University of Massachusetts Dartmouth
The School for Marine Science and Technology

Water Quality Monitoring Program for the Popponesset Bay and Waquoit Bay Estuaries

(summary of summer 2017 results)

By:

Brian Howes, Ph.D.
Roland Samimy, Ph.D.
Sara Sampieri Horvet, M.S.

Coastal Systems Program
School of Marine Science and Technology (SMAST)
University of Massachusetts – Dartmouth

For:

Mashpee Water Quality Monitoring Consortium:

Mashpee Wampanoag Tribe
&
Town of Mashpee Waterways Commission
&
Coastal Systems Program SMAST-UMD

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BACKGROUND AND OVERVIEW:

The Mashpee Water Quality Monitoring Program is an on-going collaborative effort between the Mashpee Wampanoag Tribe, the Town of Mashpee and the Coastal Systems Program (CSP) within the University of Massachusetts – Dartmouth, School of Marine Science and Technology (SMAST). The project has a two-fold goal: 1) sustain a continuing assessment of the nutrient related water quality of the Waquoit Bay and Popponesset Bay Estuaries relative to regulatory standards (TMDL's) and 2) monitor improvements in water quality resulting from restoration efforts (e.g. oyster propagation, dredging, N removals by freshwater systems, wastewater treatment, etc.) as undertaken by the Town, Tribe and others. The program goals are achieved through the collection and analysis of water samples and associated field parameters relevant to assessing the health of estuarine habitats within the Waquoit Bay and Popponesset Bay Systems, Cape Cod, MA. (Figure 1). These data form the basis for: 1) gauging short and long-term trends in water quality, 2) validating the Massachusetts Estuaries Project threshold modeling approach for Waquoit Bay + Popponesset Bay and 3) determining compliance with USEPA and MassDEP nitrogen targets set under the Clean Water Act by TMDL analysis that has been previously formalized for all of Mashpee's estuarine waters.

In order to develop a sustainable long-term program, a consortium was created whereby sample collection is completed by volunteers recruited by each consortium partner and by public participants, with equipment and analytical costs distributed between the Mashpee Wampanoag Tribe and the Town of Mashpee. The Mashpee Water Quality Consortium was developed under a Memorandum of Understanding (2009) between the Mashpee Wampanoag Tribe, the Town of Mashpee and the Coastal Systems Program (CSP-SMAST). The Consortium is managed through the Mashpee Waterways Commission. It is an important part of the ongoing efforts to develop nitrogen management plans for the restoration of these systems and to determine the level of "success" through the consistent collection of key habitat quality metrics throughout each system in the most cost-effective manner possible. This program is the only method for providing a cross comparable baseline for gauging long-term changes in water quality, as the Towns of Mashpee, Falmouth and Barnstable implement their nitrogen management alternatives for the restoration of the Waquoit Bay and Popponesset Bay systems.

Nutrient related water quality decline continues to represent one of the most serious threats to the ecological health of nearshore coastal waters in southeastern MA and nationally. Coastal embayments, because of their enclosed basins, shallow waters and large shoreline area, are generally the first indicators of nutrient loading from terrestrial sources. Although each embayment system maintains a capacity to assimilate watershed nitrogen inputs without degradation, as loading increases, a point is reached at which the assimilative capacity is exceeded and nutrient related water quality degradation begins to occur. Continuing increases in nitrogen inputs beyond this threshold level result in further declines in habitat quality. Because nearshore coastal salt ponds and embayments are the primary recipients of nutrients carried via surface and groundwater transport from terrestrial sources, it is clear that activities within the watershed, often miles from the water body itself, can have chronic and long lasting impacts on these fragile coastal environments.

Figure 1. Regional locus map depicting Waquoit Bay and Popponesset Bay and their source waters, Vineyard Sound and Nantucket Sound, respectively.

Both the Waquoit Bay and Popponesset Bay Estuarine Systems are highly nitrogen enriched and show impaired nutrient related water quality throughout most of their component basins over the past decade (Overview of the 2010 Water Quality Monitoring Program for the Popponesset Bay and Waquoit Bay Estuaries, June 2011). The tidal rivers (Mashpee River, Childs River, Quashnet River) and major tributary basins (Eel Pond/River, Shoestring Bay and Ockway Bay) showed poor water quality, while the main basins and Jehu and Hamblin Ponds showed moderate to high water quality. It should be noted, however, that both Waquoit Bay and Popponesset Bay appear to be showing few additional impairments. Overall, the systems continue to support impaired habitat quality but there appears to have been a general gradual improvement in regions of Waquoit Bay and Popponesset Bay which have historically shown significantly impaired water quality (Health Index <30) and small recent improvements or no changes in the moderately impaired areas from 2013-2017 and either stable or variable conditions in the high quality areas (Health Index >60) in the lower main basins. However, analysis of the full record for each estuary indicates that while conditions in 2016 and 2017 are generally similar to or slightly improved over the long term baseline, the improvements observed during 2010-2015 appear to have diminished with the advent of the large phytoplankton blooms in 2016 and 2017 in the Mashpee River, Shoestring and Ockway Bays and in the Childs and Quashnet Rivers.

The Upper Childs and Quashnet Rivers (and to a lesser extent the Upper and mid Mashpee River) in 2016 and 2017 were the most impaired estuarine basins within the Town of Mashpee and among the most impaired on Cape Cod. The present Technical Memorandum is an update to the water quality baseline to include the results of each summer's sampling program, 2010-2017.

Protection and restoration of coastal embayments from nitrogen overloading has resulted in a focus on determining the assimilative capacity of these aquatic systems for nitrogen. While this effort is ongoing (e.g. USEPA TMDL studies), southeastern Massachusetts has been the site of intensive efforts in this area (Eichner et al., 1998, Costa et al., 1992 , Ramsey et al., 1995, Howes and Taylor, 1990, Falmouth Coastal Overlay Bylaw). These efforts resulted in the 2002 implementation of the Massachusetts Estuaries Project (MEP). The goal of the MEP has been to determine the nitrogen thresholds for each of the estuaries in southeastern Massachusetts to support TMDL development by the USEPA and MassDEP and to set estuary specific targets for nitrogen management plans aimed at restoring/protecting these systems. MEP assessments and threshold development have been completed for both Popponesset Bay and Waquoit Bay, including the eastern sub-embayments of Waquoit Bay.[1]

MEP analyses indicated that almost all of the estuarine reaches within the Popponesset Bay and Waquoit Bay Systems are near or beyond their ability to assimilate additional nutrients without impacting their ecological health. Nitrogen levels are elevated throughout both systems and as watershed development continues, estuarine conditions are projected to decline further until nitrogen management is implemented.

The result is that nitrogen management of these estuaries is aimed at restoration, not protection or maintenance of existing conditions. Nitrogen management within Popponesset Bay has already begun with the consistent annual maintenance of the flow through the tidal inlet, propagation of oysters within the system and capping of the Town of Mashpee landfill. In addition, watershed nitrogen management planning has been completed (CWMP 2015) with the goal of reducing the major sources of nitrogen (primarily septic system discharges), conducting "in estuary" N removal by shellfish, and possibly enhancing nitrogen removed during transport fromsources to the estuary by enhancing natural attenuation through pond and stream restoration.[2]

SITE DESCRIPTION

Popponesset Bay

The Popponesset Bay Estuarine System is located within the Towns of Mashpee and Barnstable, on Cape Cod, Massachusetts. The Bay's watershed is primarily distributed among the Towns of Mashpee and Barnstable, with a small portion of the upper-most region of the watershed located in the Town of Sandwich. The Popponesset Bay Estuarine System exchanges tidal water with Nantucket Sound through a single maintained inlet at the tip of Popponesset Spit. The Popponesset Bay estuarine system consists of five tributary sub-embayments: 1) Popponesset Bay (main basin + Popponesset Creek), 2) Pinquickset Cove, 3) Ockway Bay, 4) Mashpee River (lower or tidal region) and 5) Shoestring Bay (Figure 2).

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[1] Massachusetts Estuaries Project Nutrient Threshold Reports can be accessed via the Web at http://www.oceanscience.net/estuaries. This site is maintained by the SMAST MEP Technical Team (SMAST, Applied Coastal, CCC) for the public.

[2] 2014. Town of Mashpee Sewer Commission, Draft Recommended Plan / Draft Environmental Impact Report.

Comprehensive Watershed Nitrogen Management Plan. GHD Inc. under contract to Sewer Commission.
The Draft EIR/Draft Recommended Plan received EEA approval certificate in September 2014 allowing the Town of Mashpee to proceed with preparation of its FEIR.

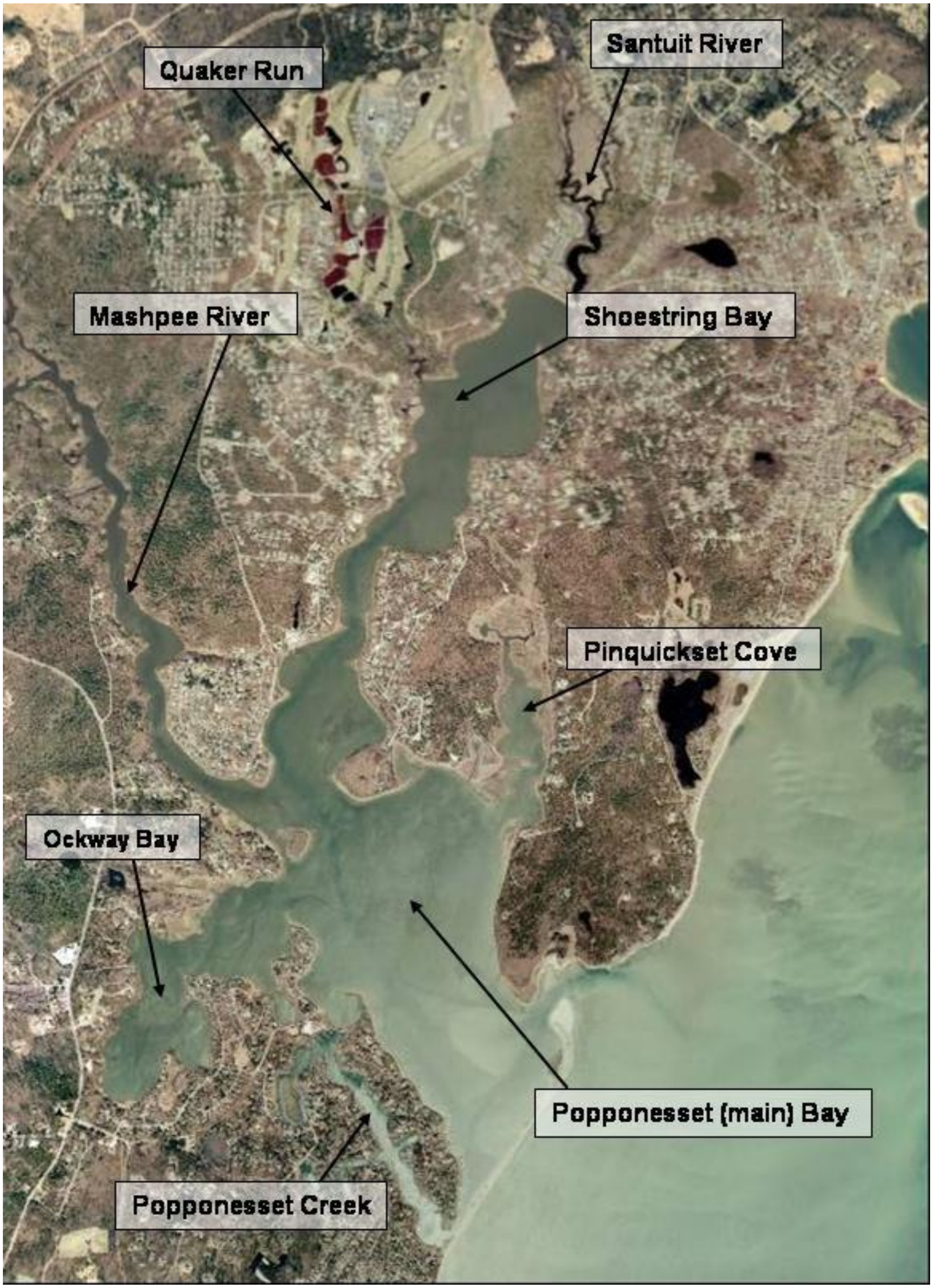

Figure. 2 Popponesset Bay System component basins. Tidal waters enter the Bay through the single inlet from Nantucket Sound. Freshwaters enter from the watershed primarily through 3 surface water discharges (Mashpee River, Santuit River, Quaker Run) and direct groundwater discharge.

Within the Popponesset Bay System, the tidal portion of the Mashpee River functions as a Cape Cod tidal river, with extensive bordering salt marsh, tidal flats and large salinity fluctuations. In contrast, Popponesset Bay, Shoestring Bay and Ockway Bay are typical embayments, dominated by open water areas, having only fringing salt marshes, relatively stable salinity gradients and large basin volumes relative to the tidal prism (i.e. the volume of water entering on a flooding tide). Although Shoestring Bay, Ockway Bay, Mashpee River and Pinquickset Cove and the main basin of Popponesset Bay have different hydrologic characteristics, tidal forcing for all of these component systems is generated from Nantucket Sound. Nantucket Sound, exhibits a moderate to low tide range, with a mean range (high to low tide) of about 2.5 ft. Since the water elevation difference between Nantucket Sound and Popponesset Bay is the primary driving force for tidal exchange (flushing), the local tide range naturally limits the volume of nutrient enriched water flushed from the system during each tidal cycle. It should be noted that the Popponesset Bay System is more sensitive to water quality declines from nitrogen enrichment than estuaries bordering Cape Cod Bay or the outer Cape, where the tide range is much higher (tide range off Stage Harbor Chatham is ~4.5 ft, Wellfleet Harbor is ~10 ft).

