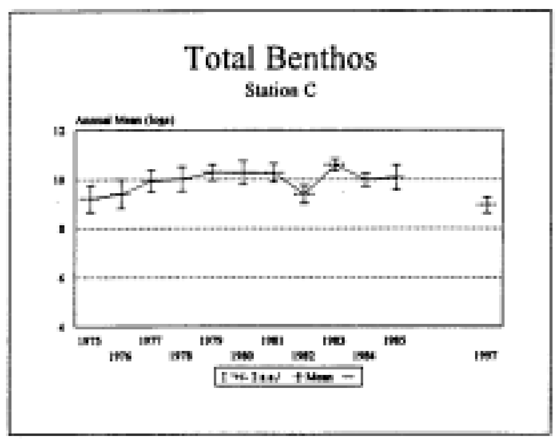


Figure 3.24. Annual variations in median densities of total benthos at stations F and C and annual log mean densities plus and minus 2 S.E. (MRI 1999).

Ampelisca and *Nucula* (Figure 3.25), have varied in numbers, but with no consistent trend. While *Mediomastus* may be experiencing a decline in numbers at present, it is still above the 1975 level (Figure 3.25). Therefore, it appears that

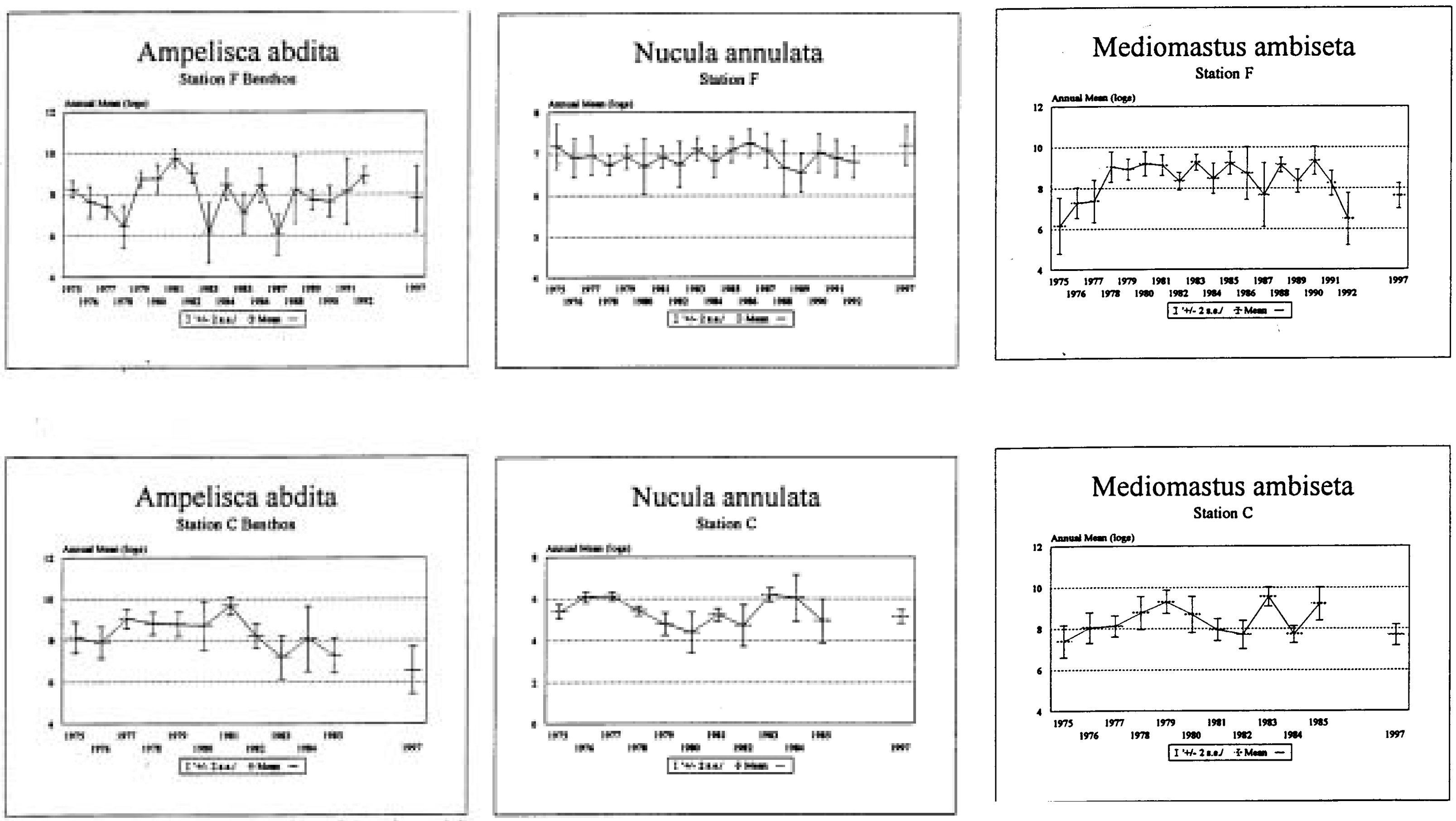


Figure 3.25. Annual variations in median densities of *Ampelisca abdita* (left panels), *Nucula annulata* (middle) and *Mediomastus ambiseta* (right) at stations F and C and annual log mean densities plus and minus 2 S.E. (MRI 1999).

