Chapter 13
An Ecosystem-based Perspective of Mount Hope Bay

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13.1 Introduction

Water-column characteristics of Mount Hope Bay, a large shallow embayment located in the northeastern portion of Narragansett Bay (Fig. 13.1), are described here for selected periods during 1999–2003. These observations provide new information that adds to our knowledge base about the functioning of shallow estuarine systems, Mount Hope Bay's relevance to the functioning of the greater Narragansett Bay ecosystem, and Mount Hope Bay's relevance to management issues of the region. In this chapter, we explore the potential links among the structure, function, and composition of the Mount Hope Bay ecosystem, and possible ecosystem-based management approaches that may be used for restoring lost functions of the bay ecosystem. Of particular importance to this discussion is the fact that the coastline of Mount Hope Bay is shared by two states: Rhode Island and Massachusetts. Hence, the Mount Hope Bay ecosystem provides unique challenges to those management strategies that adopt guiding principles of ecosystem-based management.

13.2 Physical Setting and Land Use

Mount Hope Bay is a large shallow embayment in the uppermost, northeastern corner of Narragansett Bay. The bay connects with Narragansett Bay proper at the East Passage, and stretches approximately 11 km north and east to the mouth of the Taunton River estuary. Surface waters of Mount Hope Bay cover an area of approximately 35 km^2 (Kauffman and Adams, 1981) with a mean water column depth and volume of 5.7 m and 2.0×10^8 m^3 at mean low water, respectively (Chinman and Nixon, 1985). Bathymetrically, Mount Hope Bay

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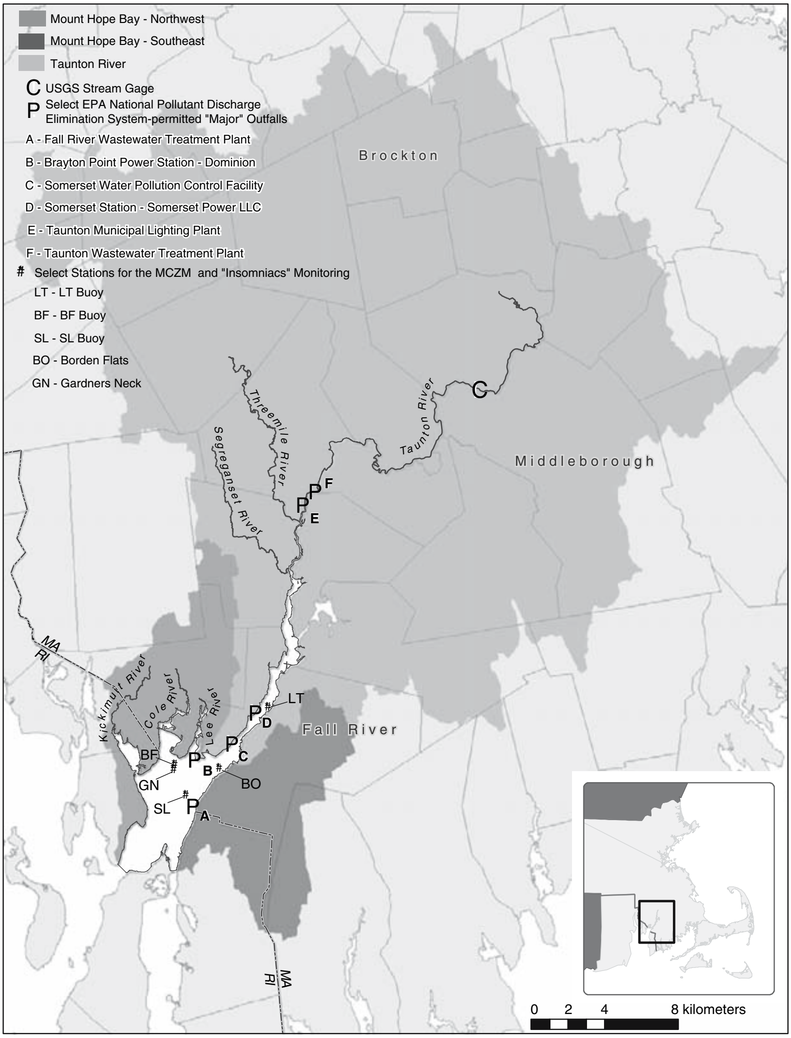

Fig. 13.1 Mount Hope Bay region, including three watersheds (Taunton River, Northwest Mount Hope Bay, and Southeast Mount Hope Bay), and the locations of autonomous monitoring buoys (#), WWTFs (A–F), major NPDES sites (P), and the USGS Taunton River gauge (C).

consists of two regions: the shallow flat area that occupies the north and western area, and the deeper waters of the main shipping channel that runs south–north along the eastern boundary. The Taunton River is the second largest river in Massachusetts and flows approximately 64 km before draining into Mount Hope Bay.

Approximately 70% of Mount Hope Bay's surface water lies within the boundary of the state of Rhode Island, yet nearly the entire watershed is located within the state of Massachusetts. The Taunton River watershed is the largest of the three sub-watersheds (Fig. 13.1), representing 89% of the total drainage area for this system. The US Geological Survey (USGS) maintains three gauges within the Taunton River watershed; one each located in the Taunton, Three Mile, and Segreganset Rivers. These gauges account for approximately 60% of the total drainage area for the entire Mount Hope Bay watershed. The annual mean discharge of the gauged portion of the Taunton River derived from monthly averages for the period of record (USGS gauge, Bridgewater, MA; 1927–2003, not inclusive) is 1.08×10^7 m^3 d^{-1}. The monthly averaged flow from the second largest tributary below the USGS gauge (Three Mile River) was found to significantly co-vary with Taunton River flow ($r^2 = 0.99$; Fig. 13.2) for comparable years (1967–2003). Using USGS reported annual flows for the Taunton River near Bridgewater, MA, and linearly extrapolating to the total drainage area of the Mount Hope Bay watersheds (Pilson, 1985), the estimated total annual riverine input into Mount Hope Bay is 2.5×10^7 m^3 d^{-1}. When compared to mean daily flows of major rivers (e.g., Blackstone and Pawtuxet) discharging into Narragansett Bay (Nixon *et al.*, 2005), the Taunton is the

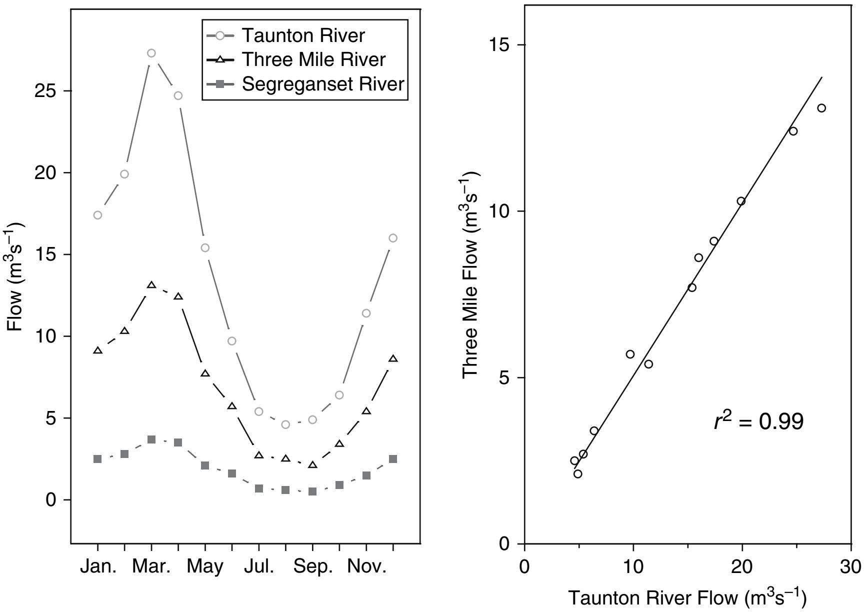

Fig. 13.2 USGS monthly discharge summaries for each period of record for the Taunton, Three Mile, and Segreganset Rivers in the Taunton River watershed and simple linear regression plot between the Taunton and Three Mile Rivers. Mean monthly averages from the period 1967–2003 were derived from USGS gauged flows *(http://ma.water.usgs.gov/basins/tauntonstw.htm)*.

Table 13.1 Estimates of freshwater inputs to Mount Hope Bay (USGS gauge data and MAGIS data layers).

Surface Area (km^2)	Taunton (gauged)	676
	Three Mile (gauged)	217
	Segreganset (gauged)	27
	Total	1380
Annual mean flows ($\times 10^6$ m^3 d^{-1}) adjusted mL, for non-gauged portion of watershed	Taunton	2.48
	Wastewater[a]	0.12
	CSOs[b]	0.01
	Direct Rainfall	0.01
Estimated total freshwater flows	2.6×10^7 m^3 d^{-1}	

[a] Below the USGS Taunton River gauge near Brockton.
[b] Prior to the Fall River CSO abatement.

largest riverine source of fresh water to the greater Narragansett Bay ecosystem. A summary of freshwater discharge to Mount Hope Bay from the watersheds is provided in Table 13.1.

13.2.1 Land Use Classification

There are three major sub-watersheds in the Mount Hope Bay system: the Taunton River, Mount Hope Bay–Northwest, and Mount Hope Bay–Southeast (Fig. 13.1). The 1:24,000 scale land use data for 1985 and 1999 (MA) and for 1988 and 1995 (RI) were rectified to coincide for analytical purposes, but are herein referred to as 1985 and 1999, since 97% of the watershed is within Massachusetts. With a focus on water quality, 29 MacConnell classes for Massachusetts and 31 Anderson classes for Rhode Island were aggregated to form eight land use bins (Table 13.2).

13.2.1.1 Mount Hope Bay Watershed Land Use Results

Between 1985 and 1999, rates of low-density residential development were the greatest component of the developed land category for each of the three Mount Hope Bay sub-watersheds (Table 13.3). Medium-density residential development (i.e., greater than or equal to 0.25 acre and less than one acre) also increased significantly, with a total net gain of 27 km^2 (21%). From an N loading perspective, forest loss and increases in areas classified as urban and residential improve rapid N transport through watersheds (Alexander *et al*., 2002).

13.2.1.2 Sub-watershed Results

Between 1985 and 1999, rates of low-density residential development were the greatest component of the developed land category for each of the three sub-

Table 13.2 Land use class descriptions for Mount Hope Bay watersheds.