In addition to the offshore tide range, tidal damping (reduction in tidal amplitude) within the embayment itself from a constricted tidal inlet or internal channels can further reduce tidal flushing. Fortunately, within the Popponesset Bay System, only minimal tidal damping has been observed. Tidal damping further magnifies the effects of watershed nitrogen inputs. It appears that the tidal inlet continues to operate efficiently due the Town of Mashpee's active and consistent inlet maintenance program. Given the present hydrodynamic characteristics of the Popponesset Bay System, it appears that estuarine habitat quality is primarily dependent on the level of nitrogen loading to bay waters rather than restrictions to tidal flows within the component sub-embayments.

Nitrogen loading to the Popponesset Bay System was assessed by the Massachusetts Estuaries Project and partitioned relative to its five (5) component basins: Pinquickset Cove, Ockway Bay, Mashpee River (lower or tidal region), Shoestring Bay, and Popponesset Bay. The watershed for this estuarine system contains approximately 13,000 acres dominated by single-family residences. Commercial and residential land-uses primarily in the southern portion of Mashpee and in the Barnstable region create a large nutrient load to the Popponesset Bay System. The nitrogen loading from the more heavily populated areas of the Town of Mashpee is focused on the northern reaches of the estuarine system. System-wide, approximately three quarters of the nitrogen load from single-family dwellings enters the Shoestring Bay and Mashpee River basins before entering the main basin of Popponesset Bay.

In evaluating management alternatives, it is important to note that Popponesset Bay is a relatively dynamic system. Popponesset Spit is continually expanding and eroding, once nearly extending to the inlet channel to the Three Bays System to the north. The spit frequently experiences periodic over wash (Aubrey and Gaines 1982). The present inlet position is relatively new, resulting from a breach of the spit in the hurricane of 1954. Similarly, within the main Bay, several islands apparent 50 -100 years ago have been incorporated into other landforms with unquantifiable effects on the circulation of Bay waters. Thatch Island and Little Thatch Island within the lower main Bay have "joined" with the spit, most likely due to a combination of the natural processes of overwash of the barrier beach and shoreline retreat. Daniels Island, at the entrance to Ockway Bay, has been joined to the mainland by filled causeways, apparently filling salt marshes and changing the local circulation pattern. Hydrodynamics have also been altered within Popponesset Creek due to dredging and channelization of wetlands.

Within the watershed to Popponesett Bay there have been changes to the freshwater systems which attenuate nitrogen during transport to bay waters. Most notable of the changes has been the modification to riparian zones either through channelization, restriction, or filling of freshwater wetlands and, in some cases, transformation of portions of the watershed to cranberry agriculture. Most of the alterations have reduced the nutrient buffering capacity of these systems, thus magnifying the nitrogen loading to the bay. However, the predominant watershed alteration has been the shifting of fields and pine-oak forest to residential and commercial development, with its resultant increasing nitrogen input to the watershed, aquifer and ultimately bay waters. This recent shift in land-use has likely resulted in this estuary receiving its highest rates of nitrogen loading than at any period over the past 400 years. Previous large shifts in land-use, primarily from forest to agriculture did not have the same resultant enhancement in nitrogen loading. Historically, agriculture practice generally recycled nitrogen (as opposed to modern practice of using commercial fertilizers) and the population was <10% of today. The present year-round population per square mile is greater than the entire town population of 50 years ago (total population based on 2000 census for the Towns of Mashpee, Sandwich, and Barnstable are 12,946, 20,136 and 47,821 respectively). It appears that the nitrogen attenuation capacity of the freshwater systems has been reduced, as the need to intercept the nitrogen loading to the watershed has increased. While this may be a partial cause of the present estuarine decline, it may also represent a potential opportunity for restoration of bay systems.

Waquoit Bay

The Waquoit Bay embayment system is located within the Towns of Falmouth and Mashpee, Massachusetts on Cape Cod. Like Popponesset Bay, the Waquoit Bay watershed is primarily distributed among the Towns of Falmouth and Mashpee, with a small portion of the upper-most region of the watershed located in Sandwich. The southern shore is a barrier beach that separates the Waquoit Bay System from adjacent Nantucket Sound (Figure 3). Waquoit Bay is composed of a main bay with multiple associated sub-embayments (Quashnet River, Hamblin Pond, Jehu Pond, Eel River/Pond, Childs River). These sub-embayments constitute important components of the region’s natural and cultural resources. In addition, like for Popponesset Bay, the large number of sub-embayments greatly increases the shoreline of the system and decreases the travel time of groundwater from the watershed recharge areas to bay regions of discharge. The main bay has two primary openings to Nantucket Sound, a historically open inlet in the main bay and a relatively dynamic inlet that connects Eel Pond to Nantucket Sound. More recently, Hurricane Bob in 1991 created a third inlet immediately east of the Eel Pond entrance; however, this inlet has closed over the past few years. The inlet to the main bay has been fixed with jetties initially in 1918 (east) and 1937 (west), with subsequent lengthening and enhancements. The second inlet has been generally open over the past 50 years. The opening of the second inlet significantly increased the tidal range and flows within the Waquoit Bay System and caused important ecological shifts to its tidal wetlands and possibly other estuarine habitats (Orson and Howes, 1992). Overall, these important “natural and unnatural” hydrodynamic shifts, coupled to anthropogenic alteration of the watershed, supports a highly altered estuarine habitat.

The Waquoit Bay system is located within the Mashpee Pitted Outwash Plain that supports numerous kettle ponds (Oldale 1992). The Quashnet River Estuary is a drowned river valley estuary resulting from rising sea-level flooding the lower reaches of the Quashnet River. Hamblin and Jehu Pond appear to be drowned kettle ponds currently exchanging tidal flows with Waquoit Bay through tidal rivers, Little River and Great River respectively. Both the Hamblin Pond and Jehu Pond subsystems support significant saltwater wetland resources. The tidal reach of the Quashnet River Estuary is located within the Town of Falmouth while much of the freshwater region of the Quashnet River and its watershed is found in the Town of Mashpee.

Figure 3. Waquoit Bay and its component sub-embayments. Tidal waters from Nantucket Sound enter the main Bay through a single armored inlet in the barrier beach and an unarmored inlet to the Eel Pond sub-embayment. Freshwaters enter the estuary primarily through two major surface water discharges (Childs River to Eel Pond and Quashnet River to the main basin), several smaller streams (e.g. Red Brook), and direct groundwater discharge.

The Quashnet River is one of the two major surface water inflows to the Waquoit Bay System and originates in John's Pond. Hamblin Pond is divided between the Towns of Falmouth and Mashpee, while Jehu Pond is entirely situated within the Town of Mashpee. Within the Quashnet River, Hamblin Pond, and Jehu Pond sub-embayments geomorphic and hydrologic alterations include the damming of the Quashnet (Moonakis) River to drive mills and alteration of riparian zone for cranberry agriculture, as well as the creation of roadways altering tidal circulation around Monomascoy Island. However, the over-riding change affecting these sub-systems appears to have been the shift from pine/oak forest to farming to current residential land-uses, with its associated large increases in watershed nitrogen loading to the estuarine system. Most of the main basin of Waquoit Bay, as well as Eel Pond and Childs River lie within the Town of Falmouth. Their shorelines are highly developed, particularly in the area of Seacoast Shores. As a result of nitrogen entering from its watershed, Childs River is among the more highly impaired estuarine habitats within the region.

The nature of enclosed embayments in populous regions brings two opposing elements together: as protected marine shorelines they are popular regions for boating, recreation, and land development; as enclosed bodies of water, they may not be readily flushed of the pollutants that they receive due to the proximity and density of development near and along their shores. In particular, the Waquoit Bay system and its sub-embayments along the Falmouth and Mashpee shores are eutrophying from high nitrogen loads in the groundwater and runoff from their watersheds. Much of the Waquoit Bay System is currently beyond its nitrogen loading threshold and is currently showing various levels of nitrogen related habitat impairment.

The eastern Waquoit Bay basins, Quashnet River, Hamblin Pond/Little River, Jehu Pond/Great River, and Sage Lot Pond, show clear estuarine characteristics, with extensive salt marsh area, tidal flats and large salinity fluctuations. In contrast, the open water portions of Waquoit Bay and Eel Pond show more typical characteristics of open water areas, having only fringing salt marshes, relatively stable salinity gradients and a large basin volume relative to tidal prism. The tidal forcing for these subsystems, as for Popponesset Bay, is generated from Nantucket Sound. Nantucket Sound adjacent the inlets through South Cape Beach and the southern shore of Washburn Island, exhibits a moderate to low tide range, with a mean range of about 2.5 ft. Since the water elevation difference between Nantucket Sound and Waquoit Bay is the primary driving force for tidal exchange, the local tide range naturally limits the volume of water (and its entrained nutrients) that can flush into and out of the Bay System during a tidal cycle. Similar to Popponesset Bay, its relatively small tide range makes Waquoit Bay proportionally more sensitive to nitrogen related water quality impairments then estuaries on Cape Cod Bay and on the outer Cape with significantly larger tidal ranges, typically 10 ft to 4.5 ft, respectively.

Fortunately, there is minimal tidal damping through the Waquoit Bay inlet. It appears that the main tidal inlet is operating efficiently, possibly due to the active inlet maintenance program and the dual inlet configuration of the overall system. Similarly, within the eastern Waquoit Bay System, the tide generally propagates through the three focal sub-embayments with little attenuation, consistent with relatively unrestricted tidal exchanges. Given the present hydrodynamic characteristics of the Waquoit Bay System, it appears that estuarine habitat quality is primarily dependent on nitrogen loading to bay waters rather than tidal characteristics within the component sub-embayments. Due to the relatively well flushed conditions observed in these three sub-embayment systems, habitat degradation is mostly a result of the high nutrient loads currently being documented in these systems, not restricted tidal flows.

The watershed for this estuarine system contains approximately 10,250 acres, the predominant land-use based on area being public service/government, including the Massachusetts Military Reservation and protected open space along the Quashnet River. Public service occupies 54% of the total watershed area to eastern Waquoit Bay. In contrast, while single-family residences occupy approximately 15% of the total watershed area to eastern Waquoit Bay, this land use class represents 61% of all the parcels**.** Commercial properties are fairly limited within the watershed, with two small clusters located on Route 28 and Route 151. Relative to the Waquoit Bay System, residential land-uses create the major nutrient load.

ESTUARINE MONITORING PROGRAM

The Mashpee Water Quality Monitoring Partnership was established to collect baseline nutrient related water quality data and to track restoration and management "success" in Popponesset Bay and Waquoit Bay relative to the benchmarks established in the MassDEP/USEPA TMDL[3] for Popponesset Bay and Waquoit Bay, inclusive of its eastern sub-embayments. The program was first established to support the Massachusetts Estuaries Project (MEP) analysis for all of Mashpee's estuarine waters, which was completed in the summer 2011. The Town of Mashpee Estuarine Water Quality Monitoring Project focuses on the 2 estuaries within the Town, which provide significant recreational, fisheries and aesthetic resources to the Town's citizenry:

- Popponesset Bay
  - Mashpee River
  - Shoestring Bay
  - Ockway Bay
  - Main Bay
  - Pinquisset Cove
  - Santuit River
  - Off Shore Station

- Waquoit Bay
  - Hamblin Pond – Little River
  - Jehu Pond – Great River
  - Main Bay
  - Childs River
  - Eel Pond
  - Quashnet River
  - Red Brook

As stated above, the concept underlying the establishment of the Monitoring Program by the Mashpee Wampanoag Tribe and the Town of Mashpee was to establish a long-term water quality monitoring effort for Popponesset Bay and Waquoit Bay relative to the TMDL process under the Clean Water Act, and compliance monitoring associated with the TMDL. The present monitoring effort is significantly reduced over prior sampling efforts for these estuaries. This reduction in sampling intensity was acceptable as the prior high frequency sampling was required to support the MEP analysis, while the present effort is to track long-term changes due to the implementation of management alternatives for restoration of these nitrogen impaired bays. By establishing a stable, low frequency monitoring program and by using trained volunteers, costs of compliance monitoring to the Town have been significantly lowered making the program sustainable over the long-term. The stream-lined program builds upon the more intensive efforts conducted previously.

[3] TMDL or Total Maximum Daily Load is the regulatory requirement for restoration of an aquatic system under the Clean Water Act as proscribed by MassDEP and USEPA.

The Mashpee Waterways Commission (Steve Pinard 2009-2013; Don McDonald 2014-present) has been responsible for overall program organization with assistance from Rick York (Natural Resources), including the recruiting of volunteers. The Mashpee Wampanoag Tribe Natural Resources Staff (Chuckie Green) have been full partners in this effort and participated in each of the sampling events. The structure of the program relies on volunteers, with each estuary having a "Bay Captain" who oversees the sampling teams for each sampling event and ensures proper sample transfers and submittal of chain of custody forms. The technical aspects of the project are under the direction of Dr. Brian Howes, Director of the Coastal Systems Program at SMAST-UMD and Sara Sampieri Horvet, the Coastal Systems Analytical Facility Manager (ssampieri@umassd.edu). Volunteers were enlisted from each of the 3 Towns bordering the 2 estuaries: Falmouth, Mashpee and Barnstable. All field team members are volunteers, regardless of their other affiliations, as all members are dedicated to the restoration and protection of Mashpee's culturally and economically valuable estuarine resources.