conditions have been relatively “stable” in regard to benthic populations over the past two decades.   Stability, however, does not mean that environmental conditions are of high quality, only that sufficient changes have not occurred to alter the community structure in regard to either species or numbers of individuals. This finding is consistent with the limited water quality data that suggests that the present nutrient enriched conditions have existed for several decades.

6. Mt. Hope Bay Nutrients

There has been remarkably little work on nutrients in Mt. Hope Bay. This contrasts greatly with knowledge of the Rhode Island portion of Narragansett Bay, which, due to decades of research efforts by scientists and students of the Graduate School of Oceanography at the University of Rhode Island, is one of the most-intensively studied estuaries in the world.

A draft report that was part of an effort to develop an "Action Plan for the Taunton River Watershed" (complied by the Urban Harbors Institute, University of Massachusetts Boston) contains data on nutrients in Mt. Hope Bay (total nitrogen, ammonia, total phosphorus). In addition, Boucher (1991) studied total dissolved and particulate nitrogen and phosphorus in the Taunton River estuary. Together these sets of nutrient data indicate that nutrient levels in Mt. Hope Bay are high, with river flow and groundwater as important factors in nutrient variability. Boucher found decreasing nutrient concentrations moving downstream from the Taunton River to Mt. Hope Bay.

Pilson and Hunt (1989) presented data on a large variety of water quality parameters, including nutrients from samples throughout Narragansett and Mt. Hope Bays from cruises in October and November, 1985, and April and May, 1986. Included were data on dissolved inorganic nitrogen (ammonia, nitrate, nitrite) dissolved organic nitrogen, particulate nitrogen, dissolved silicate and phosphate, and total dissolved and particulate phosphorus. Pilson and Hunt found that dissolved organic nitrogen was the most abundant form of nitrogen. The more easily utilized dissolved inorganic forms such as nitrate, nitrite and ammonia declined in spring, presumably due to phytoplankton uptake. This decrease was proportionately greater for nitrogen than phosphorus, because the water column had N:P ratios typically less than the Redfield ratios for marine plankton. This suggests that Narragansett Bay is closer to being limited by nitrogen than by phosphorus. There was a decrease in nutrient levels moving from the Providence River and Mt. Hope Bay down to the mouth of Narragansett Bay. Measured inputs of nutrients from rivers and sewage outfalls were sufficient to replace the total mass of water-column nutrients of Narragansett Bay in 40-125 days, depending on season.

Marine Research, Inc., has analyzed dissolved inorganic nutrients at several sites in Mt. Hope Bay at least once per month from 1972 to 1985 (inclusive), and again from March 1997 through February 1998 (see MRI 1999). Ammonia concentration at the open-water Mt. Hope Bay stations followed the expected pattern of lowest concentration (1-2 μMol) in late winter/early spring increasing to greatest concentration (to near 10 μMol) in late summer/early autumn. Annual mean ammonia concentration was between 4.0 μMol (1973, 1974, 1976) and ca. 7.5 μMol (in 1979) during 1972 to 1985 monitoring. The 1997/98 annual mean ammonium concentration at the same stations, and analyzed with the same laboratory protocol, was ca. 12.5 μMol, a dramatic (ca. 2-fold) and statistically significant increase over 1972-1985 ammonia concentration observations. No explanation for the elevated 1997/98 ammonia concentration is apparent (MRI 1999). Mt. Hope Bay nitrate concentration displayed the expected pattern of a winter maximum (near 13 μM November through January) and summer minimum (near 1 μM or less in July). Comparison of mean 1972-1985 nitrate concentration (ca. 5 to 6 μM) to apparently elevated 1997-98 mean annual nitrate concentration (ca. 12 μM) yielded no statistically significant difference (MRI 1999). Mt. Hope Bay nitrate concentration in April to August 1997, however, was higher than the 1972-85 mean values for those months. Dissolved inorganic phosphate concentration in Mt. Hope Bay had an annual pattern of late winter/spring minima (near 1 μM or less) increasing to an autumn maximum (near 4 μM in October). Mean annual concentration figures of ca. 1.5 μM (1985) to <5 uMol (1980) were not significantly different from the 1997/98 mean annual value of ca. 2.1 μM (MRI 1999). Dissolved silicon concentration, important for diatom growth, was not reported in MRI (1999). Because of the 1986-1996 gap in nutrient sampling, whether the observed 1997/98 differences in Mt. Hope Bay ammonia and nitrate concentration are symptomatic of a long-term trend, or are anomalous to 1997/98, is not known.