Land Use Class[a]	Land Use Description
Agricultural	Cropland, pasture, orchard, cranberry bog, nursery
Disturbed Open	Strip mine, quarry, gravel pit, landfill, junkyard
Maintained Open	Parks, playfield, playground, marina, golf course, tennis court, swimming pool, power line, pipeline, cemetery, vacant undeveloped land (urban)
Natural Open	Forest, salt marsh, forested and non-forested freshwater wetland, abandoned agricultural field, meadow
Residential Low	Lots greater than or equal to 1 acre
Residential Medium	Lots greater than or equal to 0.25 and less than 1 acre
Residential High	Lots less than 0.25 acre
Urban (i.e., Commercial, Industrial, Transportation)	Shopping center (i.e., primary sale of products and services), manufacturing, industrial parks, airport, divided highway, railroad, freight storage, dock, pier, storage tank

[a] Land use classes were derived from the aggregation of MacConnell (1973) and Anderson *et al*. (1976) land use classification systems.

watersheds, though medium and high residential land use categories also featured gains. Table 13.4 shows the Taunton River sub-watershed with an increase in residential low density land use of 45 km^2 (51%). The northwest and southeast sub-watersheds show respective increases in the residential low category by 32 and 25%, but these sub-watersheds make up just 13% of the total land area in the Mount Hope Bay watershed. Half of the 25 inclusive cities and towns in the watershed had greater than 60% of their buildable land developed by 2001 (MA EOEA, 2003).

The largest urban centers are Fall River (located in the southeast sub-watershed) with a human population of 92,000 and Brockton (located in the northern reaches of the Taunton River sub-watershed) with 94,000 (US Census

Table 13.3 Mount Hope Bay watershed land use trends.

	Land Use Class[a]	1985 Area (km^2)	1999 Area (km^2)	Change (km^2)	Change (%)
Mount Hope Bay	Agricultural	138	118	−20	−15
(1,550 km^2)	Disturbed open	18	14	−4	−24
	Maintained open	48	46	−2	−4
	Natural open	994	927	−67	−7
	Residential high	48	53	5	10
	Residential medium	96	143	47	49
	Residential low	130	156	27	21
	Urban	77	91	15	19

[a] Land use classes were derived from the aggregation of MacConnell (1973) and Anderson *et al*. (1976) land use classification systems.

Table 13.4 Mount Hope Bay sub-watershed land use trends.

	Land use class[a]	1985 Area (km^2)	1999 Area (km^2)	Change(km^2)	Change (%)
Taunton River 1,370 km^2	Agricultural	122	104	−18	−14
	Disturbed open	17	13	−4	−24
	Maintained open	42	40	−2	−4
	Natural open	891	826	−65	−7
	Residential high	32	36	4	13
	Residential medium	89	135	45	51
	Residential low	116	140	24	21
	Urban	63	77	14	23
Southeast (SE) 93 km^2	Agricultural	4	3	0	−10
	Disturbed open	0	0	0	4
	Maintained open	4	4	0	−2
	Natural open	56	54	−1	−3
	Residential high	10	10	0	2
	Residential medium	2	2	0	25
	Residential low	7	8	1	16
	Urban	10	10	0	0
Northwest (NW) 86 km^2	Agricultural	13	11	−2	−16
	Disturbed open	1	1	0	−40
	Maintained open	3	3	0	3
	Natural open	48	47	−1	−2
	Residential high	6	7	0	6
	Residential medium	5	6	2	32
	Residential low	7	8	1	17
	Urban	4	4	0	12

[a] Land use classes were derived from the aggregation of MacConnell (1973) and Anderson *et al*. (1976) land use classification systems.

Bureau, 2000). These municipalities are served by the two largest wastewater treatment facilities (WWTFs) in the Mount Hope Bay watershed.

13.3 Human Uses and Values

Mount Hope Bay has been used historically for fishing, navigation, and shipping, though today fisheries resources remain largely unavailable for human use because of pollution, habitat loss, and changes in biological components similar to those observed for the larger Narragansett Bay ecosystem (MRI, 1983; Gibson, 1996).

The upper reaches of Mount Hope Bay, including the lower Taunton River, were used for the harvest of oysters (*Crassostrea virginica*) and became a viable commercial fishery in the late 1800s (Belding, 1921). By 1907, however, oysters from portions of the Taunton River estuary were considered enough of a threat to human health because of pollution that commercial interests in the fishery ended.

River herring (*Alosa pseudoharengus* and *A. aestivalis)* supported another important early fishery, and early local news accounts report of Native Americans using the Taunton River each spring for harvesting river herring (Belding, 1921). By the turn of the 20th century, the Taunton River and its tributaries were considered to be substantially polluted with sewage and industrial waste. Because of declining herring stocks and antiquated uses (fish oils were used in the manufacturing of paint and cosmetics and medicinal applications), little demand existed for the river herring fishery, and commercial interests in Taunton River herring ceased altogether by the 1960s. Today, the Mount Hope Bay system is recognized by the Commonwealth of Massachusetts as an important habitat for alewives and other herring species. The Nemasket River for instance, located within the Taunton River watershed, contains one of the most prolific herring runs in Massachusetts. Efforts by state and federal agencies, as well as other non-governmental organizations, are being conducted to remove impediments to anadromous fish and return the Taunton River and its tributaries to a more pre-industrial state. Recent concerns about dramatic declines in the number of herring returning for spawning have resulted in a moratorium in Massachusetts on the harvesting, possession, and sale of river herring through 2008.

At present, human use continues primarily as commercial shipping (coal supply and cargo shipping), waste management (municipal wastewater disposal, stormwater runoff, combined sewer overflows and industrial cooling), and secondary recreation (boating and fishing). The Port of Fall River, which is located in upper Mount Hope Bay, is the second largest cargo shipping port in Massachusetts. There are seven Massachusetts-based wastewater treatment facilities within the watersheds of Mount Hope Bay. From monthly mean data reported to the US Environmental Protection Agency (US EPA) for 2002, the two large WWTFs serving the municipalities of Fall River and Taunton averaged an annual discharged of treated effluent of 32 and 8.4×10^6 m^3, respectively, directly into Mount Hope Bay. Based on effluent reporting data to EPA for 2004, the Brockton WWTF, located in the upper portion of the Taunton River (above the USGS gauge in Bridgewater) adds an additional 23×10^6 m^3 y^{-1}. Prior to recent improvements by the City of Fall River, municipal combined sewer overflow (CSO) outfalls discharged approximately 4.9×10^6 m^3 of rainwater runoff and partially treated sewage to Mount Hope Bay each year. The freshwater volumes from these sources below the USGS gauging station on the Taunton River are minor (about 8.6×10^7 m^3 y^{-1}) when compared to the Taunton's discharge, which is estimated to be below 8×10^9 m^3 y^{-1}, but may be important with respect to contaminant loadings to the bay.

Because of the shallow nature of Mount Hope Bay and its relatively large surface area, water temperature responds readily to changes in heat flux

(Mustard *et al.*, 1999). Late summer temperature averages (using infrared satellite imagery from 1984 to 1995) found Mount Hope Bay to be 0.8°C warmer than other shallow embayments in the upper Narragansett Bay region. Industrial cooling to the bay is dominated by 1.4×10^{10} W of heat discharged annually from the Brayton Point Electric Power Station (US EPA, 2003; Fan and Brown, 2006). The Brayton Point facility is a 1600-MW electric power facility located on the northern shore of Mount Hope Bay. Spaulding and Swanson (Chapter 8) and Chen *et al.* (Chapter 9) detail circulation impacts of this thermal input to Mount Hope Bay. Fan and Brown (2006) produced a heat budget for Mount Hope Bay using simple box models and found that the Taunton River contributed negligible heat load (~4%) when compared with the heat load from the Brayton Point facility. The US EPA identified the Brayton Point facility as the major contributor to significant detrimental changes observed in the aquatic and biological conditions of Mount Hope Bay (US EPA, 2002). By 2002, the Brayton Point facility was withdrawing bay water at a rate of approximately 4×10^6 m^3 d^{-1}. In 2003, EPA issued a new National Pollution Discharge Elimination System (NPDES) permit that identified near total reductions in both heat loading and water withdrawals (96% and 94%, respectively) as necessary in order to achieve compliance with state and federal regulations as outlined in the NPDES section of the Clean Water Act (33 U.S. Code §§ 1342).

13.4 Environmental Management

13.4.1 Designated Uses

Management strategies for aquatic ecosystems typically rely on water quality standards as a starting point for implementing measures that mitigate anthropogenic impacts. These impacts are often evaluated under the umbrella of established “designated uses” (e.g., aquatic life habitat, fish consumption, shellfish harvesting, and swimming) and have traditionally focused on water quality. Currently, water quality standards that guide local management contain two important elements: designated beneficial use or uses (e.g., recreation, water supply, fishing and others) and numerical or narrative targets for specific contaminant levels above which contaminants have been shown to interfere with the ecosystem’s healthy, natural biological community.

Mount Hope Bay shares borders with Rhode Island and Massachusetts and use designations are distinct to each jurisdiction. The differences among each state’s class-specific criteria are highlighted in Table 13.5. A move towards ecosystem-based management strategies may require states that share ecosystems to redefine designated uses and align supporting criteria to be more sensitive to ecosystem functioning.

Table 13.5 Comparison of class-specific water quality criteria for marine surface water classifications among Massachusetts and Rhode Island states. Compiled from the current Code of Massachusetts Regulation, Massachusetts Division of Water Pollution Control (314CMR 4.00) and RIDEM (2000).

State	Rhode Island			Massachusetts		
	SA	SB/SB1	SC	SA	SB	SC
DO (mg L^{-1})	≥6 except as naturally occurs	≥5 except as naturally occurs.		≥6 unless background conditions are lower; ≥75% saturation due to a discharge	>5	≥5 for at least 16 h in a 24-h period
Temp (°C)	28.3 max. Raised no more than 0.9 (16 June–September) Raised no more than 2.2 (October–16 June) No increase above the recommended limit on most-sensitive water use.			29.4 max. 26.7 daily, temperature rise due to discharge <0.8	29.4 max. 26.7 daily	29.4 max. rise in temperature due to discharge <2.8
Fecal C (100 mL^{-1})	14 and 49	50 and 500	None in such concentrations that would impair specified use	14 and 43[a]	88 and 260[a]	1,000 and 2,000
Solids	Discharges of sludge, solid refuse, floating solids, oil, grease, scum are not allowed		None in such concentrations that would impair specified use	Surface waters shall be free from floating, suspended, and settleable solids in concentrations or combinations that would impair any use assigned, would cause aesthetically objectionable conditions, or impair benthic biota or degrade the chemical composition of the bottom		

Table 13.5 (continued)

State	Rhode Island			Massachusetts		
	SA	SB/SB1	SC	SA	SB	SC
Nutrients	Concentrations shall not exceed levels that would impair any usages or cause undesirable or nuisance aquatic species associated with cultural eutrophication, be preventive or minimize accelerated or cultural eutrophication. Total phosphorus, nitrates and ammonia may be assigned site-specific limits based on reasonable best available technologies. Where waters have low tidal flushing rates, applicable treatment to prevent or minimize accelerated or cultural eutrophication may be required for regulated non-point source activities.			Shall not exceed the site-specific limits necessary to control accelerated or cultural eutrophication		

[a] Geometric mean or median of Most Probable Number method, second number reflects the value at which 10% of samples can not exceed. Different standards (higher) apply for those areas not designated for shellfishing.