Volunteer sampling teams were supplied with the necessary sampling equipment to conduct field measurements of physical parameters as well as to collect water samples for subsequent nutrient analysis by the SMAST Analytical Facility. The physical parameters included: total depth, Secchi depth (light penetration), temperature, estuary state, weather, wind speed and direction, and oxygen content. Laboratory analyses include: salinity, nitrate + nitrite, ammonium, dissolved organic nitrogen, particulate organic nitrogen, total nitrogen, chlorophyll-a pigments and orthophosphate (Table 1). All analytical methodologies have been previously approved for use in the SMAST Analytical Facility by EPA, Mass. CZM, NOAA and NSF and the Massachusetts Estuaries Project.

Table 1. Summary of estuarine sampling and parameters analyzed.

Location	Dissolved Nutrients	Particulate Nutrients	Chlorophyll /Pheophytin	Field Parameters
Waquoit Bay				
All CR, ER and WB	X	X	X	X
Popponesset Bay				
All PB and SR	X	X	X	X

As was the case with the prior year's (2016) monitoring effort, the 2017 Mashpee Water Quality Monitoring Program was very successful in its organizational aspects (and % sample capture). The success of the program relative to meeting the sampling goals showed once again that properly implemented volunteer sampling efforts can provide cost effective, high quality data for tracking the status of water quality in both Waquoit and Popponesset Bay Systems, and can support compliance monitoring with the USEPA/MassDEP TMDLS for these systems. In addition, under the recently upgraded program structure, it should be possible to track short-term changes in nutrient related water quality with greater certainty than in previous years.

Each volunteer water sampling team was trained/re-trained and outfitted with sampling equipment for collection of water samples at assigned sampling stations. Staff from the Coastal

Systems Laboratory within SMAST conducted the training sessions and took part in the field sampling, both to assist the effort, as part of QA/QC procedures, and to insure proper transport and delivery of samples to the Coastal Systems Analytical Facility[4].

As in previous years, sampling focused on the warmer summer period when nutrient related water quality conditions are the poorest. Sampling of both bays was completed on the same days in 2017: July 12, July 26, August 10, and August 24. Samples were collected at each station at mid water depth on an ebbing tide for nutrients and surface, mid and bottom for physical parameters including temperature, salinity and dissolved oxygen (depending on the station depth).

The Water Quality Monitoring Program occupied the same sampling sites as in previous sampling years to allow for direct comparisons and track any changes in nutrient related water quality within each of the different basins of each bay. The major change in the 2010-2017 program from the prior effort that was implemented to support the MEP analysis, is the reduction in the overall sampling effort (number of dates/year) while providing the same spatial coverage. This approach allows for incorporation of all historical data, provides the necessary spatial distribution required for management analysis, while also providing a continuing solid assessment of the current nutrient related water quality within the Town's estuaries. Monitoring locations for water quality sample collection were established in order to generate a well distributed network of sampling stations that would yield data at a high enough density with sufficient spatial distribution to ultimately resolve estuarine gradients (Station Maps, Figure 4, 5). Stations were confirmed by GPS prior to sampling.

The monitoring approaches and parameters assayed are fully consistent with the Quality Assurance Project Plan (QAPP)[5] of the Massachusetts Estuaries Project. Samples and field data were collected at 16 locations within the Popponesset Bay system (inclusive of offshore boundary station) and 19 locations within the Waquoit Bay system.

Stations are of 3 types: (1) embayment stations (2) offshore-boundary condition station and freshwater inflow stations. As in 2016, a total of 148 water samples for nutrients (includes QA samples) were collected in the 2017 field season:8 0 in the Waquoit Bay system and 68 in the Popponesset Bay system. The offshore station is used as one gauge of the boundary conditions in nearshore Nantucket Sound (Table 2, 3 and 4).

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[4] The Coastal Systems Analytical Facility is sited within the School for Marine Science and Technology, UMASS-Dartmouth at 706 S. Rodney French Blvd, New Bedford, MA. 02744 (Sara Sampieri, 508-910-6325; ssampieri@umassd.edu). The laboratory supports a full range of environmental assays, with detection limits suited for natural waters. The laboratory data is accepted for both research and regulatory (USEPA, MassDEP, MCZM, NOAA) projects.

[5] Quality Assurance Project Plan is reviewed and must be accepted by MassDEP and USEPA for the information generated by a study to be seamlessly incorporated into regulatory planning or proof of compliance studies under the Clean Water Act. All of the approaches, protocols and analytical methods are part of the MEP's QAPP as well as other QAPP's for water quality monitoring in southeastern Massachusetts.

Table 2. Summary of sampling sites and schedule for the Popponesset Bay and Waquoit Bay systems, summer 2015; * Samples include one QA sample

Waquoit Bay Sub-Systems and Sampling Stations

Date	Waquoit Bay WB12, 13	Childs River CR01, 02, 03	Eel River ER01, 02, 03	Quashnet River WB06, 07, 08, 09	Hamblin Pond WB04, 10	Jehu Pond WB01	Great River WB02, 03	Red Brook WB05	Seapit River WB11	Total
July 6	3*	3	3	4	2	1	2	1	**1**	**20**
July 20	3*	3	3	4	2	1	2	1	**1**	**20**
Aug 03	3*	3	3	4	2	1	2	1	**1**	**20**
Aug 17	3*	3	3	4	2	1	2	1	**1**	**20**
Total	**12**	**12**	**12**	**16**	**8**	**4**	**8**	**4**	**4**	**80**

Popponesset Bay Sub-Systems and Sampling Stations

Date	Mashpee River PB01,	Shoestring Bay PB05,0 6, 07	Ockway Bay PB09, 10	Popp Bay PB08, 11, 12, 13	Off Shore PB 14	Pinquickset Cove PB15	Santuit River SR05	Total
July 6	4	3	2	5*	1	1	1	**17**
July 20	4	3	2	5*	1	1	1	**17**
Aug 03	4	3	2	5*	1	1	1	**17**
Aug 17	4	3	2	5*	1	1	1	**17**
Total	**16**	**12**	**8**	**20**	**4**	**4**	**4**	**68**

Table 3. Summary of sampling sites and schedule for the Popponesset Bay and Waquoit Bay systems, summer 2016

Waquoit Bay Sub-Systems and Sampling Stations

Date	Waquoit Bay WB12, 13	Childs River CR01, 02, 03	Eel River ER01, 02, 03	Quashnet River WB06, 07, 08, 09	Hamblin Pond WB04, 10	Jehu Pond WB01	Great River WB02, 03	Red Brook WB05	Seapit River WB11	Total
July 6	3*	3	3	4	2	1	2	1	**1**	**20**
July 22	3*	3	3	4	2	1	2	1	**1**	**20**
Aug 05	3*	3	3	4	2	1	2	1	**1**	**20**
Aug 22	3*	3	3	4	2	1	2	1	**1**	**20**
Total	**12**	**12**	**12**	**16**	**8**	**4**	**8**	**4**	**4**	**80**

Popponesset Bay Sub-Systems and Sampling Stations

Date	Mashpee River PB01, 02, 03, 04	Shoestring Bay PB05,0 6, 07	Ockway Bay PB09, 10	Popp Bay PB08, 11, 12, 13	Off Shore PB 14	Pinquickset Cove PB15	Santuit River SR05	Total
July 6	4	3	2	5*	1	1	1	**17**
July 22	4	3	2	5*	1	1	1	**17**
Aug 05	4	3	2	5*	1	1	1	**17**
Au22	4	3	2	5*	1	1	1	**17**
Total	**16**	**12**	**8**	**20**	**4**	**4**	**4**	**68**

Table 4. Summary of sampling sites and schedule for the Popponesset Bay and Waquoit Bay systems, summer 2017; * Samples include one QA sample

Waquoit Bay Sub-Systems and Sampling Stations

Date	Waquoit Bay WB12, 13	Childs River CR01, 02, 03	Eel River ER01, 02, 03	Quashnet River WB06, 07, 08, 09	Hamblin Pond WB04, 10	Jehu Pond WB01	Great River WB02, 03	Red Brook WB05	Seapit River WB11	Total
July 6	3*	3	3	4	2	1	2	1	**1**	**20**
July 20	3*	3	3	4	2	1	2	1	**1**	**20**
Aug 03	3*	3	3	4	2	1	2	1	**1**	**20**
Aug 17	3*	3	3	4	2	1	2	1	**1**	**20**
Total	**12**	**12**	**12**	**16**	**8**	**4**	**8**	**4**	**4**	**80**

Popponesset Bay Sub-Systems and Sampling Stations

Date	Mashpee River PB01, 02, 03, 04	Shoestring Bay PB05,06, 07	Ockway Bay PB09, 10	Popp Bay PB08, 11, 12, 13	Off Shore PB 14	Pinquickset Cove PB15	Santuit River SR05	Total
July 6	4	3	2	5*	1	1	1	**17**
July 20	4	3	2	5*	1	1	1	**17**
Aug 03	4	3	2	5*	1	1	1	**17**
Aug 17	4	3	2	5*	1	1	1	**17**
Total	**16**	**12**	**8**	**20**	**4**	**4**	**4**	**68**

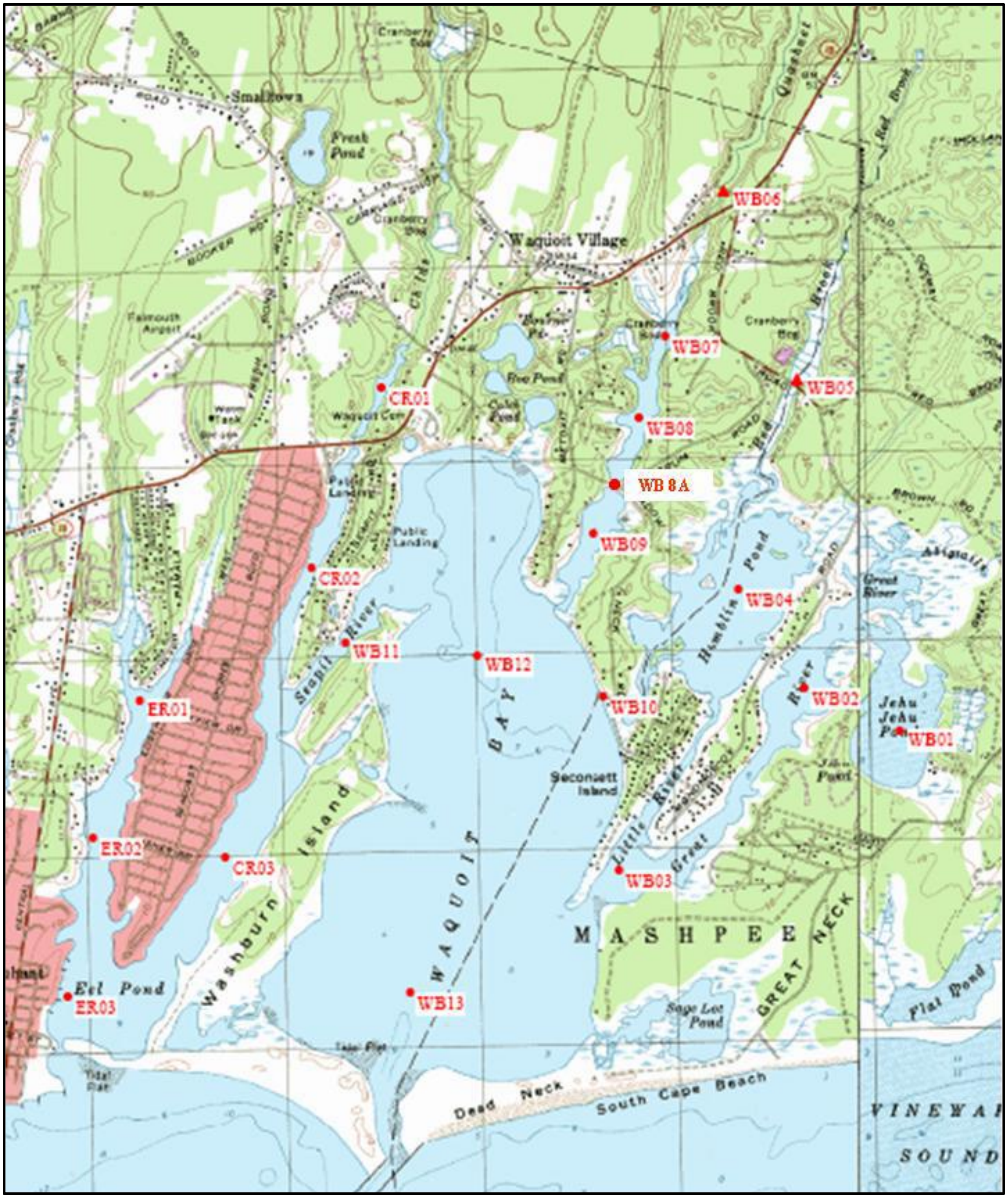

Figure 4. Water quality sampling stations associated with the Waquoit Bay System (2001-2017). Samples were collected synoptically between 5:30 - 8:30 AM on ebbing tides.

Figure 5. Water quality sampling stations associated with the Popponesset Bay System (1997-2017). Samples were collected synoptically between 5:30 - 8:30 AM on ebbing tides.

MONITORING RESULTS

In regard to the Popponesset Bay and Waquoit Bay Systems, nutrient related water quality decline continues to represent the primary environmental problem facing the citizens of Mashpee, Falmouth, Barnstable and Sandwich. Nitrogen management planning and implementation are underway and the Mashpee Water Quality Monitoring Partnership is tracking short and long term changes resulting from continued watershed nitrogen loading increases, variation in tidal flushing, and implementation of nitrogen management alternatives (including propagation of oysters). As implementation is still in its early stages, it is not surprising that the results of the 2010-2017 Mashpee Water Quality Monitoring Program indicate that both Popponesset Bay and Waquoit Bay continue to show poor nutrient related water quality throughout most of their tidal reaches, particularly in the upper portions of each system. However, with the collection of multi-year high quality data, it appears that the more impaired areas of Popponesset Bay and Waquoit Bay were showing some improved water quality through 2015, while the higher quality areas still appear to be stable (see below). Unfortunately both bays experienced large blooms and an associated decline in water quality in summers of 2016 and 2017 and both estuaries still support impaired habitats and remain below the water quality levels set by the MassDEP/EPA TMDL. Summer 2016 was dominated by a very large bloom of *Cochlodinium* (Rust Tide), which was found in many other southeastern Massachusetts estuaries, including adjacent Three Bays, and had negative effects on water clarity and bottom water dissolved oxygen as the bloom declined. Although *Cochlodinium* has sometimes been thought to impact shellfish, there was no evidence that it did so in the 2016 blooms in Mashpee estuaries. Summer 2017 showed higher TN levels at the upper stations in the Mashpee River and Shoestring Bay portions of the Popponesset Bay system compared to measured levels in 2016 and earlier years with commensurately elevated levels of total pigment in both 2016 and 2017 (measure of phytoplankton levels). Similarly, the Quashnet River upper basins showed very much higher TN levels in 2017 than previously, with a resulting very large phytoplankton bloom. In both estuaries these tributary basins receive significant freshwater inflows from the rivers discharging to their headwaters and it appears that there were above average freshwater inputs (carrying nitrogen and other constituents) in 2017 as seen in slightly depressed salinities in 2017. Given the 2 consecutive years of large phytoplankton blooms, monitoring will be closely tracking bloom events in summer 2018.

The overall salinity gradients within each estuary in 2010-2017 are generally consistent with historical patterns (Figures 6 and 10), but with slightly lower levels observed in upper tidal reaches of both estuaries in 2017. The gradients show the effects of the large freshwater discharges to the headwaters of the upper tributary basins. For example, the Childs River and Quashnet River estuarine reaches in Waquoit Bay and the Mashpee River in Popponesset Bay are functionally tidal rivers with drowned river valley morphology and significant stream discharge to the headwaters. As a result the saline waters entering on the flooding tide from the adjacent main basin become significantly diluted. The uppermost reaches of the Quashnet River and the Mashpee River showed salinities generally ~5 ppt (Figures 6 and 10). In 2017 the salinity of the Mashpee River was significantly lower than previous years which also effected the station at the confluence of the Mashpee River and Shoestring Bay, both openings to the Main Bay (PB-Head or PB08). The Childs River also shows significant inter-annual variation with the long term salinity at the head of the Childs River generally around 10 ppt (long term mean), but in recent years, 2010-2016, showing higher salinity levels in the headwaters of ~16-18 ppt. However, as in the Mashpee River, salinity at the head of the Childs River in 2017 was lower at around 10 ppt, likely due to the high freshwater inflows in 2017 compared to 2010-2015 (related to variations in annual precipitation). The elevated salinity levels for the period 2010-2016 likely resulted from lower freshwater inflows (due to some drought years) allowing more saline water to push higher up into the Childs River estuary. Freshwater inflows are rich in nitrogen from terrestrial sources and support much of the eutrophication in the estuarine receiving waters. Interestingly, the corresponding average TN levels at the Childs River head station has remained relatively constant from historic levels through 2015, with only 2016 and 2017 showing an increase. In 2016 the major increase in TN was associated with the very large phytoplankton bloom. In 2017, TN level at the head of the Childs River was higher than historic levels but down from the peak year of 2016. The increased level in TN for 2017 corresponds to the slightly lower salinity measured at the uppermost Childs River station, an indication of increased freshwater flow from the watershed.

It should be noted that in 2016 and 2017 the Quashnet River above the Meadow Neck Road bridge (consistent with prior years) continued to be very brackish with low salinities (upper, <5 ppt, and mid, <8 ppt, stations) as has been observed in the long term record and samplings from 2010 through 2016. The abrupt increase in salinity from the mid station to the lower basin (~22 ppt {2016} and ~19 ppt {2017}), an increase of around 10 to 12 ppt depending on the year, was thought to result from a restriction in tidal flow in this region. However, no significant tidal restriction (tidal damping) was found in a follow-up study completed by the Coastal Systems Program (SMAST) in 2016-2017 in collaboration with the Towns of Mashpee and Falmouth. This study also confirmed, using tidal stage data, that there is very little tidal damping due to the Meadow Neck Road bridge. It may rather be that the basin configuration and circulation in the middle to upper portions of the Quashnet River support lower salinities than the larger lower basin, nearest the tidal inlet. Brackish salinities within this upper basin have been observed in past years, but in recent years, a freshening appeared to be occurring that did not continue into the drought year of 2016. Salinity in 2017 was slightly lower than in 2016, most likely due to increased freshwater discharge from the Quashnet River as a result of higher precipitation in 2017. Upon return to more average annual rainfall conditions, if this basin further freshens, phosphorus management may need to be evaluated (Figure 18). In concert with these recent salinity shifts and higher rainfall, the upper Quashnet River experienced a very significant peak in TN with an extreme phytoplankton bloom in 2017 (total chlorophyll-a of >100 ug/L). It is possible that this was the result of a return to more normal freshwater input conditions after years of lower precipitation. Events such as in 2016 and 2017 underscore the need for long-term monitoring to separate anthropogenic from natural effects.

Like the Childs and Quashnet Rivers within Waquoit Bay, in Popponesset Bay, the Mashpee River upper basin also continues to support brackish salinities (3-5 ppt) very similar to the upper Quashnet River Basin. However, the Mashpee River has supported a stable salinity structure for many years and no tidal restrictions are found within the tidal river itself.

In contrast to these riverine habitats, the larger more open basins within both Waquoit and Popponesset Bay Systems generally show only small salinity gradients and little variation in average salinities from year to year. This pattern results from their larger volumes, proportionally lower freshwater inflow rates and relatively large tidal flows and closer proximity to the lower nitrogen, higher salinity waters of Nantucket Sound, especially the lower main basins of Popponesset Bay, Waquoit Bay and Eel Pond. The generally high salinities (~25-30 ppt) of these major basins is typical of the shallow enclosed estuaries of southeastern

Massachusetts where major rivers are generally absent and tidal volumes are large relative to freshwater discharges. It should be noted that salinity in 2017 at these open basin stations was lower than in 2016 which is consistent to the more average annual precipitation conditions observed in 2017. 2016 was commonly considered a drought year following several years of lower than average freshwater inflow to the estuaries from groundwater and surfacewater, supporting the higher observed salinity in the open basin stations in lower Waquoit Bay and Popponesset Bay.

Monitoring results from summers 2010-2017 continue to show that total nitrogen levels throughout the Waquoit Bay and Popponesset Bay Systems are significantly enriched over the high quality inflowing waters of Nantucket Sound (0.28 mg/L TN) entering during flooding tides and are generally consistent with prior historical data except for periodic spikes in the semi-enclosed small tidal river basins (Figure 7 and 11). The pattern of nitrogen gradients in both systems roughly follows the salinity gradients, as the major source of the "excess" nitrogen is from groundwater and surface freshwater inflows. Within each sub-embayment, nitrogen levels were highest within the headwaters and declined with decreasing distance from the tidal inlets, with the lowest nitrogen levels being recorded at the stations proximate to each inlet. In both systems there are inter-annual differences, probably the result of inter-annual variation in weather related factors (wind, rain, temperature, etc.) or small differences in the sampling. For example, based on the 2010-2012, 2016 and 2017 TN averages, there is a very high average TN value in the upper reaches of the Quashnet River, much higher than in the long-term historical data or the 2013-2015 average results (Figure 7). As observed in both 2017 and 2016, the higher TN years are caused by elevated PON levels associated with major phytoplankton blooms as represented by very high total pigment levels, which was also observed in the multi-year, 2010-2012, record. These “peaks” in TN were not repeated in 2013, 2014, or 2015. The cause of the large phytoplankton blooms is a combination of temperature, sunlight and circulation which allows a bloom to develop, possibly related to pulses of inorganic nitrogen inputs in streamflow. Levels of TN and total pigment where higher in 2017 compared to 2016, most likely due to higher freshwater inflow to the estuarine portion of the Quashnet River as precipitation returned to more average levels. The variation itself indicates the need to maintain a long-term baseline to be able to demonstrate changes in water and habitat quality related to changes in nitrogen loading versus inter-annual variations related to circulation and weather. However, ultimately the blooms and poor water quality reflect the high watershed nitrogen loading that continues as nitrogen mitigation is implemented and the magnitude and frequency of large blooms are troubling if they represent a new trend.

In general, the 2010-2017 sampling results are consistent with the prior years in showing that these tributary basins are still well above their assimilative capacity with total nitrogen levels well above their TMDL designated threshold. The threshold total nitrogen level for these basins varies from 0.5 mg L^{-1} for Quashnet to restore bottom animal habitat to 0.38 mg L^{-1} for Hamblin and Jehu Ponds to re-establish eelgrass habitat (Figure 7). It should be noted that Hamblin and Jehu Pond only recently lost their eelgrass habitat and therefore may be able to be restored more quickly than other larger basins that are much farther beyond their acceptable nitrogen thresholds. However, there is some evidence that small eelgrass patches have re-established themselves in Jehu Pond. In addition, TN levels in the Hamblin Pond and Jehu Pond portions of the overall Waquoit Bay system have been relatively stable so that detecting even small improvements as nitrogen management alternatives are implemented, e.g. oysters, in these tributary salt ponds appears achievable. This is also the case in the Eel River. Childs River and

Quashnet River show more TN variability due to annual hydrologic variability. As such continued monitoring is critical to account for the variability.

The nitrogen thresholds for Popponesset Bay were developed via a completed system-wide Massachusetts Estuaries Project analysis and codified within a MassDEP/USEPA TMDL. Popponesset Bay and its component basins have lost their historical eelgrass habitat (prior to 1995) and the upper tributaries presently support impaired or degraded habitat for benthic animal communities. The 2010-2017 sampling results are consistent with the prior years in showing that nitrogen levels of the tributary basins are still well above their TMDL designated thresholds, which vary from 0.5 mg L^{-1} for Shoestring and Ockway Bays (0.55 mg L^{-1} in upper Mashpee River) and 0.38 mg L^{-1} for the Popponesset Bay main basins (sentinel station near tip of Mashpee Neck) to re-establish eelgrass habitat (Figure 11). Equally important, it appears that recent TN levels have significantly increased over historic (pre-2010) conditions (particularly in the Mashpee River and Shoestring Bay), which is generally associated with habitat decline. In contrast, the main basin has remained relatively constant due to its volume, flushing rate and continuing maintenance of the tidal inlet, but is also showing nitrogen enrichment.

The consequences of these elevated total nitrogen levels can be seen in the high amounts of phytoplankton biomass (measured as chlorophyll-a pigments),which saw bloom conditions in 2016 and 2017 (Mashpee River and Shoestring Bay), and associated depletion of bottom water oxygen.

Since estuarine phytoplankton, including those in Waquoit and Popponesset Bays, are stimulated by nitrogen additions, the effect of the nitrogen enrichment is to cause phytoplankton blooms and turbid waters within both estuaries. Generally, the reaches with the highest nitrogen (Figures 7, 11) support the highest chlorophyll-a pigment levels (Figures 8, 12), although local factors can interfere with this response. Analysis of the total chlorophyll-a and particulate organic nitrogen (PON) data indicate that the PON is directly related to the chlorophyll-a concentration (R^2=0.96). This underscores the contention that the particulate matter in the water column of these estuaries in not "imported" but comprised of phytoplankton growing within the water column, providing a direct link between nitrogen additions and poor water clarity. These measurements support the Town’s management plan, which focuses on lowering the nitrogen levels to reduce phytoplankton biomass and improve water and habitat quality and likely restore eelgrass beds.

In the Waquoit Bay system, the 2010-2015 chlorophyll-a levels are generally consistent with the long-term historical data, however, results from 2016 and 2017 are significantly higher (Childs River, Quashnet River, Seapit River, Jehu Pond), supporting the contention that the overall estuary is presently nitrogen enriched, resulting in high levels of phytoplankton production and blooms when environmental conditions are right. In addition to the amount of phytoplankton, it is important to note the large and prolonged bloom in summer 2016 as well as 2017, to levels not previously observed. The effects of continuing nitrogen enrichment is to increase average pigment levels and also to increase the frequency and duration of periodic blooms (Figure 8). Average levels of ~3 ug L^{-1} are typical of high quality coastal waters, with average levels of <5 ug L^{-1} in summer in shallow estuaries still indicative of moderately healthy waters. Average chlorophyll-a levels >10 ug L^{-1} indicates some impairment. It will be important to track the frequency and magnitude of these blooms in coming years to assess if the trend is real or ephemeral.