13.4.2 Environmental Monitoring

State environmental managers continue to design monitoring programs that conform to their jurisdictional boundaries, probably due in part to the traditional use of jurisdictional boundaries in state land management practices. Aquatic systems that transcend these boundaries are often not evaluated or monitored in a manner that allows for the application of sound ecosystem-based principles, as evidenced in Curley *et al.* (1974).

Since the early 1970s, water quality monitoring undertaken in Mount Hope Bay has been conducted to assess impacts caused by water usage for condenser cooling by electric power generation and from wastewater discharges from local municipalities. By the mid-1990s, dramatic changes were observed in the fish populations of Mount Hope Bay (Gibson, 1996). Trawl survey abundance trends for a number of species connected the collapse of winter flounder stocks in Mount Hope Bay to coincidental increases in power generation at the Brayton Point station (Gibson, 2002).

Near continuous monitoring of water quality parameters from efforts sponsored by the Brayton Point facility in 1997 revealed dramatic changes of water quality in both the surface and bottom water of upper Mount Hope Bay. Episodic anoxic and low dissolved oxygen levels were observed in surface and bottom waters for two fixed monitoring stations during a 6-week, late-summer monitoring period near the facility. Figure 13.3 shows the details of dissolved oxygen and salinity concentrations during the last week in August, 1997. On several occasions, dissolved oxygen levels at both stations fell below 3 mg L^{-1}, a level below which aquatic biologists believe to be detrimental to supporting healthy ecosystems (Baden *et al.*, 1990; Johansson, 1997). Of particular interest in the 1997 dissolved oxygen data is surface concentrations that were lower than the corresponding dissolved oxygen concentrations in the bottom waters at the Gardners Neck site, near where the Taunton River enters into Mount Hope Bay. Historically, dissolved oxygen values below 3 mg L^{-1} have been reported for areas in Mount Hope Bay specifically in bottom waters of the lower and upper reaches of the tidally influence Taunton River (Curley *et al.*, 1974; MRI, 1983).

In Mount Hope Bay, impairment of use is often linked with excess contamination by fecal coliform, heat, suspended matter, nutrients, or chemicals of environmental concern, and manifested by changes in the biological community, related losses of essential aquatic habitat, low dissolved oxygen, or fish kills. Excessive nutrient loading to Mount Hope Bay has been identified as a major stressor by resource managers since the late 1960s (Curley *et al.*, 1974). Because of increases in the urbanization of coastal areas, many marine embayments today may be receiving nutrient loads in excess of their capacities to adequately assimilate these pollutants (Bricker *et al.*, 1999; Howarth *et al.*, 2000; Bowen and Valiela, 2001; Howarth *et al.*, 2002). The resultant consequence, referred to as eutrophication, is frequently becoming the source of some

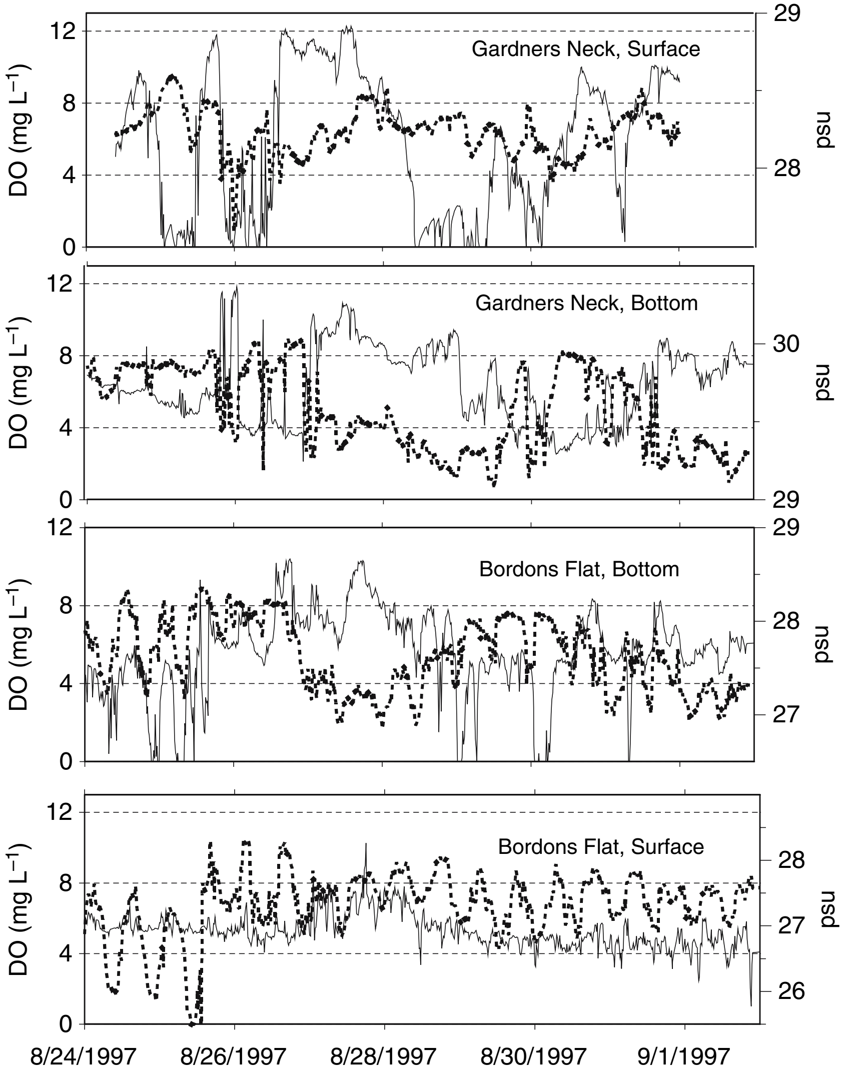

Fig. 13.3 Water column observations of salinity (dashed line) and dissolved oxygen (solid line) at two stations in upper Mount Hope Bay. Gardners Neck (41.7013N, 71.2130W) and Bordons Flats (41.7022N, 71.1755W).

of the most widespread and serious impacts occurring in coastal waters (Diaz and Rosenberg, 1995; NRC, 2000; Bricker *et al.,* 2006).

For upper Narragansett Bay, the ability of Rhode Island WWTFs to meet end-of-the-pipe water quality standards (3–8 mg L^{-1}) are currently being evaluated as a means to reduce nitrogen loading and achieve desired water quality goals. Furthermore, efforts are underway by the Massachusetts Department of

Environmental Protection's (MA DEP) Estuaries Project to develop a nitrogen TMDL for Mount Hope Bay. The Massachusetts process attempts to identify acceptable water quality characteristics, namely site-specific water column N concentrations known to be supportive of key aquatic habitats, and link to an understanding of the system's hydrodynamics in order to determine allowable levels of nitrogen loading. Monitoring of water column nutrient species and freshwater flow from most of the streams and rivers by MA DEP is in progress during the preparation of this chapter.

13.5 Selected Water Quality Observations, 1999–2003

The Massachusetts Office of Coastal Zone Management (MCZM) began a pilot project designed to document some of the occurrences of hypoxia and/or anoxia in Mount Hope Bay waters, and to assess the potential of cumulative effects from multiple stressors on the biological integrity of the bay ecosystem. MCZM targeted their efforts to discerning the role of the Taunton River and its watershed on the frequency and magnitude of hypoxic events in upper Mount Hope Bay, and to begin evaluating the importance of water quality on observed changes in the biology of the ecosystem. Monitoring was designed to answer questions such as: What are the sources and/or mechanisms controlling low dissolved oxygen in surface and bottom waters? What are the timing, duration, and frequency of these events, and are they ecologically significant? Are the Taunton River and its watershed significant contributors to the low dissolved oxygen observed in Mount Hope Bay?

Observations from water quality surveys in Mount Hope Bay are from near-continuous monitoring via autonomous modules deployed by MCZM in the Taunton River estuary as a pilot project in 1999. This project was later expanded to include stations located in upper Mount Hope Bay near the Lee and Cole Rivers, and in waters straddling the Massachusetts–Rhode Island border near the center of Mount Hope Bay (Fig. 13.1). The pilot project was further expanded in 2000 to include a survey of contemporary levels of nutrients, chlorophyll, particulate organic carbon, and total suspend matter (TSM) in the water column. As part of this analysis, data from bay-wide dissolved oxygen surveys conducted in the Mount Hope Bay system during the MCZM pilot are presented.

13.5.1 Procedure and Methods

Commercially available autonomous environmental monitoring buoys (YSI/Endeco) were deployed in Mount Hope Bay by MCZM beginning in 1999 in the lower Taunton River, and in the central and upper portion of Mount Hope Bay the following year. These systems were fitted with sondes programmed to monitor salinity, temperature, dissolved oxygen, pH, and on occasion, turbidity, chlorophyll fluorescence, and photosynthetically active radiation (PAR: 390–710 nm) every 15 min. PAR light attenuation data were collected using LICOR® 2π sensors. All data were reviewed for adherence to initial and continuing calibration. Monitoring buoys were typically deployed in late spring/early summer and sonde performance checked every two weeks, or weekly when bio-fouling significantly increased near the end of July and into August. Sondes were swapped out with pre-calibrated replacements, or removed for a few days and serviced prior to re-deployment.

For dissolved oxygen, sensors were checked for in-air 100% saturation by wrapping the sensor housing with a wet towel and obtaining a reading after minimum equilibration time of 3 min. Periodic discrete water samples were obtained during field surveys at sensor depth and compared with the determination of dissolved oxygen concentrations via classic Winkler procedure (Strickland and Parsons, 1972). Salinity calibration and periodic performance checks were conducted using conductivity standards (Myron L Co.) for brackish (16.6 mS) and coastal marine waters (30.1 mS). Periodic performance checks were conducted at the beginning of each field excursion using a secondary standard of Massachusetts Bay water (30.44‰) that had been collected and stored in a large carboy (20 L) and periodically re-analyzed and compared to simultaneous analyses with the University of MA/Boston Seabird® CTD system.