The western basins of Waquoit Bay tend to have relatively high chlorophyll-a levels, while the eastern basins (Hamblin Pond, Jehu Pond) continue to support only moderate levels (consistent with moderate TN levels). But again, total chlorophyll-a levels in 2016 and 2017 are still slightly higher than the long term average at most stations, including in the eastern basins and did approach the 10 ug/L threshold cut point that indicates decreasing habitat health. The levels of nitrogen and total chlorophyll-a pigment in the eastern basins of Waquoit Bay are consistent with these basins only losing eelgrass recently and having only moderate nitrogen enrichment. However, most waters of both estuarine systems have total chlorophyll-a averages greater than 5 ug L^{-1}. These levels of phytoplankton biomass result in enhanced deposition of organic matter to the bottom sediments which results in higher amounts of oxygen uptake, negative impacts of organic matter loading on the bottom dwelling organisms and at highest levels, bottom habitats comprised of sulfidic-organic rich soft sediments after many years of nitrogen enrichment. Also, the higher amounts of phytoplankton in the water column increases the amount of oxygen being consumed during periods of low light and darkness adding to oxygen depletion and loss of fish, shellfish and bottom dwelling animals and the organisms that feed upon them. Equally significant, the higher amounts of phytoplankton increase turbidity in the water column and reduce the amount of light that can penetrate to support eelgrass plants that are rooted to the bay bottom. This shading effect is one of the primary proximate causes of eelgrass loss world-wide, and in Popponesset Bay and Waquoit Bay specifically. Eelgrass has not been observed for over a decade in Popponesset Bay and has been reduced in Waquoit Bay to a few remaining patches in Hamblin Pond and Jehu Pond (Short and Burdick, 1996). Concomitantly, observed macroalgal growth and accumulations stimulated by high nitrogen inputs have been significant across Waquoit Bay and large areas within the Popponesset Bay Estuary. Macroalgal accumulations are a key metric indicating nitrogen enrichment and impaired habitat quality due to the associated negative effects of smothering the benthic habitat and overwhelming eelgrass habitat. Eelgrass has not been observed in the Quashnet River sub-embayment for many decades; instead high levels of macroalgae have been documented (Curley et al., 1971, Valiela et al., 1992).

Oxygen depletion of bottom waters was variable but still evident within both systems in 2010-2017 and were generally consistent with historical data, however, except for the low 2017 DO levels in Shoestring Bay and upper Quashnet River, there were no exceptionally high or low DO levels observed. Interestingly, in 2017 the generally low DO at specific stations in the Waquoit Bay system (particularly the Quashnet River) and Popponesset Bay systems (Mashpee River and Shoestring Bay) followed the distribution of higher total chlorophyll-a and TN levels (Figures 9, 13). The linkage of oxygen depletion to nitrogen enrichment is seen in most year's results with higher oxygen levels at lower levels of nitrogen enrichment and greater depletion in basins with higher nitrogen enrichment. In the Popponesset Bay Estuary, oxygen depletions was observed at all stations at levels below the MassDEP water quality standard and to levels deemed stressful to estuarine organisms, particularly in Shoestring Bay. Also significant is that 8 of the 13 stations sampled in Popponesset Bay in 2017 showed lower DO than the 2013-2015 average and only 3 stations showed higher DO levels. DO conditions in Waquoit Bay in 2017 showed no clear inter-annual trend when compared to the average levels for 2013-2015. In 2017, seven stations showed lower DO concentrations compared to the 2013-2015 average and 9 stations were higher. In 2016, ten stations showed lower DO concentrations compared to the 2013-2015 average and only 3 stations were higher. The more depressed DO levels at specific stations in

2016 and 2017 are likely the result of the large, prolonged phytoplankton blooms that occurred in both summers, which results in higher organic loading to the sediments and elevated water column night-time respiration. However, it is likely that the basins of these estuaries remain generally nutrient and organic matter enriched to the point where oxygen depletion will begin to occur when vertical mixing of the water column decreases or a period of low light occurs (Sawabini et al. 2014). Both factors are inter-related and both likely are in effect in these eutrophic waters.

Popponesset Bay showed a parallel pattern to Waquoit Bay, with higher chlorophyll-a and lower D.O. in 2017 compared to the 2013-2015 average as well as the long-term average in most of its basins. The causes of reduced DO levels appear to be the same in both estuaries: the linkage of nitrogen enrichment to organic matter load (chlorophyll-a) to low D.O in bottom waters. Again the observed inter-annual differences can be enhanced by meteorological conditions of low light and wind resulting in less oxygen input through photosynthesis and vertical mixing of oxygen rich surface waters to the bottom, yielding greater depletion between years even at the same level of nitrogen enrichment. This phenomenon has been quantified for many estuaries throughout the region and is likely true for estuaries in general. However, if the observed levels observed in 2016 and 2017 persist over the next few seasons, it will indicate a further decline in nutrient related health particularly in the Mashpee River and the Quashnet River. While it is not currently known what caused the large prolonged phytoplankton blooms in the summers of 2016 and 2017 (particularly in Mashpee River, Shoestring Bay and the head of Okway Bay), it may be associated with higher TN concentrations from higher freshwater inflows due to more average annual precipitation in 2017. It is important to note that the nutrient and organic rich conditions of these estuarine basins keep them poised for low oxygen conditions when other external factors become operative (storms, low light, wind, temperature, etc).

NUTRIENT RELATED WATER QUALITY INDEX

As a simple guide for water quality assessments, the key nutrient related parameters collected as part of the monitoring program can be integrated into a single Index, to provide a simple view of the general nutrient related water quality of the Waquoit Bay and Popponesset Bay Estuarine Systems. This combined metric, the Bay Health Index for these estuaries was constructed based on the multi-year monitoring results (long-term, 2010-2012, 2013-2015 and 2016-2017). The Bay Health Index was developed for Buzzards Bay embayments based upon levels of nitrogen (inorganic and organic), total chlorophyll-a, bottom water oxygen and the depth of light penetration (Secchi depth). While the index does not provide a quantitative assessment of habitat health and is not suitable for salt marsh dominated estuaries or freshwater, it does give a useful picture of the general level of estuarine water quality and spatial gradients within estuaries and may be used to assess temporal trends (Tables 4 and 5). The average summer conditions throughout the Waquoit Bay and Popponesset Bay Systems were used to parameterize the Index. The scores for each parameter were calculated and the average score for each station (across the 5 parameters) calculated (Tables 6 and 7) for each time period. These scores are then compared to a guide of "acceptable" ranges for each parameter to rank the station (Table 8). It should be understood that the resulting Index and the designation of acceptable ranges for each parameter are approximate and provide less certainty than site-specific analysis which include habitat assessments (e.g. eelgrass, benthic infauna). However, the Index does provide a convenient tool for comparing regions within an estuary and between estuaries.

It is clear that there are strong gradients in nutrient related water quality within each estuary which continued through 2016 and 2017 and that they are similar to the long-term pattern (Figures 14a,b, 16a,b). The overall pattern is similar to that of the separate parameters used in calculating the Index. Both embayment systems show only poor to moderate quality throughout the whole of their tidal reaches, with poorest nutrient related water quality within the tidal rivers and tributary basins and, with moderate quality in the main basins. Only the waters in the region of the tidal inlet show high water quality as these regions are typically the last reach of an estuary to become impaired from watershed nitrogen loading, since this area is being swept with the high quality waters of Nantucket Sound (Figure 16, outer station) for almost the entire flooding tide. For this reason, the final areas of eelgrass habitat or high quality benthic animal habitat in a eutrophying estuary are typically found within the region of the tidal inlet.

The Health Index, as a composite of all major nutrient related water quality parameters, also allows for a tracking of temporal trends in water quality. Given the natural variation in water quality associated metrics, it is difficult to determine small short term changes. This is particularly true if changes result from a number of small and/or dispersed improvements in tidal flushing, nitrogen source reductions, etc. However, with the growing dataset it is now possible to examine if change is occurring within these estuaries (improving/declining). To this end, the Index data from Waquoit Bay from 2010-12, 2013-15 and 2016-17 were compared to the historical baseline (Figure 15) with a similar analysis for Popponesset Bay (Figure 17). These comparisons are now sufficiently robust to show trends in estuarine health based on the integrated Index at the different sites between years. Values falling above the 1:1 line show an improvement, values below the line indicate a decline and values near or on the line suggests, no change at that site in that year from historical conditions. In Waquoit Bay it now appears that there have been generally consistent water quality conditions in 2010-2012 and 2013-2015 and

2016-2017 compared to the baseline years of 1997-2009 taken as a whole (not significant at $p=0,05$). However, on a finer scale, regions of significant impairment (Index <30) did show improved conditions (but still poor) and moderately impaired areas showed moderate improvements from 1997-2009 to 2010-2015 and no change (1 site) in the highest quality sites (>60). However, the high TN and phytoplankton bloom years of 2016 and 2017 yielded a significant reduction ($p<0.05$) in the water quality Index from 2010-2015 to 2016-2017 and a return to the baseline conditions of 1997-2009. It should be noted that the declines seen in the 2016-2017 data are driven significantly by the large phytoplankton blooms in 2016-17. The importance of these events will depend on if they are merely rare events spawned by unique environmental conditions (streamflows, wind, precipitation, light) or if it is part of a trend toward increasing bloom frequency and duration due to continued nitrogen enrichment. At this time there does not appear to be any major decline in water quality throughout the Waquoit Bay System, but conditions remain poor to moderate throughout.

In comparison, water quality in the Popponesset Bay System showed more stability between years than Waquoit Bay, with no significant bay-wide differences and the only clear result being the small improvement in the poorest quality areas (long term index<30). However, Popponesset Bay also had moderately large phytoplankton blooms in 2016 and 2017, which impacted water quality. Overall, the trend of improving water quality in the poorest quality areas is a positive sign for both estuaries, as these areas are most nitrogen enriched, but the improvements were not seen in the bloom years of 2016 and 2017. Analysis of macroalgal accumulations in these areas may give insight into if the improvement is related to loading or a diversion to different primary producer (macroalgae versus phytoplankton.

The above approach yields more information on change than the color coded mapping of results (Figures 14a,b and 16a,b) which are based on single years and Index ranges. The direct comparisons are based on individual sites for individual years compared to the baseline conditions. This comparison indicates that for Waquoit Bay (Figure 15), the intermediate areas of impairment in the lower main basins tended to show poorer water quality in 2016-2017, consistent with the observed higher chlorophyll-a (bloom) and oxygen depletions. Popponesset Bay showed a similar pattern (Figure 17) of slightly lower water quality in the main basin in 2016-17 compared to historical levels and experienced a moderately large phytoplankton bloom (which also occurred in Three Bays 2016) with associated bottom water oxygen depletions. At present it is not possible to determine if the system is entering a new level of eutrophication or if the 2016 and 2017 phytoplankton blooms are a response to unique environmental conditions associated with precipitation, light levels and wind. More analysis is needed to determine the importance of the phytoplankton blooms to the restoration plan for these estuaries and if it is the result of a “rare” set of weather conditions or if it will become the new normal in response to continuing high levels of nitrogen enrichment.

MONITORING CONCLUSIONS AND RECOMMENDATIONS

Overall, both the Waquoit Bay and Popponesset Bay Estuarine Systems were highly nitrogen enriched and showed impaired nutrient related water quality in 2010-2017, similar to the long-term pattern. The tidal rivers (Mashpee River, Childs River, Quashnet River) and major tributary basins (Eel Pond/River, Shoestring Bay and Ockway Bay) are all showing poor water quality as evidenced by the Bay Health Index. All basins show nitrogen levels above their TMDL thresholds, periodic oxygen depletions below the state water quality standard and to levels shown to be stressful to estuarine organisms, paired with periodic major phytoplankton blooms. Only the main basins of Waquoit Bay and Popponesset Bay continue to show moderate water quality, but with Hamblin Pond, Great River and Jehu Pond also showing declines in 2017. The major water quality event of 2016 was a large prolonged bloom of *Cochlodinium* (Rust Tide), which was found in many southeastern Massachusetts estuaries, including adjacent Three Bays, and had negative effects on water clarity and bottom water dissolved oxygen as the bloom declined. Although *Cochlodinium* has sometimes been thought to impact shellfish, fortunately there was no evidence of shellfish loss in the recent blooms in Mashpee estuaries. 2016 was also a different weather year, with little rainfall and diminished surfacewater inflows. Summer 2017 showed higher TN levels at the upper stations in the Mashpee River and Shoestring Bay portions of the Popponesset Bay system compared to measured levels in 2016 and earlier years with commensurately elevated levels of total pigment in both 2016 and 2017 (measure of phytoplankton levels). Similarly, the Quashnet River upper basins showed very much higher TN levels in 2017 than previously, with a resulting very large phytoplankton bloom. In both estuaries these tributary basins receive significant freshwater inflows from the rivers discharging to their headwaters and it appears that there were above average freshwater inputs (carrying nitrogen and other constituents) in 2017 as seen in slightly depressed salinities in 2017. Given the 2 consecutive years of large phytoplankton blooms, monitoring should include tracking bloom events in summer 2018. The extent to which these major phytoplankton blooms are a response to relatively rare environmental conditions versus a response to continuing high levels of nitrogen enrichment will be a focus of the Mashpee Water Quality Monitoring Partnership over the next several years, as it directly relates to management and restoration of these estuaries.

With watershed development continuing, estuarine conditions have been projected to decline further until nitrogen management is implemented. Nitrogen management within Popponesset Bay has already begun with the maintenance of the flow through the tidal inlet, propagation of oysters within the system and capping of the Town of Mashpee landfill. In addition, watershed nitrogen management planning has been completed throughout Mashpee watersheds focusing on reducing the major sources of nitrogen (primarily septic system discharges) and possibly enhancing nitrogen removed during transport from the sources to the estuary by pond and stream restoration.

Specific findings:

(1) Both Waquoit Bay and Popponesset Bay appear to be showing few additional impairments, although 2016 and 2017 were poor water quality years due to large phytoplankton blooms coupled with high TN and oxygen depletion. These large blooms were seen in each of the tributary basins to the main basin of Popponesset Bay where chlorophyll-a levels were the highest on record at most stations in 2016 and 2017. Overall, the systems continue to support impaired

habitat quality. Based upon the composite water quality index, there appears to have been a general gradual improvement in overall Waquoit Bay and Popponesset Bay in 2010-2015 compared to 1997-2009, but less so in 2016-2017. However, examination station by station indicates that regions which have historically shown significantly impaired water quality (Health Index <30) have improved slightly (though highly impaired still) and regions in the main basins with moderate impairment that have shown small recent improvements or no changes have been either stable or without significant trends. Based upon the composite index, there were no high water quality areas within either estuary in 2016-2017. It should be noted that the declines associated with summer 2016 and 2017 data are driven significantly by the large observed phytoplankton blooms. The importance of these events will depend on if they are rare and infrequent due to unique environmental conditions or part of a trend toward increasing bloom frequency and duration due to continued nitrogen enrichment. Overall, the 2010-2015 trend in both bays of improving water quality in the poorest quality (most nitrogen enriched) areas, is now less but conditions are not significantly lower than the 1997-2009 baseline. Unfortunately, both estuaries still support impaired habitats and remain below the water quality levels set by the MassDEP/EPA TMDL.

(2) Quashnet River above the bridge was relatively fresh in 2016-2017, continuing the trend of prior years. A separate study (with the Towns of Mashpee and Falmouth) of tidal flows associated with the Quashnet Estuary did not find any major restrictions related to the inlet, bridge or open channel. However, dredging a channel through the flood tidal delta may yield some improvement for water quality. In addition, the results did show that the uppermost tidal reach of the Quashnet is a major nitrogen sink and the sediment should not be disturbed. The study also delimited areas where oysters can survive and grow. TN levels are very high within the upper Quashnet basins and very large phytoplankton blooms were observed in 2016 and 2017 (among the highest on record within Mashpee Estuaries).

(3) Analysis of the total chlorophyll-a and particulate organic nitrogen (PON) data indicate that the PON is directly related to the chlorophyll-a concentration (R^2=0.96). This underscores the contention that the particulate matter in the water column of these estuaries is not "imported" but comprised of phytoplankton growing within the water column. This supports the management plan, which indicates that lowering the nitrogen levels within the estuaries will reduce phytoplankton biomass and improve water and habitat quality.

(4) Oxygen depletion of bottom waters (Figures 9, 13) was variable but still evident within both systems in 2012-2014 and were generally consistent with historical data, following the distribution of nitrogen enrichment and elevated Chlorophyll-a levels. The large phytoplankton blooms in summers of 2016 and 2017 resulted in high total chlorophyll-a levels and increased oxygen depletion in basins where the bloom was observed. The linkage of oxygen depletion to nitrogen enrichment is seen over the long term record and in 2016/2017, with higher oxygen levels at lower levels of nitrogen enrichment and greater depletion in basins with higher nitrogen enrichment. In addition, oxygen data from 2016/2017 supports the linkage between nitrogen enrichment, organic matter loading and oxygen depletion, with enhanced depletion likely due to meteorological forcing factors (wind, light intensity, temperature) as seen in other estuaries in throughout the region.

(5) It appears that the monitoring program has become sufficiently robust to be able to detect changes within the estuaries in response to implementation of management alternatives. Also,

the natural variation obscuring detection of year to year changes is overcome by continued long-term monitoring.

Improvements:

Because of the variability in the dissolved oxygen data, a few recommendations stand out to strengthen the oxygen data base in the Waquoit and Popponesset systems.

Because dissolved oxygen in the water column, especially bottom waters, are subject to periodic episodes of hypoxia/anoxia and because D.O. is such an important component in structuring aquatic ecosystems, as in 2016, we feel that two possible approaches can be taken to improve the oxygen data collection:

1) Continue of Winkler Titrations on water samples where meter readings of D.O. are < 5mg/L. Winkler titration is a more accurate and precise method for quantifying dissolved oxygen concentrations in samples expected to have low DO levels,

2) Collect bottom water light records from Hamblin and Jehu Pond to refine the level of improvement needed to restore eelgrass in these basins as shellfish are deployed by the Town in these basins.

3) Deploy continuously recording dissolved oxygen and chlorophyll mooring at critical location(s) in the Waquoit and Popponesset Bays systems (min. 30-day deployment) to quantify the temporal details of oxygen depletions and blooms during the period of the summer most prone to conditions of low water quality.

Based upon the very large phytoplankton blooms in 2016 and 2017 that appear to be related to freshwater inflows, we recommend re-establishing the MEP stream gauges to track inter-annual variations in freshwater inflows to refine analysis of short-term versus long-term determinants of water quality within each estuary. This will address the question of whether water quality is reaching a new level or if we are only seeing the responses to short-term unique environmental conditions.

In addition, due to the habitat impairments related to continued accumulations of macroalgae, survey of macroalgal accumulations in both estuaries are needed to give insight into: (a) the areas of direct impact on benthic animal communities and low bottom water D.O., (b) the extent to which macroalgae are modifying the nitrogen related water quality and (c) the extent to which they are playing a role in sequestering and releasing nitrogen, thus effecting the occurrence and duration of phytoplankton blooms.

The Mashpee Water Quality Monitoring Partnership has grown to be one of the most successful programs in the region and has provided a sound assessment of the present health of the bays. The Monitoring Program has again proven that it can provide high quality data for tracking the status of both Waquoit and Popponesset Bay Systems and for determining compliance with the USEPA/MassDEP TMDLS for these systems, all in a cost effective manner. The Coordinator (Don MacDonald, Waterways Committee) and volunteers from the Mashpee Wampanoag Tribe, the Town and SMAST continue to meet sampling targets and produce high quality data with the goal of restoring the Town's estuarine waters.

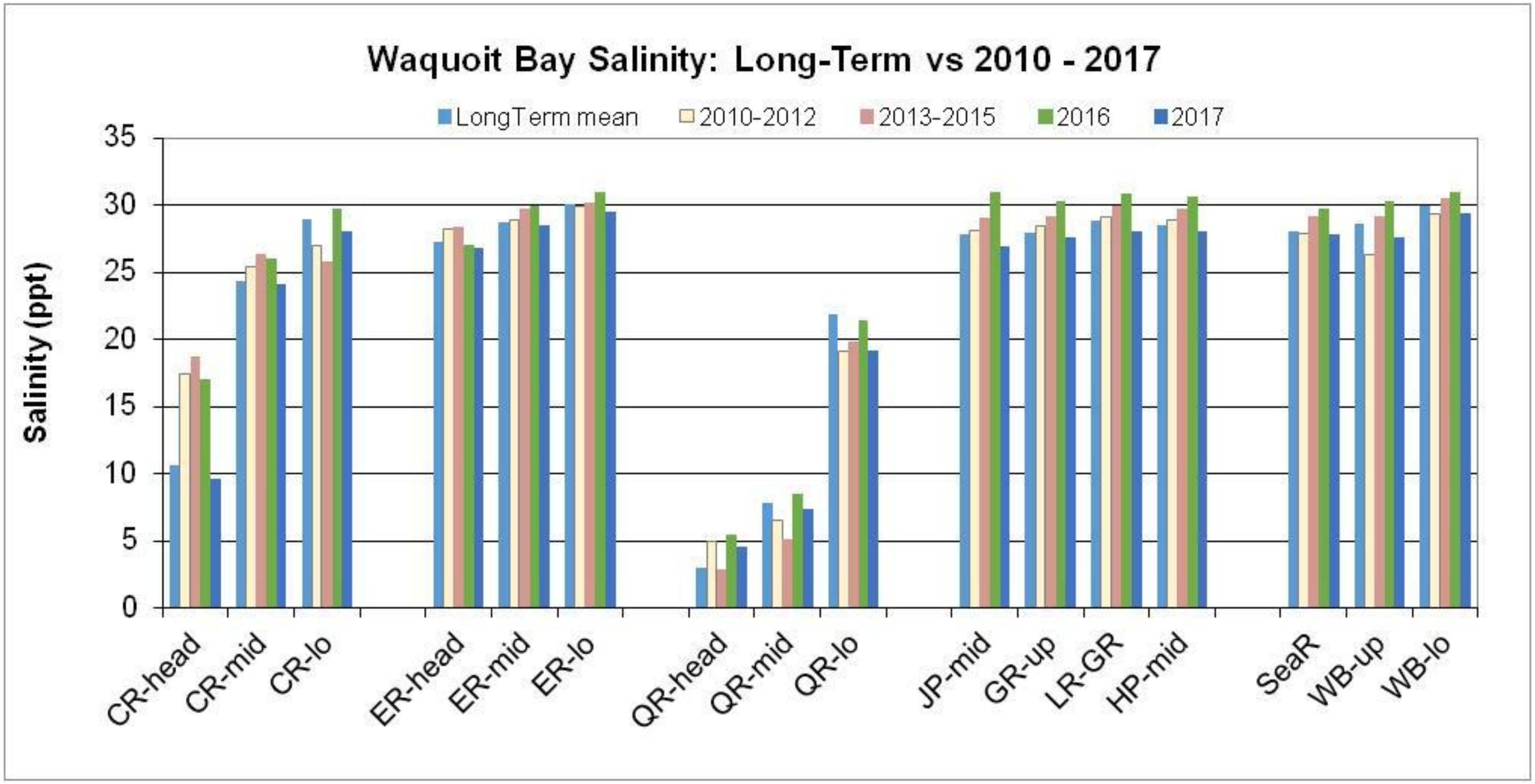

Figure 6. Salinity Distribution throughout the Waquoit Bay Estuarine System long-term and in the summers of 2010-2017. Freshwater enters through groundwater all along the shoreline, with additional "point" inflows from the Moonakis River, Childs River, and Red Brook. These freshwaters mix with the saline waters of Nantucket Sound entering through the tidal inlets. CR - Childs River, ER - Eel River, QR - Quashnet River, JP - Jehu Pond, GR - Great River, LR-GR - Little River-Great River confluence, HP - Hamblin Pond, SeaR - Seapit River, WB - Waquoit Bay main basin; head - uppermost reach, mid - middle reach, lo - lower basin near mouth or inlet.

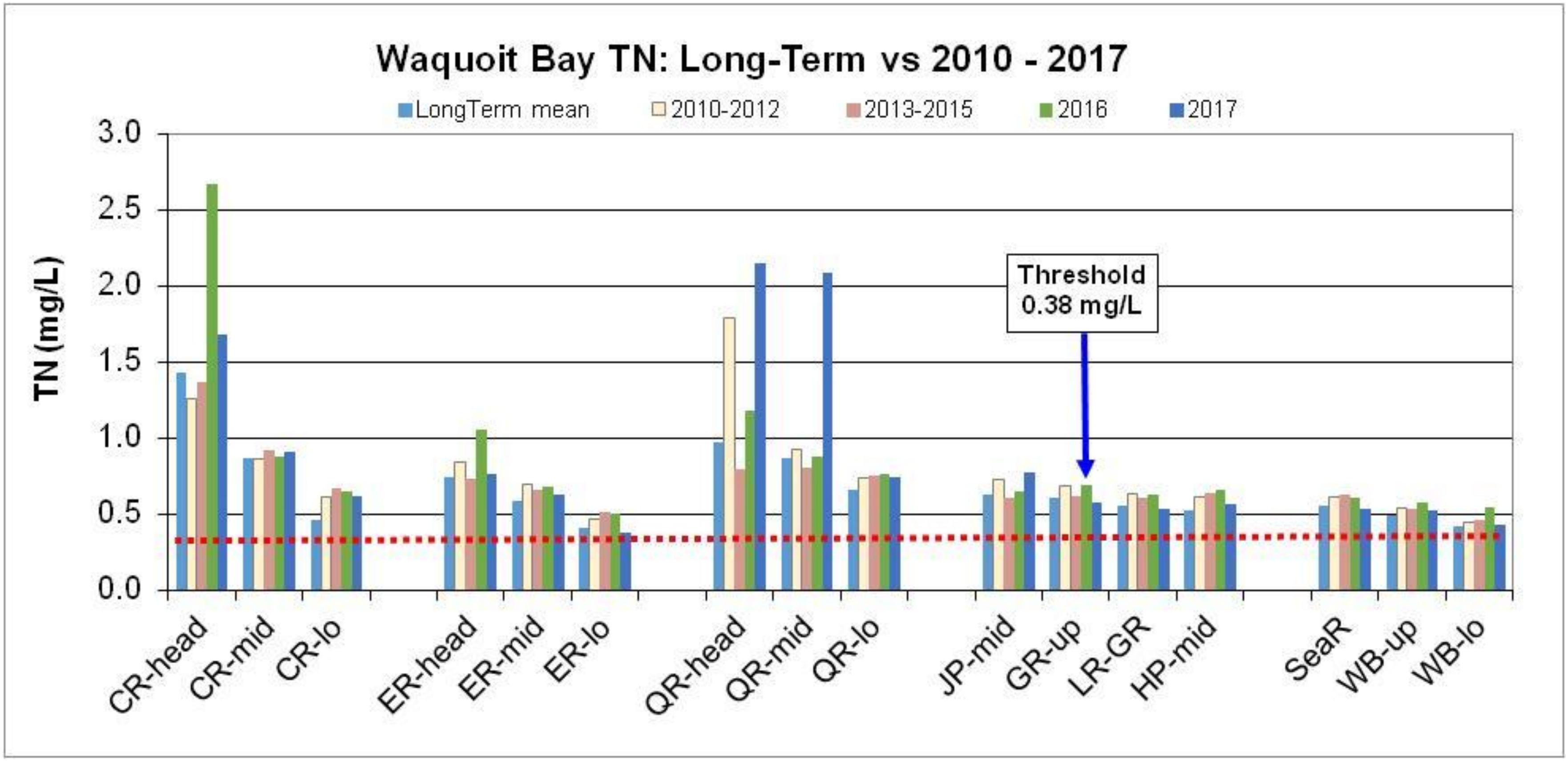

Figure 7. Distribution of Total Nitrogen within the Waquoit Bay Estuarine System, long-term and during the summers of 2010 through 2017. Nitrogen enters through groundwater inflows all along the shoreline, with additional "point" loads from the upper regions of the watershed via Moonakis River, Childs River, and Red Brook. These nitrogen loads plus recycling within the estuary mix with the low nitrogen waters of Nantucket Sound entering through the tidal inlets to create the observed gradient. CR - Childs River, ER - Eel River, QR - Quashnet River, JP - Jehu Pond, GR - Great River, LR-GR - Little River-Great River confluence, HP - Hamblin Pond, SeaR - Seapit River, WB - Waquoit Bay main basin; head - uppermost reach, mid - middle reach, lo - lower basin near mouth or inlet. The red line shows the offshore TN concentration (0.28 mg/L) and "Threshold" is the TMDL target for restoration.