Water quality surveys conducted during the late summer through early fall in 2000 included analysis of dissolved inorganic nutrients (DIN) from ten stations in Mount Hope Bay. Each survey included hydrocasts for temperature and salinity, and the collection of discrete water samples for chlorophyll *a* (Chl *a*), DIN ($NO_2 + NO_3$, NH_3, O-PO_4, SiO_4, etc.), particulate organic carbon and nitrogen (POC/N), and TSM at the surface, middle (depth permitting), and bottom of the water column. Discrete samples were collected using Niskin water samplers (General Oceanics) and transferred to acid-cleaned (HCl) 2-L polycarbonate bottles. Subsamples for nutrients were syringe-filtered in the field, the filtrate quickly frozen using dry ice and stored frozen for later analysis. The remaining sample was filtered (Whatman GF/F glass microfiber media, nominal pore size 0.7 μm) in the field and the filters returned to the lab for processing of chlorophyll, POC/N, and TSM. Analyses for DIN and Chl *a* were performed at the University of MA/Boston. Analytical methods, desired method accuracy, and detection thresholds for monitoring parameters are listed in Table 13.6.

Data from Prell *et al.* (2004), as well as MCZM's DIN surveys, are used here to describe water column conditions during the late summer periods of 1999–2003. The resultant dissolved oxygen and surface water nutrient contour plots present nutrient concentration gradients generated using the kriging option in Surfer® (Golden Software, Inc.). Kriged concentration gradients are derived from a regression technique used in geostatistics to approximate or interpolate data for representation in two- and three-dimensional space. The kriging method was used to interpolate the sampling grid because it is a less sensitive method to the non-random sampling design (Cressie, 1991). Because the spatial interpolation is a minimum variance-based estimation technique,

Table 13.6 Target accuracy and detection limits for laboratory measurements.

Parameter	Method	Reference	Accuracy[d]	Lower Detection ($\mu g\ L^{-1}$)
Ammonia	Phenol/hypochlorite (autoanalyzer)	Guffy *et al.* (1988)	5%	1
Nitrite + nitrate	Cd–Cu reduction/ sulfanilamide/N-ED HCl_2	Guffy *et al.* (1988)	5%	1
Total particulate carbon/ nitrogen	Elemental analyzer	Hedges and Stern (1983)[a]	5%[e]	6
Reactive silicate	Molybdatium blue autoanalyzer	Guffy *et al.* (1988)	5%	3
Orthophosphate	Molybdenum Blue (autoanalyzer)	Guffy *et al.* (1988)	5%	3
Chlorophyll *a*	Acetone extraction fluorometric	Strickland and Parsons (1972)[b]	10%	0.01
Total suspended solids (TSS)	Desiccator, gravimetric microbalance	UMass Boston protocol[c]	5%	0.5 mg L^{-1}

[a] Modified for the Perkin–Elmer Model 2400 CHN Elemental Analyzer.
[b] pp. 201–203.
[c] Using 0.4 μm polycarbonate (Poretics) membrane filtration.
[d] Accuracy based on results of laboratory control standards and spiked samples.
[e] Precision based on relative percent difference of sub-sample analysis. No spikes are available for POC/PON analysis.

these concentration maps ultimately contain less variability than the actual sampling data, which should be noted when drawing conclusions from these plots. The uncertainties associated with these estimates can be large, especially for interpolations with lower sample density. Interpretation must be sensitive to two important points: (1) a small portion of the water column was sampled and (2) these descriptions generalize processes that occur over a period of many hours (typically 8) during which significant tidal oscillation has occurred.

13.5.2 Autonomous Water Quality Monitoring

Results from autonomous monitoring of salinity, temperature, and dissolved oxygen from 2000 to 2003 in upper Mount Hope Bay are summarized from three stations: culminating in 2003 with monitoring buoy systems in the lower Taunton River, the bottom waters off of Brayton Point in an area labeled as Brayton Flats, and adjacent to the shipping channel near the Fall River WWTF straddling the state border, termed the State Line station. In 2003, these three stations were monitored as a supplemental to EPA's winter flounder habitat characterization efforts in Mount Hope Bay (CoastalVision, 2004).

For most of the summer, Mount Hope Bay surface waters (~20–27‰) remain somewhat isolated from the deeper, more saline water (~30‰) of greater Narragansett Bay. In 2003, bay waters near the State Line station remained stratified with respect to salinity and temperature from the beginning of monitoring (late July) through mid-September, except for a brief period near

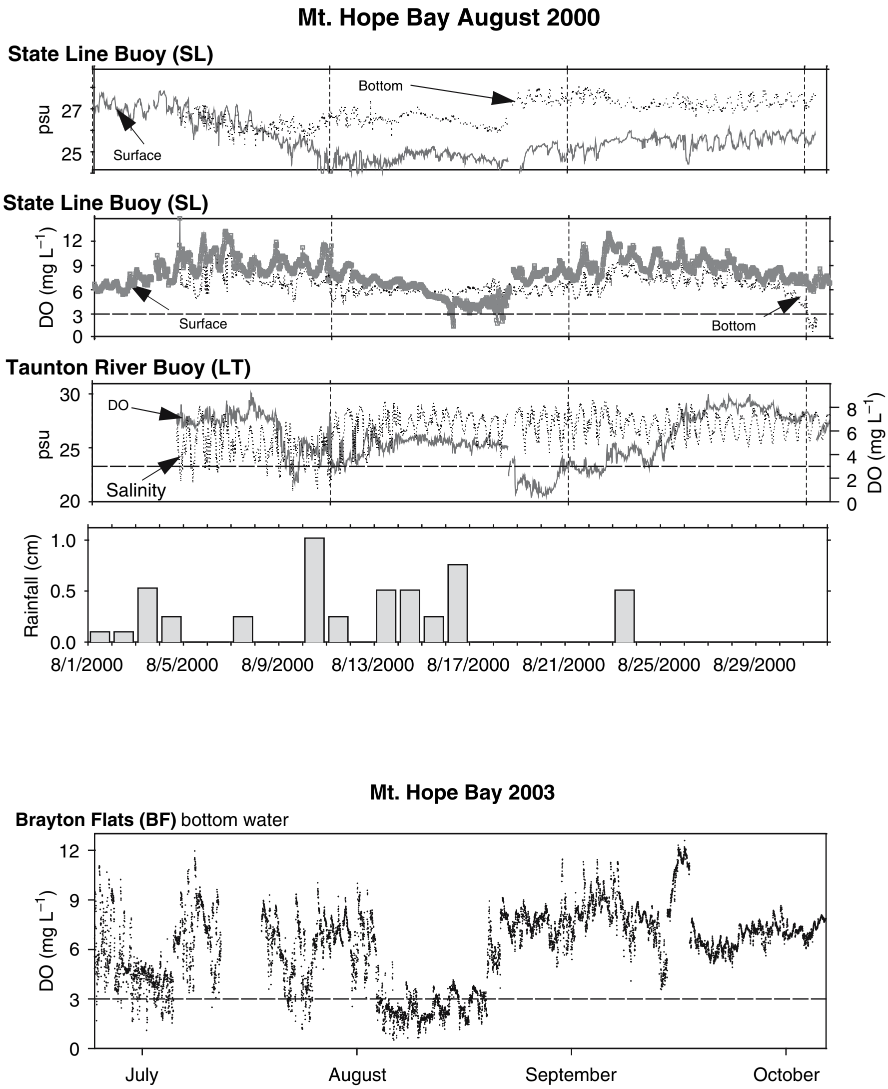

Fig. 13.4 Water quality observations derived from autonomous monitoring buoys for selected periods in 2000 and 2003.

the end of June. Similar observations for continued salinity-induced stratification during summer periods were reported at the State Line station for 2001 (Howes and Sundermeyer, 2003). Mixing periods may persist for several days as evidenced by the convergence of salinity concentrations in surface and deep waters for August 2000 (Fig. 13.4). Surface water temperatures at all stations typically exceeded 25°C during late summer.

For most of the monitoring period, Mount Hope Bay showed signs of relatively healthy dissolved oxygen levels (>4 mg L^{-1}). However, low dissolved oxygen concentrations were observed at all autonomous monitoring stations, typically falling below critical levels in late summer (see Fig. 13.4). Though the autonomous data for Mount Hope Bay is not inclusive for 1999–2003, the most critical period with respect to dissolved oxygen appears to occur during August when freshwater runoff is low (see Fig. 13.2), heat flux is near maximum (Fan and Brown, 2006), and water column stratification is most pronounced. In several instances during the late summer, episodic dissolved oxygen concentrations at or below the critical levels of 2–3 mg L^{-1} were observed in the upper portion of the water column (Fig. 13.4). The role of the Taunton River on summer dissolved oxygen concentrations in Mount Hope Bay may be important, and is implied by the data from the lower Taunton River station (Fig. 13.4, top panel, center). Here, water column dissolved oxygen concentrations <3 mg L^{-1} persisted for nearly 40 h in mid-August, 2000. Recovery of dissolved oxygen concentrations followed a series of step-like increases over a period of 5–6 days. However, this transient low dissolved oxygen event was not evident at the mid-bay State Line station where dissolved oxygen concentrations were observed to be $\geq$6 mg L^{-1}.

Dissolved oxygen concentrations reported for the Brayton Flats station in 2003 (CoastalVision, 2004) show episodic behavior in the shallow region near the Lee and Cole Rivers in upper Mount Hope Bay (Fig. 13.4, lower panel), with two pronounced periods of depressed dissolved oxygen concentrations (early July and August). During the more severe August 2003 event, dissolved oxygen levels in the bottom waters at Brayton Flats were typically less than 3 mg L^{-1}, lasting for a period of 2 weeks, with the lowest concentrations near 0.6 mg L^{-1}. Comparable water quality data for the lower Taunton River is not as complete during this period, but show concentration levels above 4 mg L^{-1} at least until August 15, 2003, well after the onset of low dissolved oxygen at Brayton Flats. Dissolved oxygen concentrations in bottom waters at the State Line station during this period were also near or above 4 mg L^{-1} (CoastalVision, 2004). A clearer understanding of seasonal circulation in upper Mount Hope Bay, and an additional monitoring station near the entrance to the Taunton River estuary, is needed in order to better understand the nature of these surface water low dissolved oxygen observations and their significance to the ecology of the system. Chen *et al.* in Chapter 9 of this volume provide initial model results for Mount Hope Bay, and provide insight into requirements for future progress in this direction.

13.5.3 Summer 1999–2003 Mount Hope Bay Dissolved Oxygen Surveys

Synoptic surveys designed to assess spatial dissolved oxygen levels (along with standard water quality parameters such as salinity and temperature) at over 100 stations in Narragansett Bay were performed during summer periods from 1999 to 2003 (Prell *et al.*, 2004). Further details regarding these data are presented by Saarman *et al.* and Deacutis in Chapters 11 and 12, respectively.