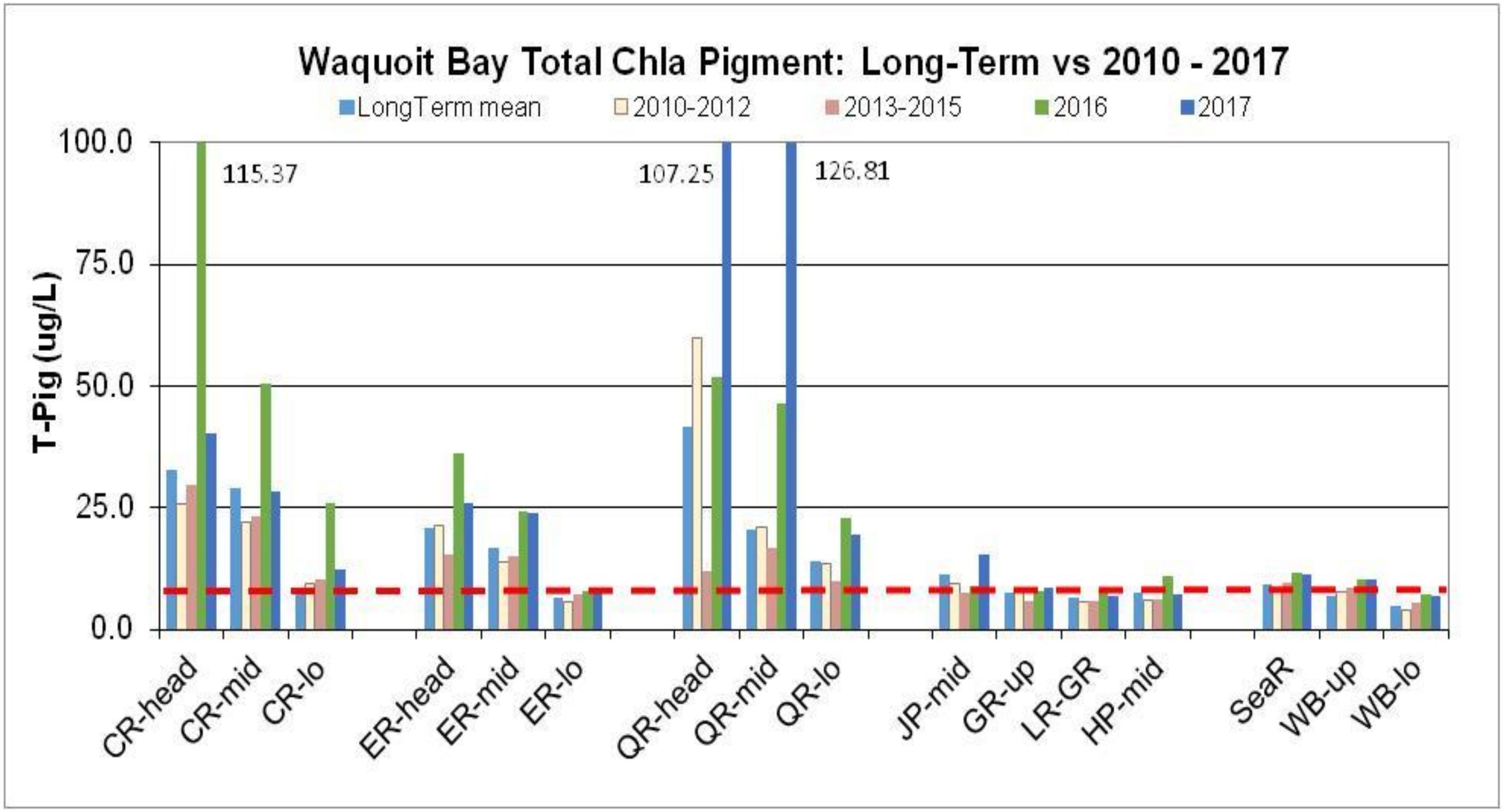

Figure 8. Total Chlorophyll-a pigment levels throughout the Waquoit Bay Estuarine System over the long-term and in summers of 2009 through 2017. Phytoplankton pigment levels are a gauge of phytoplankton biomass, which is a response to nitrogen loading. Values over 10 indicate nitrogen enrichment, values <u><3</u> represent low nitrogen enriched waters (red line). CR - Childs River, ER - Eel River, QR - Quashnet River, JP - Jehu Pond, GR - Great River, LR-GR - Little River-Great River confluence, HP - Hamblin Pond, SeaR - Seapit River, WB - Waquoit Bay main basin; head - uppermost reach, mid - middle reach, lo - lower basin near mouth or inlet.

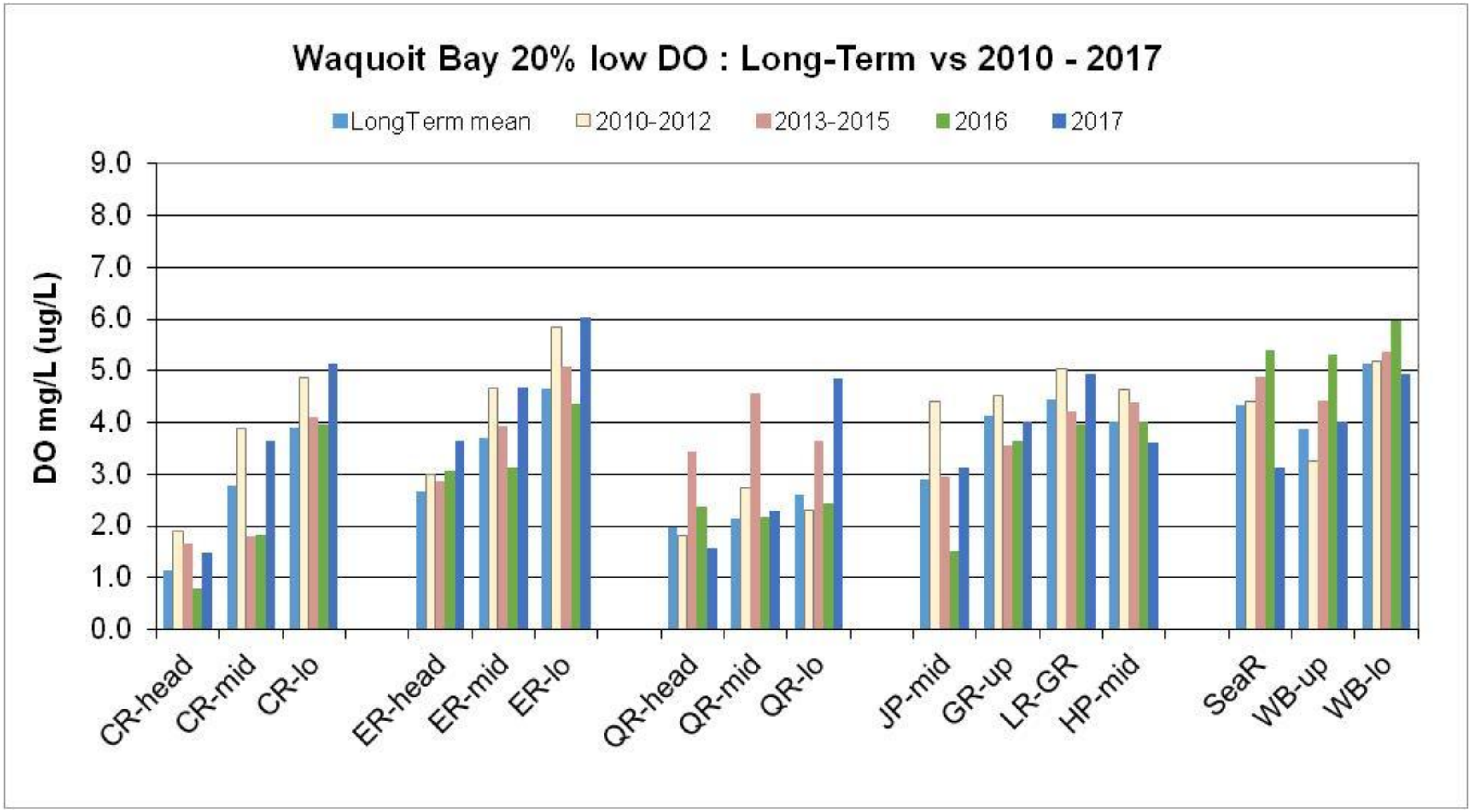

Figure 9. Minimum Dissolved Oxygen (D.O.) levels throughout the Waquoit Bay Estuarine System over the long-term and in the summers of 2010-2017. CR - Childs River, ER - Eel River, QR - Quashnet River, JP - Jehu Pond, GR - Great River, LR-GR - Little River-Great River confluence, HP - Hamblin Pond, SeaR - Seapit River, WB - Waquoit Bay main basin; head - uppermost reach, mid - middle reach, lo - lower basin near mouth or inlet.

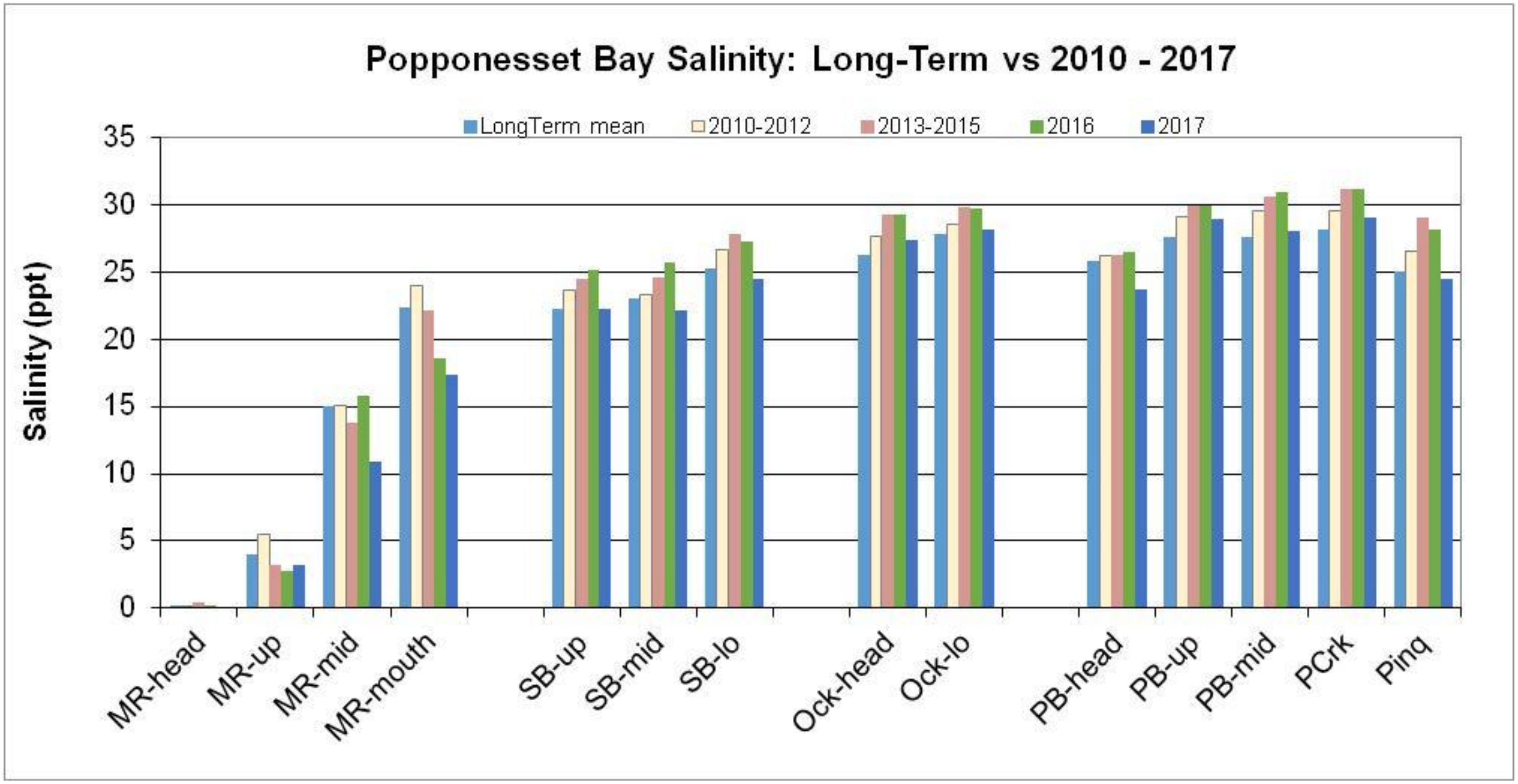

Figure 10. Salinity Distribution throughout the Popponesset Bay Estuarine System (2010-2017). Freshwater enters through groundwater all along the shoreline, with additional "point" inflows from the freshwater reach of the Mashpee River and from the Santuit River to Shoestring Bay. These freshwaters mix with the saline waters of Nantucket Sound entering through the single tidal inlet. MR - Mashpee River, SB - Shoestring Bay, Ock - Ockway Bay, PB - Popponesset Bay, PCrk - Popponesset Creek, Pinq - Pinquickset Cove.