Water column observations of salinity and dissolved oxygen collected in Mount Hope Bay during this period were used to estimate synoptic water quality concentration fields and represent late summer conditions for Mount Hope Bay. Typical transects extend from Narragansett Bay stations beyond the Mount Hope Bridge in the south, to just north of the Braga Bridge in the lower Taunton River estuary along the axis of the main shipping channel (Fig. 13.5). Figure 13.6 shows summer cross-sections from 1999 to 2003. Each transect plot contains station locations (Prell *et al.*, 2004) and an overlay of sampling depths (white open circles) to illustrate the sample density used for generating contour plots. Five surveys, typically conducted during the month of August, are summarized here to provide a cursory view of summer dissolved oxygen dynamics in Mount Hope Bay, and to identify potentially sensitive

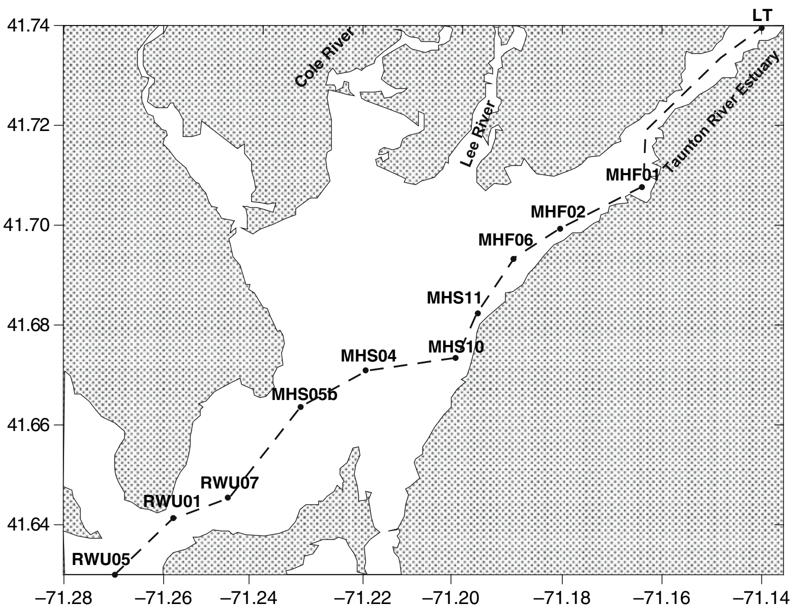

Fig. 13.5 Stations [Prell *et al.* (2004); Chapter 11] used to generate section views along the long axis of Mount Hope Bay. Station LT represents the MCZM autonomous monitoring site located in the Taunton River estuary during 1999–2003.

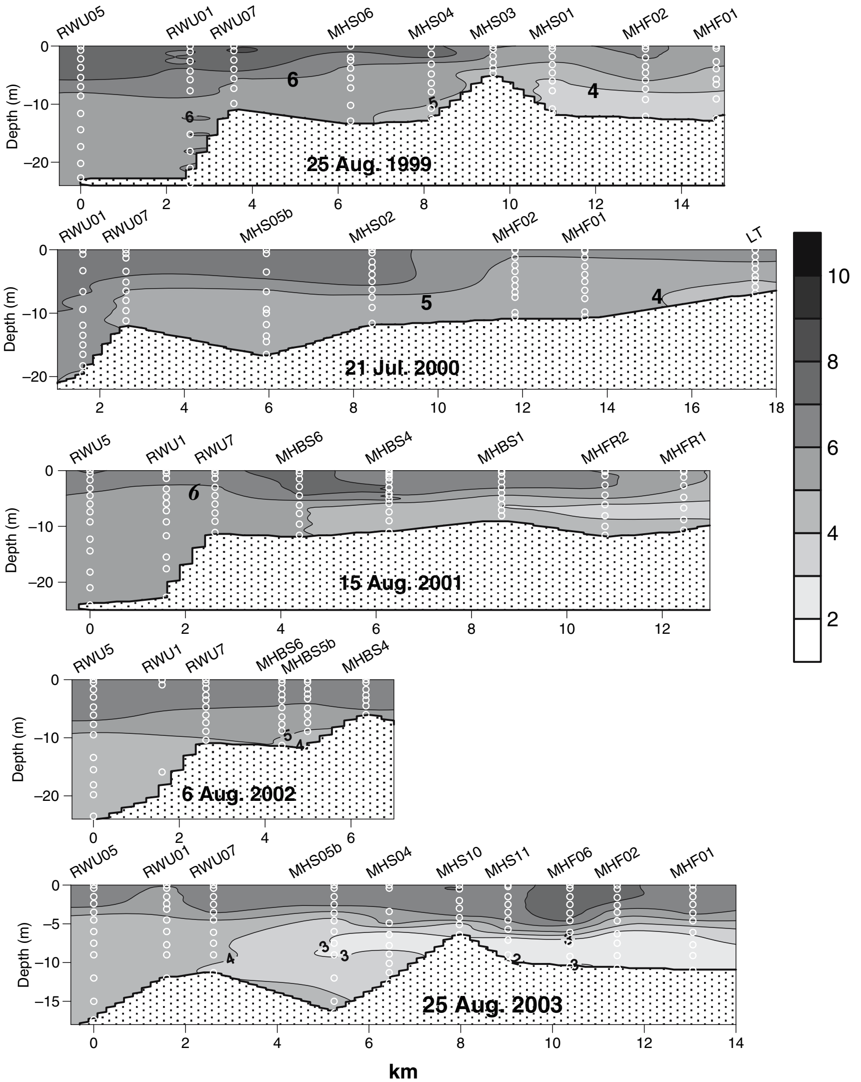

Fig. 13.6 S–N cross-sectional plots of the dissolved oxygen concentration field (milligram of O_2 per liter) in Mount Hope Bay for mid–late summer seasons, 1999–2003. Stations (see Chapter 11, and Fig. 13.5) used in each plot are shown. Open circles represent the samples taken at depths that were used to in interpolating each concentration field.

areas. No August data were collected for upper Mount Hope Bay during 2000, so late July data for 2000 are shown instead.

During these surveys, most of Mount Hope Bay exhibited relatively healthy levels of dissolved oxygen—greater than the designated water quality standards for these waters—and were generally not considered as impaired with respect to dissolved oxygen when compared to the greater Narragansett Bay system. The water column for these bay-wide surveys was typically stratified, with respect to salinity, temperature, and dissolved oxygen (CoastalVision, 2004). In general, higher dissolved oxygen concentrations were observed in surface waters relative to deeper waters. Surface waters with the highest dissolved oxygen concentrations ($\sim$7 mg L^{-1}) typically occurred in the lower portion of Mount Hope Bay, near the East Passage of Narragansett Bay. However, higher dissolved oxygen levels (>8 mg L^{-1}) associated with freshwater input in the upper portion of Mount Hope Bay was observed during the August 2003 survey. Because semi-diurnal tidal mixing dominates the circulation of the bay (Spaulding *et al.*, 1999), it is important to note the described surveys were conducted over the period of 6–8 h during which significant tidal mixing occurred and may have resulted in some artifacts in our portrayal of the position of maxima and minima dissolved oxygen layers. Tidal excursions of heated effluent from Brayton Point from satellite imagery (Mustard *et al.*, 1999) indicate excursion distances of near one-half the length of the bay (5–6 km), and may be of importance to these interpretations.

The dissolved oxygen concentration fields generated from survey data across the central portion of Mount Hope Bay along west–east transects offer little information for generalizations, partly because of the poor spatial coverage in our sampling design, and are not shown. However, these analyses hint of higher surface dissolved oxygen concentrations in the western portion of the bay, especially near station MHN05, and could be indicative of processes such as longer water residence times and/or higher primary productivity, and subsequent *in situ* production of oxygen from photosynthesis.

Lower dissolved oxygen concentrations were usually observed in the upper reaches of Mount Hope Bay, associated with the deeper waters of the main shipping channel in the vicinity where the lower Taunton River exchanges with Mount Hope Bay (Braga Bridge, US Interstate 195). The August 2003 survey yielded lowest dissolved oxygen concentrations ($\sim$3 mg L^{-1}) in the shipping channel, extending from the lower Taunton River to approximately 9 km into the central portion of Mount Hope Bay. The sub-surface minimum was observed at 10 m depth at Station MHS05b approximately 1 h prior to low tide, and appears to be associated with the Taunton River outflow (Fig. 13.6, bottom). Interestingly, similar distribution patterns were observed for salinity, and simple linear regression was used to further explore the relationship between salinity and dissolved oxygen.

A least squares fit to the August 2003 Mount Hope Bay hydrographic data was highly significant ($r^2 = 0.69$). However, an examination of the residuals (Fig. 13.7, top panel) reveals a cluster of points with relatively higher dissolved oxygen values in the mid-salinity range near 28–29‰. All 14 of these points represent sample observations from the lower portion of Mount Hope Bay that is associated with a portion of cooler, deeper Narragansett Bay water that exchanges across the open boundary near the Mount Hope Bridge. When these points are treated as outliers, the salinity-dissolved oxygen relationship

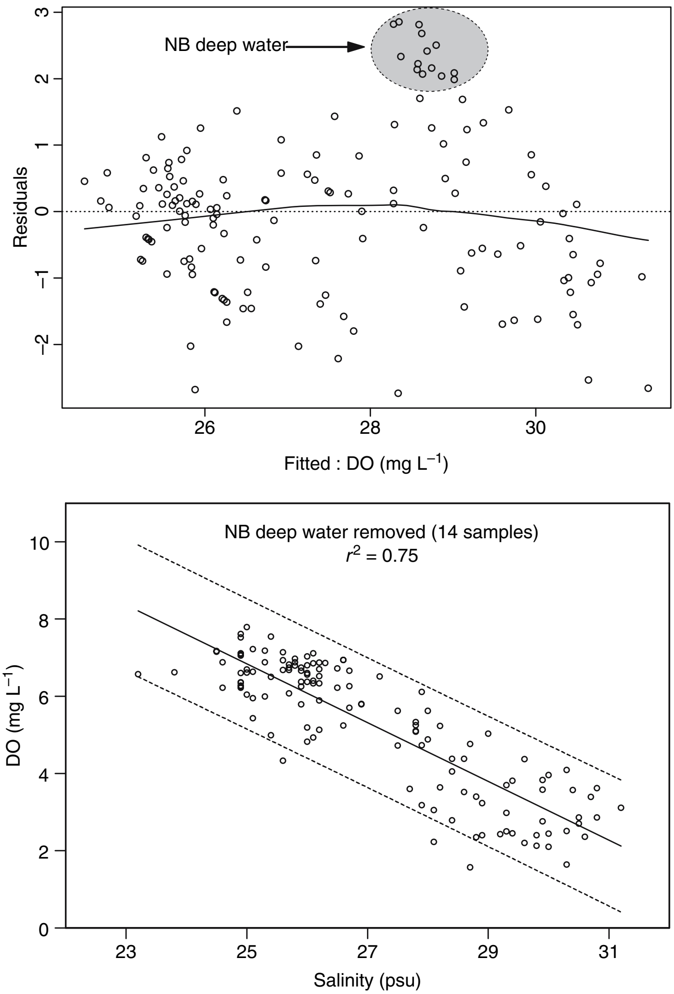

Fig. 13.7 Simple linear regression analyses of the August 2003 data (Prell *et al.,* 2004). Top panel shows a cluster of residuals that represent samples of Narragansett Bay "deep water".

improved ($r^2 = 0.75$, Fig. 13.7, bottom panel) and point to the importance of the higher salinity surface water from Narragansett Bay for establishing the conditions for water quality in Mount Hope Bay, at least for dissolved oxygen during the late summer period of August 2003.

13.5.4 2000 Summer–Fall Nutrient Surveys

The distributions of DIN and Chl *a* were monitored by MCZM at 10 stations in Mount Hope Bay from discrete water samples collected during the summer and early fall in 2000. Summaries of surface water concentration fields for sampled nutrients and Chl *a* at 2-week intervals beginning in July 2000 (7/21, 8/3, 8/18, and 8/31), and a late October survey (10/27), are illustrated in Fig. 13.8a–d. Surface contour plots for sampled nutrients and Chl *a* were generated by kriged interpolation of 10 stations using Surfer®, and at best show generalities in spatial trends.

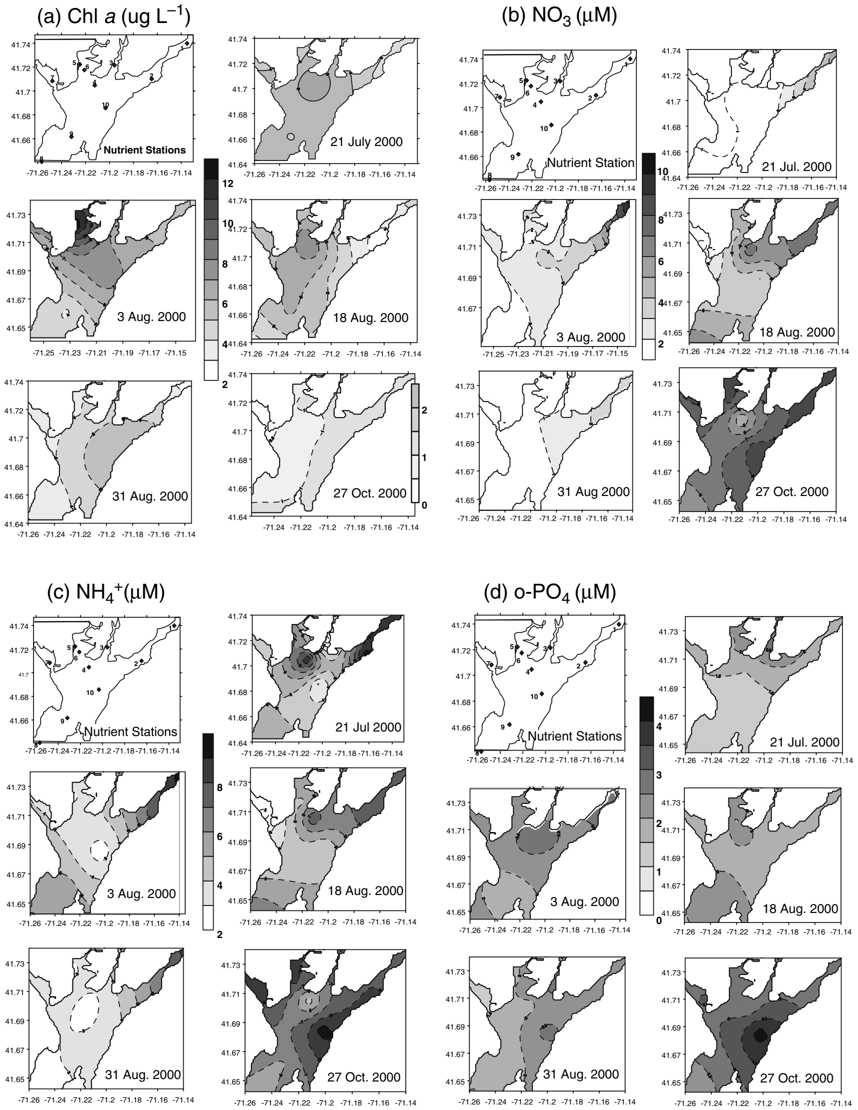

Fig. 13.8 Generalized surface water concentrations of Chl *a* (μg L^{-1}), NH_4^+, NO_3, and o-PO_4 (μM) derived from water quality monitoring by MCZM during the summer, 2000.

Overall, Chl *a* concentrations were generally higher in the central shallow portions of Mount Hope Bay during most of the surveys (Fig. 13.8a). Much of the bay area was typically at or above 5 μg L^{-1}. By the end of October, all surface water Chl *a* concentrations were closer to 1 μg L^{-1}. In early August, the highest concentrations of Chl *a* were observed in central and northwestern portions of the system. Stations in the central portion of the Mount Hope Bay were near 7 μg L^{-1} and the highest Chl *a* level (>12 μg L^{-1}) was observed at a single station in the Lee River (Station 5). It is important to note that Station 6, which is adjacent to Station 5, was not sampled during the August 3, 2000 survey, and therefore cannot be used to further substantiate the observations. Mean surface concentrations of NO_3 and NH_4^+ during this period are summarized in Fig. 13.8b,c, respectively. Mean values for NO_3 and NH_4^+ in the lower Taunton River Estuary (Stations 1 and 2) were computed for each survey during 2000 and found to be significantly higher ($p < 0.02$, repeated measures general linear model with Mauchly's *post hoc* test of sphericity; SPSS 13.0 Chicago, IL) than mean values computed for the remaining stations (i.e., Mount Hope Bay). These differences signify the importance of the Taunton River with respect to nutrient loading to Mount Hope Bay.

The general spatial trend in dissolved inorganic phosphate (o-PO_4) is shown in Fig. 13.8d. For most of the sampling events, o-PO_4 seldom exceeded 2.5 μM in the bay proper. Our kriging analyses show evidence of a strong o-PO_4 concentration gradient in surface waters near the outfall of the Fall River WWTF, possibly during the late August survey but clearly by late October. The o-PO_4 concentrations suggest that N is limiting to phytoplankton growth, based on the principle that organisms use nutrients like N and P roughly in the same proportion as chemical composition of their organic soft tissue (Broecker and Peng, 1982). This N:P ratio—also known as part of the Redfield ratio—is often expressed as 16:1. In all cases, the ratios of N:P were <10, averaging around 4.0 ($\pm$2.0, $n = 51$).

Dissolved nutrient concentrations observed in Mount Hope Bay and the lower Taunton River during 2000 were comparable to the 1982–1983 observations made by MRI (1983). The relatively similar DIN concentrations observed for Mount Hope Bay over the past 20 or so years support the conclusion by Nixon *et al.* (2005) that total nitrogen entering Narragansett Bay by way of sewage discharges has not changed significantly since the mid-1980s (and see Chapter 5, Nixon *et al.*). It is important to note that both MCZM and MRI did not monitor for dissolved organic nitrogen, which can comprise a significant portion of the dissolved nitrogen pool for these waters (Pilson and Hunt, 1989; Nixon *et al.*, 2005).

Because of the paucity of recent nutrient data for Mount Hope Bay, we rely on the MRI data to illustrate the highly variable nature of dissolved inorganic nitrogen and the seasonal response of the Mount Hope Bay system to nitrogen loading. Figure 13.9 shows NO_3 and NH_4^+ concentrations for three MRI stations: near the confluence of the Segreganset River in the upper most, tidally influenced portion of the Taunton River Estuary; mid-estuary, near the

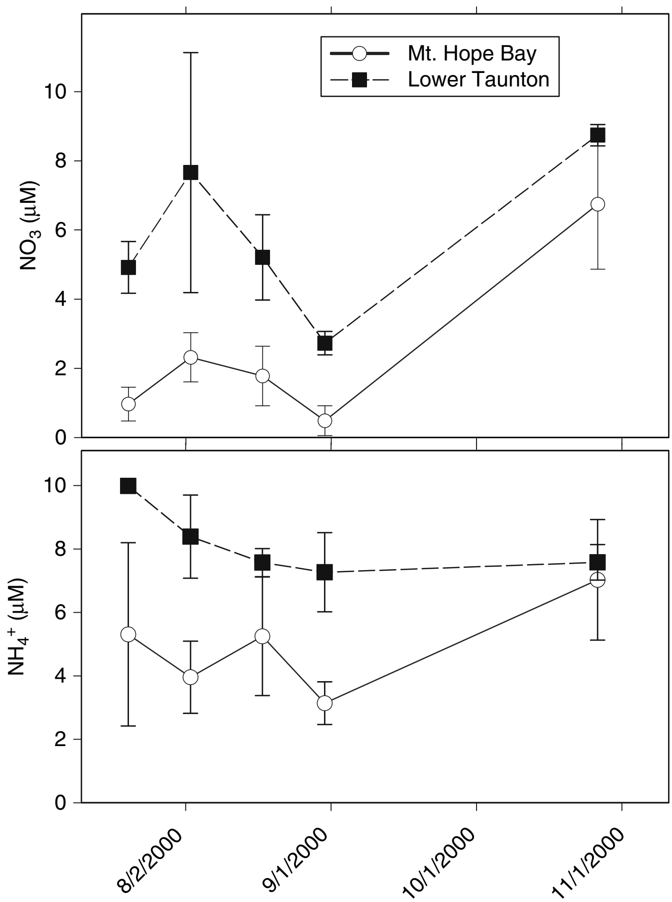

Fig. 13.9 Summary of dissolved inorganic N concentrations as mean observations from stations in Mount Hope Bay (Stations 3–10) and the lower Taunton River estuary (Stations 1 and 2) during the later part of 2000. Error bars reflect 1 SD about the mean, except for the Lower Taunton river means, where they represent the range of the two observations.

Montaup electric power station in Somerset, MA; and mid-bay, adjacent to the main shipping channel. Mean concentration values for NO_3 and NH_4^+ increased from 9 and 7 µM, respectively, in the surface waters of the lower and central bay, to 27 and 22 µM, respectively, in the upper reaches of the Taunton Estuary near the Segreganset River. Figure 13.10 indicates that a significant portion of the inorganic N load to the estuary appears to be readily diluted with higher salinity Mount Hope Bay water before exiting into Mount Hope Bay from the lower Taunton River.

The Taunton River receives significant amounts of nutrients from direct discharges of wastewater from municipal WWTFs (Save the Bay, 1998). From monthly mean data reported by the Taunton facility to EPA for 2002

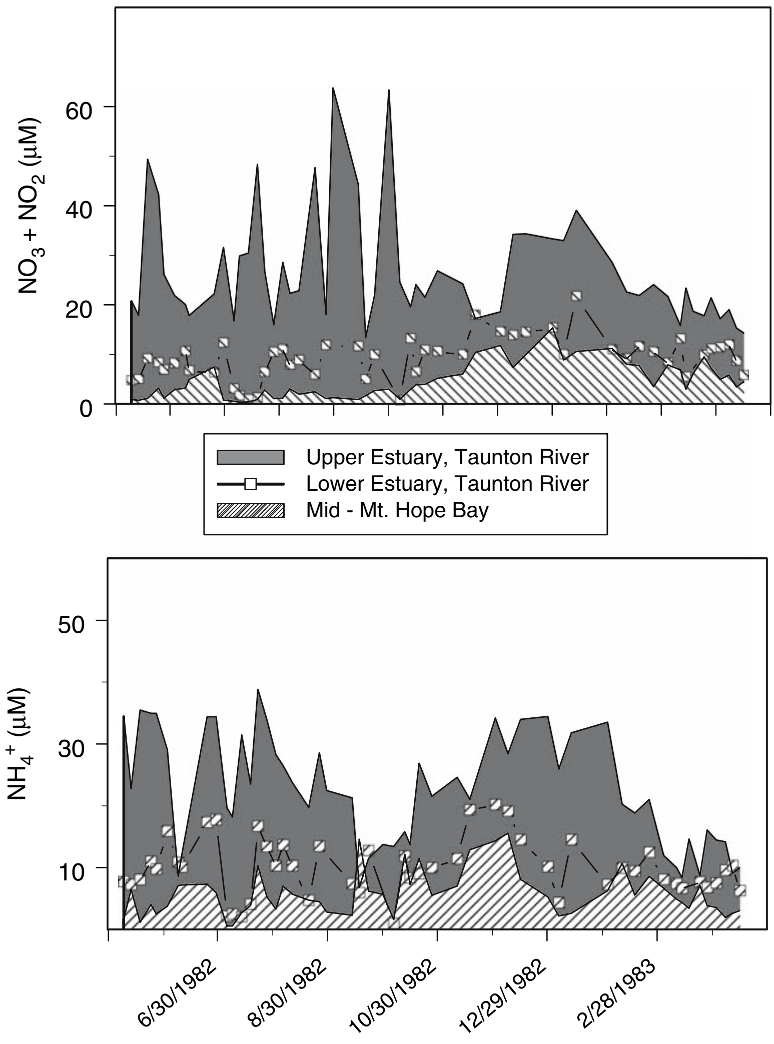

Fig. 13.10 MRI (1983) dissolved inorganic N (μM) in the Mount Hope Bay–Taunton River system from May, 1982 to April, 1983.

and the Brockton facility based on 2004 effluent data, it is estimated that these WWTFs add approximately 2.7×10^7 mol N annually directly to the lower portion of the Taunton River (Table 13.7). The Somerset and Mansfield WWTFs discharge minor flows beyond the Taunton River USGS gauge in Brockton, and contribute comparatively negligible amounts of N to the estuary. Taunton river nutrient data collected by investigators from Bridgewater State College and the Taunton River Watershed Alliance in 2000 *(www.glooskapandthefrog.org/phosphorus.htm)* provide the basis for

Table 13.7 Estimated N fluxes to Mount Hope Bay based on characteristics of WWTF derived from monthly averages reported to EPA[a,b], Taunton River discharges to the Taunton River estuary near the USGS gauge in Bridgewater, MA, and from atmospheric loadings using Howarth *et al.* (2002). Relative standard deviations are shown in parenthesis (RSD%) where monthly data from WWTF were available.

Source	Mean Flow (m^3 d^{-1}) × 10^4	Total Estimated N flux (mol N d^{-1}) × 10^3	%N as NO_3 + NO_2	%N as NH_3	Save the Bay (1998) N flux (mol N d^{-1}) × 10^3
Taunton River (Bridgewater)	108	59.6[d]	Unknown		
Fall River WWTF[a]	8.7 (16%)	84.5 (19%)	2	78	99.0
Taunton WWTF[a]	2.3 (17%)	15.1 (33%)	63	18	17.8
Somerset WWTF[c]	1.3 (5%)	0.4 (25%)	21	68	NA
Mansfield WWTF[c]	0.94 (6%)	NA	NA	NA	0.3
Brockton WWTF[b]	6.2	59.6 (32%)	2	74	5.9
Atmospheric Deposition	Indirect	30–60			
	Direct	6.8			

NA: not available.

[a] NPDES data reported to EPA for 2002.

[b] NPDES data reported to EPA for 2004. Note significant performance changes at Brockton WWTF for 2004. Total N flux for 2002 and 2003 were calculated as 86 and 81 mol N d^{-1}($\times 10^3$) respectively.

[c] NPDES data reported to EPA for 2005. Mansfield WWTF report only N species concentration minima.

[d] Upper Taunton River (Bridgewater) nutrient data from Bridgewater State College 2000 Study (20.7 × 10^3 mol N d^{-1} as TKN, 38.9 × 10^3 mol N d^{-1} as NO_3) from *www.glooskapandthefrog.org/phosphorus.htm*, includes N from Brockton and Bridgewater WWTF.

estimating nutrient loads to the upper Taunton, and they are remarkably similar to the N loading from the Brockton WWTF shown in Table 13.7.

We lack sufficient understanding to ascertain what portion of N is retained within the Mount Hope Bay system, either through deposition as particles to the sediment, uptake by fringing marshes, sequestering by or remineralization from sediments, exportation to Narragansett Bay as organic forms or other important N species, or the amount lost to the atmosphere as N_2 via denitrification.

Also important, and beyond the scope of this chapter, is an assessment of the role of atmosphere N deposition, either directly to the surface waters of the Mount Hope Bay system or to its watershed. Howarth (Chapter 3) constructs estimates of atmospheric N deposition to the Narragansett Bay ecosystem. The rate of atmospheric N deposition to the northeast is considered among the highest in North America, contributing approximately 7.1 × 10^4 mol N km^{-2} y^{-1} (Howarth *et al.*, 2002). However, in many forested watersheds, only 10–20% of atmospherically derived N enters the receiving waters (Jaworski *et al.*, 1992; Howarth *et al.*, 2002). To the surface waters of Mount Hope Bay, this then translates to a loading between 1 and 2 × 10^7 mol N y^{-1}, comparable in terms of magnitude to loadings of N associated with the larger WWTFs in the Mount Hope Bay region.

To further complicate atmospheric N deposition estimates is the potential of local atmospheric loading of N from the Brayton Point power station. Power station N emissions deposited on land and water are considered an important contributor to declining water quality (Schlesinger, 1997). Not considering the potential of a localized atmospheric contribution of N from Brayton Point to the immediate watersheds of Mount Hope Bay, we estimate between 7.2 and 8.3×10^7 mol N y^{-1} are added to Mount Hope Bay annually from wastewater discharges and atmospheric deposition (Table 13.7). If we consider the upper loading estimate of 2×10^7 mol N y^{-1} derived from atmospheric deposition, approximately 70% of the N entering Mount Hope Bay is the result of WWTF discharges. However, this estimate also does not take into account exchanges of N between Mount Hope Bay and greater Narragansett Bay (i.e., the potential of sewage-derived N from Rhode Island WWTFs to Mount Hope Bay).

13.5.5 Photosynthetically Active Radiation

The characteristics of light attenuation, specifically in the range considered as photosynthetically active (390–710 nm), were determined by MCZM on a limited set of water quality observations during the 2003 monitoring period. Habitat structure and quality are intrinsically linked to the amount and quality of solar radiation received, and therefore may serve as one of the attributes (e.g., key species growth and mortality, food) to help quantify or qualify habitat quality or suitability for resource management analyses. In fact, light attenuation is one of the key indicators used for assessing aquatic ecosystem condition (Bricker *et al.*, 1999; Batiuk *et al.*, 2000; Biber *et al.*, 2005) and is thought to be one of the major abiotic factors affecting the survivorship and health of submerged aquatic vegetation (SAV) (Dennison *et al.*, 1993; Batiuk *et al.*, 2000; Moore and Wetzel, 2000; Kemp *et al.*, 2004). Light penetration in the water column is typically described as a function of the concentrations of suspended particles and colored dissolved organic matter (CDOM) in the water column.

The PAR penetration in the water column of Mount Hope Bay, specifically during the 2003 season, is considered here to provide some initial measure of the changes of water column light penetration; in the form of light extinction coefficients (K_d), and the amount of light available at depth (I_Z) for use by primary producers. The depth at which critical light levels meet the minimum physiological requirements of seagrasses is often reported to be between 10 and 30% of the incident surface light (I_0), or around 5–14 mol quanta m^{-2} d^{-1} (Kemp *et al.*, 2004). We use the average of 46.1 mol quanta m^{-2} d^{-1} for average solar irradiance (based on field observations typical for June and July in the northern hemisphere in Bugbee, 1994).

In Mount Hope Bay, the only significant eelgrass beds were historically limited to the western shores of the Kickamuit and Lee Rivers in the northwest regions of the Bay (RI Coastal Resource Management Council, 2001). Villalard-Bohnsack *et al.* (1988) reported a complete absence of eelgrass beds in Mount Hope Bay and an extensive coverage of macroalgae beds in the Lee and Cole Rivers region during the mid-1980s. Abundant sea lettuce (*Ulva lactuca*) has been observed in many of the shallow areas of Mount Hope Bay during this study period, and may be symptomatic of increased loading of bio-available nitrogen (Short and Wyllie-Echeverria, 1996).

Water column PAR attenuation characteristics are reported here as a measure for assessing the suitability for SAV survivorship in Mount Hope Bay, and to illustrate some important limits and related controls on primary production in the Mount Hope Bay system. The extinction coefficient (K_d) was calculated from hydrocasts conducted during summer cruises on Mount Hope Bay in 2003 by performing regression analysis on the PAR versus depth data. Typical light attenuation data follow the relationship:

$$\mathrm{I_Z} = I_0 \mathrm{e}^{-\mathrm{Kdz}}$$

where z is the depth (from surface), I_Z is the light intensity at depth z, and I_0 is the light intensity at the surface.

A typical Mount Hope Bay water column profile of PAR is shown in Fig. 13.11 (top panel). The model fit of the PAR versus depth data generally showed good agreement (typically, $r^2 > 0.9$) and yielded K_d values that ranged from 0.5 to 2.4 m^{-1} (Fig. 13.11, bottom panel). Higher values of K_d, representing greater light attenuation (i.e., more turbid water), occurred later in the year during fall observations. Though PAR data were collected at different times during daylight (09:00–17:00), and thus under variable I_0, this does not affect the estimate for K_d since light extinction is only a function of the scattering properties of the medium, dependent mainly on the concentration and types of material suspended (particles) or dissolved (i.e., CDOM) in the water column (Kemp *et al.*, 2004).

13.6 Summary and Conclusions

Ecosystem-based management requires an integrated approach to environmental management that incorporates human elements as part of the ecosystem (McLeod *et al.*, 2005), and requires integrated knowledge of the functions of the ecosystem. Much of the information needed to answer the monitoring questions poised by MCZM in 1999 remains unavailable. However, the recent water quality information presented earlier provides valuable insight into the

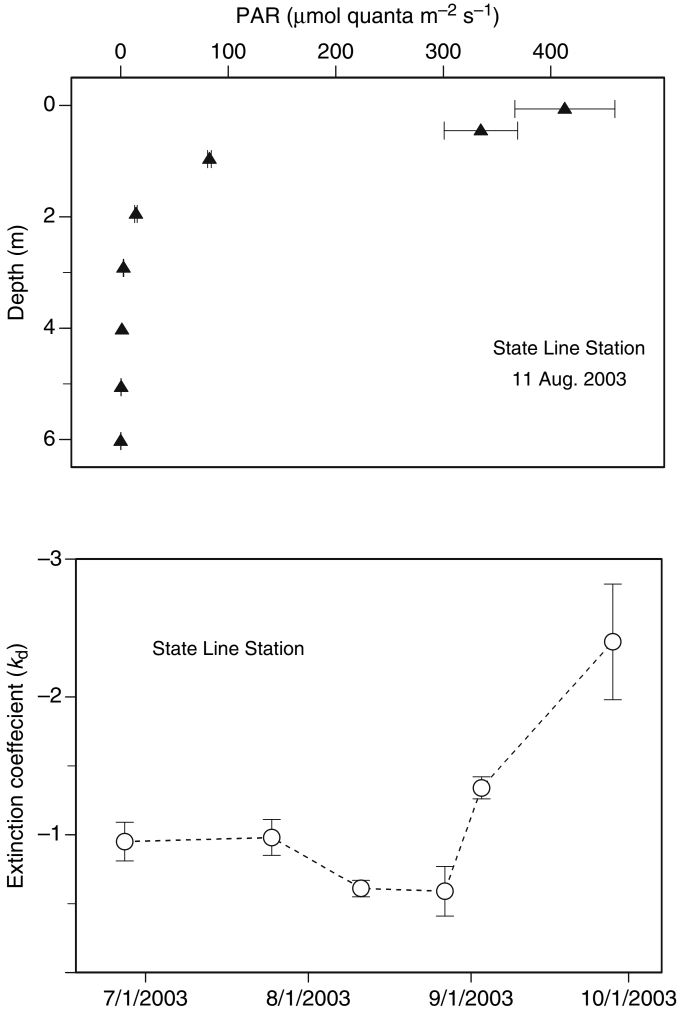

Fig. 13.11 Typical profile of PAR concentrations as a function of depth in the Mount Hope Bay water column (top panel) and PAR extinction coefficients (K_d) observed for surveys conducted between July–October, 2003 (bottom panel).

function of the Mount Hope Bay ecosystem and a direction for environmental management.

Mount Hope Bay is characterized by episodic low dissolved oxygen events in the upper central and western reaches of the bay. These low dissolved oxygen events are unique in the sense that some occur in surface waters, occasionally dropping below dissolved oxygen levels simultaneously observed in corresponding bottom waters. The link between these surface events and freshwater input from the Taunton River, by far the largest source of fresh water to the ecosystem, is thought to be important, but has not been firmly established to date. Modeling results for August, 1997 by Spaulding *et al.* (1999), however, predict that portions of the surface plume of the Taunton River discharge to be transported to the northwest toward the Lee and Cole Rivers. More detailed monitoring from July, and extending through September for several years, and an additional autonomous monitoring site near the entrance of the Taunton River, could aid in evaluating the importance of Taunton River inputs to the late summer dissolved oxygen dynamics and its influence on the biological character of Mount Hope Bay.

Much of the water column in Mount Hope Bay remained well-stratified during summer periods, mostly a result of salinity and temperature conditions, and mixing with bottom water was often limited during these periods. If surface low dissolved oxygen events are "biologically" significant, their impacts on the benthic community may be minimized by water column stratification. We have also shown that surface waters from greater Narragansett Bay can, at times, control the concentration of dissolved oxygen in Mount Hope Bay waters. This reflects, in part, the importance of exchange between Mount Hope Bay and Narragansett Bay both in magnitude (volume), and over relatively rapid (on the order of days) time scales of mixing. The critical period for low dissolved oxygen concentrations appears to be during the late summer months, when freshwater input is low and bay water is at its warmest.

Mount Hope Bay is relatively turbid, and potentially light-limited, based on limited PAR data. Details about suspended particle concentration and composition are still needed in order to evaluate the roles of phytoplankton productivity and the input of terrigenous material on water column light quality. Because light requirements for typical SAV survivorship appear to be seldom met at depths below 1 m in the water column, seagrass beds and other SAVs are probably not appropriate biological targets for habitat restoration in Mount Hope Bay. Biological criteria developed for ecosystem-based management and/or TMDLs need to be sensitive to the recent values placed on the nursery and spawning habitats of the Mount Hope Bay ecosystem, especially those related to anadromous fish habitats and bottom-dwelling finfish populations.

Mount Hope Bay is considered to be experiencing over-enrichment and appears to mirror the symptoms of eutrophication—loss of critical habitats, hypoxic events, abundance of *Ulva* sp., etc.,—in adjacent Narragansett Bay. Wastewater discharges from Massachusetts could account for as much 70% of the nitrogen flux to the bay. However, consideration should also be given to the role of exchange of material between Narragansett Bay and Mount Hope Bay as the extent of this exchange, and its significance on water quality, remains unknown. Improved modeling of inter-bay circulation, as noted by Chen *et al.* in Chapter 9, should be considered a priority research area.

Atmospheric deposition of N to Mount Hope Bay, assuming N depositional rates recently reported for the Northeastern US (Howarth *et al.*, 2002; Howarth in Chapter 3 of this volume) and N attenuation of about 80% in the Mount Hope Bay watershed, is also thought to be significant, being on the scale of loading from the two largest WWTFs discharging to Mount Hope Bay, but further research effort is needed here as well. Further evaluation of N loading from the Brayton Point power station, in the form of atmospheric emissions, could elevate the importance of atmospheric N deposition to the overall loading of N to Mount Hope Bay.

Bathymetrically, Mount Hope Bay consists of two regions: the shallow flat region of the central and northwestern and the deeper waters of the main shipping channel along its eastern boundary. Hydrodynamic models point to reduced circulation in the shallow portion of the bay (Spaulding and White, 1990; Spaulding *et al.*, 1999; Swanson *et al.,* 2006) though these models are limited when evaluating biologically important differences in these areas with respect to water circulation, water quality, water residence times, and contaminant loading. The biological/ecological component noted by Chen *et al.* in Chapter 9 should be further pursued as its application could greatly expand our understanding of ecosystem function and response in both Mount Hope and Narragansett Bay. The shallow region of the bay may contain important areas of productivity (indicated by higher values of Chl *a*) and potentially an important source of organic matter produced *in situ* for exportation to greater Narragansett Bay. Numerical models with the potential for sub-system analyses and incorporation of ecological parameters will highlight the importance of smaller scale processes such as eddy-mixing and local wind forcing. These processes may be biologically significant and key to understanding the ecological function and interaction between Mount Hope Bay and Narragansett Bay ecosystems.

Changing land use in the watershed of the Mount Hope Bay ecosystem demonstrates certain human use trends that may have important ramifications on future water quality and, subsequently, the ecological integrity of Mount Hope Bay. Land uses that experienced the greatest gains since 1985—residential and urban—reflect increases in human population to the area and pose concerns about the potential for increases in impervious cover and greater volumes of wastewater, and hence N delivery to the system. The loss of river herring from tributaries feeding into Mount Hope Bay has been linked to excessive anthropogenic pollution since the beginning of the 20th century, most notably from wastewater pollution. However, changes in land use within the Mount Hope Bay watershed that accompanies continued development contribute important factors, such as increases in the percentage of impervious cover, that affect the efficiency of N transport to bay waters. With respect to eutrophication of Mount Hope Bay, therefore, an ecosystem-based management strategy should consider improvements to wastewater treatment foremost, but should also consider concurrent efforts to better manage stormwater and on-site wastewater systems because of the impending rapid growth and development projected for the watershed (SRPEDD, 2005).

Clearly, for effective management that seeks to restore the ecological integrity of Mount Hope Bay, a departure from traditional management practices at the state-level is required. New mechanisms that allow for inter-state dialog, cooperation, and jurisdiction have yet to be defined. State-level management of the Mount Hope Bay ecosystem and greater Narragansett Bay is often hindered by jurisdictional boundaries, often times reflected in the scope of efforts to monitor and manage the environmental impacts on the ecosystem. The drafting of the 2004 NPDES permit for Brayton Point electric power station is one recent example where agencies from Rhode Island and Massachusetts, as well as federal agencies, were able to transgress these boundaries and work collectively to improve on the management of the bay ecosystem.

The management of ecosystems that extend among multiple jurisdictional boundaries is challenging. For some of these systems, regional entities have formed that, while limited with respect to the regulatory aspects of environmental management, are developing frameworks that incorporate the principles of ecosystem-based management. Examples within the US include the Gulf of Maine Council on the Marine Environment—which includes three US States as well as two Canadian Provinces—and the Council of Great Lakes Governors, which has helped to develop a regional information exchange network, providing not only environmental data but also information on economy, tourism, and education. While Mount Hope Bay is of much smaller scale than these larger regions, environmental management of the ecosystem may be better served through an environmental management council that allows for meaningful input from Massachusetts, Rhode Island, and regional and national organizations. An ecosystem-based management framework can then be applied to the greater ecosystem, capturing those management issues that often elude the more traditional state-level approach to management of coastal surface waters.

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