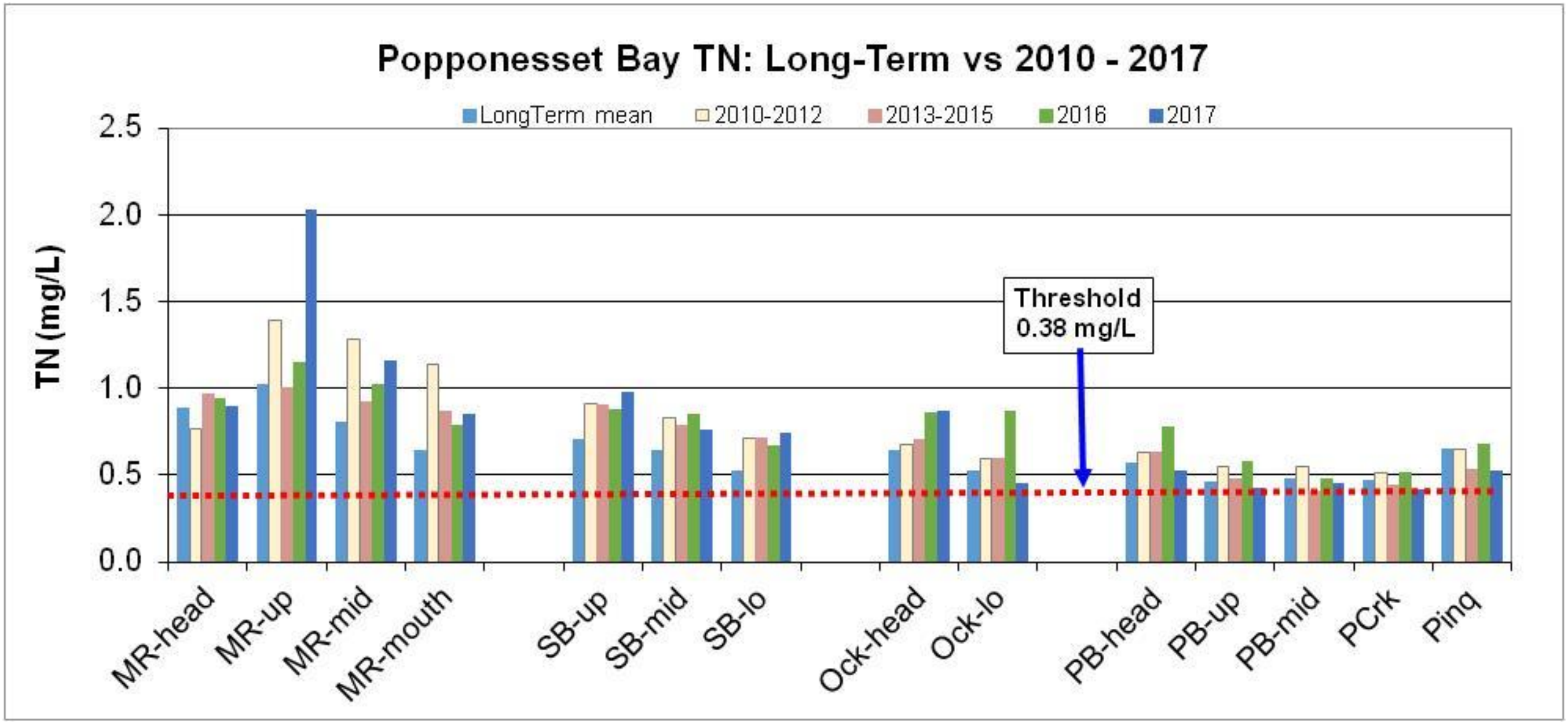

Figure 11. Distribution of Total Nitrogen within the Popponesset Bay Estuarine System. Nitrogen enters through groundwater inflows all along the shoreline, with additional "point" loads from the upper regions of the watershed via the Mashpee River and Santuit River to Shoestring Bay. These nitrogen loads plus recycling within the estuary mix with the low nitrogen waters of Nantucket Sound entering through the single tidal inlet to create the observed gradient. MR - Mashpee River, SB - Shoestring Bay, Ock - Ockway Bay, PB - Popponesset Bay, PCrk - Poppenesset Creek, Pinq - Pinquickset Cove. The red line shows the offshore TN concentration (0.28 mg/L); "Threshold" is the TMDL target for restoration. TN levels in 2010-2017 are compared to the long-term average.

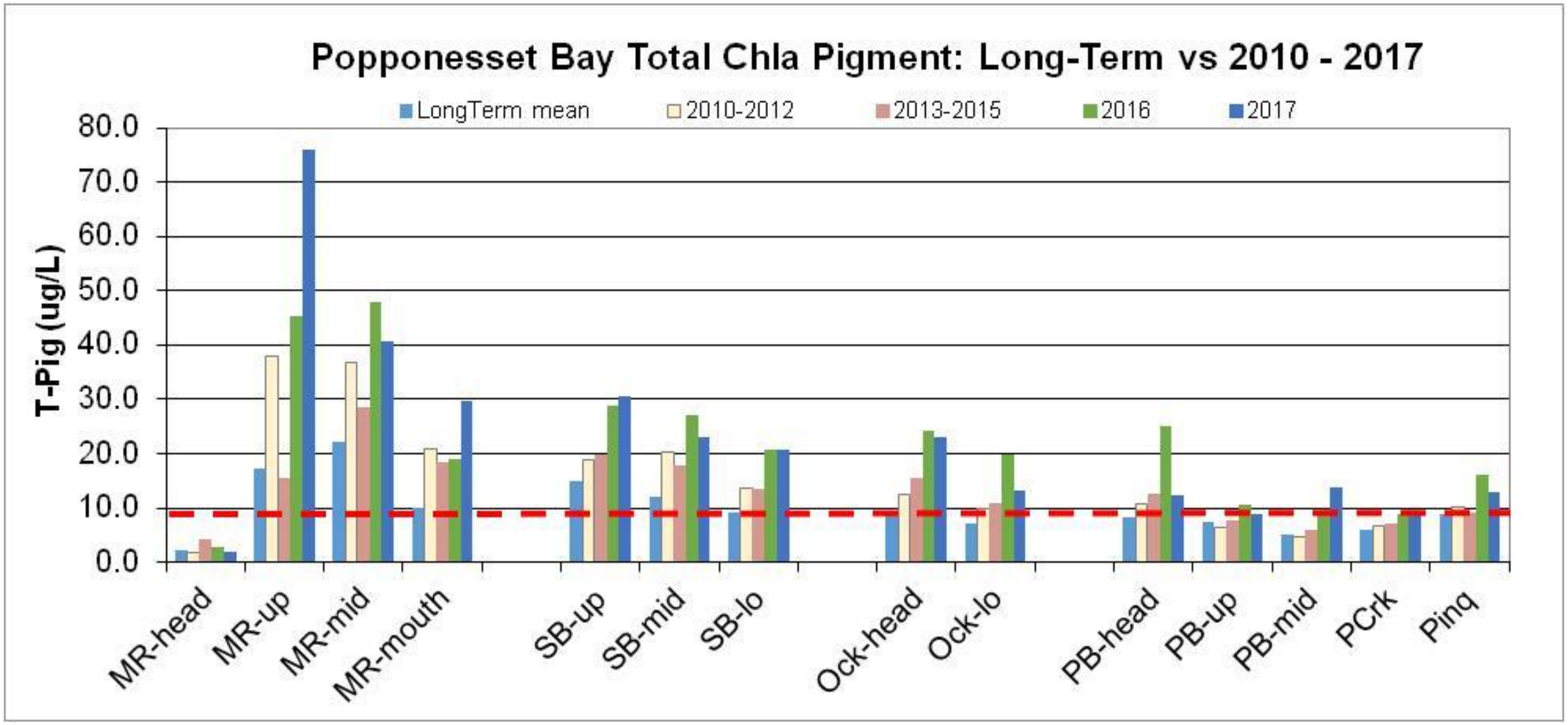

Figure 12. Total Chlorophyll-a pigment levels throughout the Popponesset Bay Estuarine System over the long-term and in summer 2010-2017. Phytoplankton pigment levels are a gauge of phytoplankton biomass, which is a response to nitrogen loading. Values over 10 indicate nitrogen enrichment, values <u><3</u> represent low nitrogen enriched waters (red line). MR - Mashpee River, SB - Shoestring Bay, Ock - Ockway Bay, PB - Popponesset Bay, PCrk - Poppenesset Creek, Pinq - Pinquickset Cove.

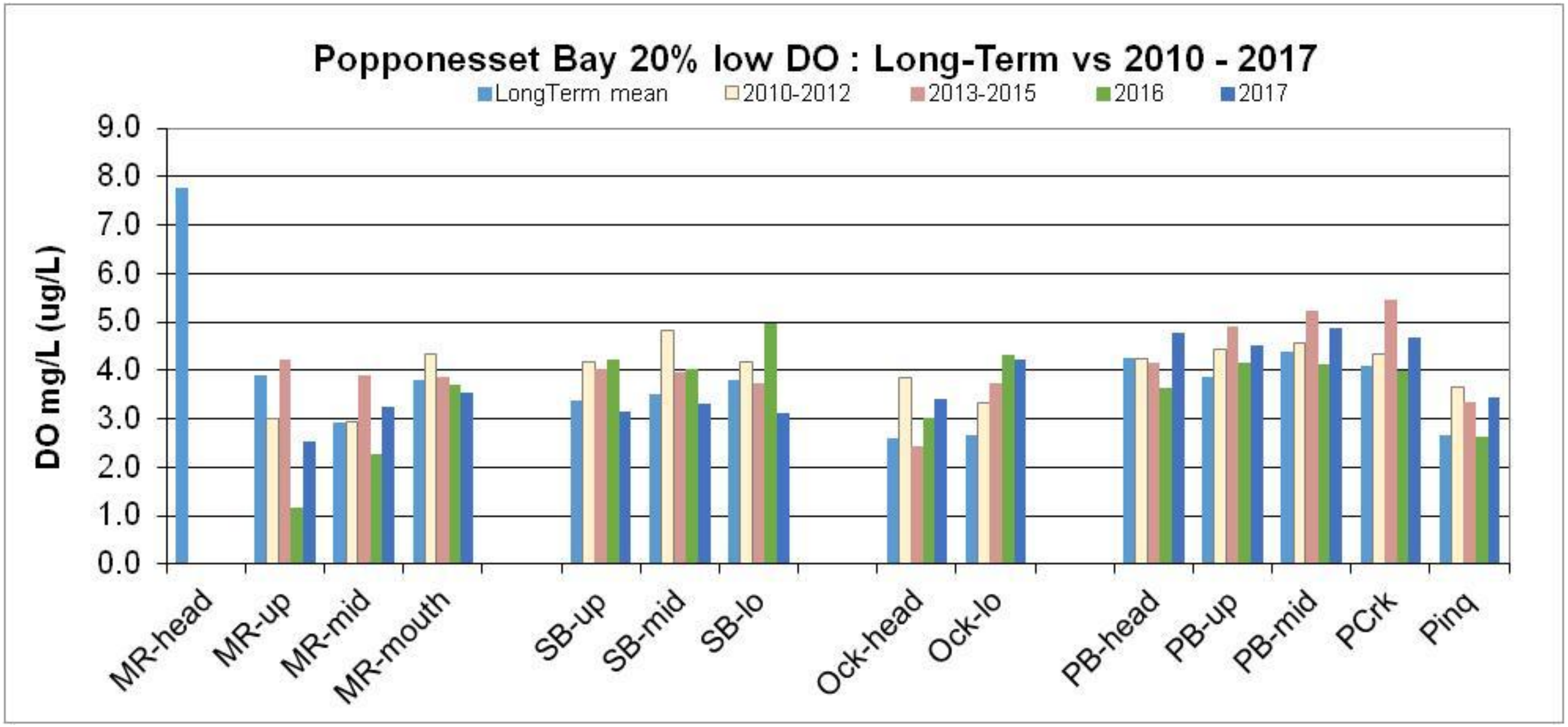

Figure 13. Minimum Dissolved Oxygen levels throughout the Popponesset Bay Estuarine System over the long-term and in the summers of 2010 through 2017. MR - Mashpee River, SB - Shoestring Bay, Ock - Ockway Bay, PB - Popponesset Bay, PCrk - Poppenesset Creek, Pinq - Pinquickset Cove.

Table 4a. Summary of water quality parameters in Waquoit Bay. Summer 2017.

2017 Station	Secchi Depth (m)	Total Depth (m)	Secchi as % W.C.	Salinity (ppt)	20% Low D.O. (mg/L)	20% Low D.O. (% Sat)	PO4 (mg/L)	NH4 (mg/L)	NOx (mg/L)	DIN (mg/L)	DON (mg/L)	PON (mg/L)	TON (mg/L)	TN (mg/L)	DIN/DIP Molar	T-Pig (ug/L)
Childs River																
CR01	0.66	0.69	96%	9.58	1.48	19.40	0.02	0.04	0.55	0.59	0.42	0.67	1.09	1.68	69.35	40.26
CR02	1.27	1.64	78%	24.12	3.64	38.41	0.01	0.04	0.02	0.06	0.42	0.44	0.85	0.91	9.78	28.14
CR03	1.66	2.36	70%	28.03	5.15	68.20	0.01	0.03	0.01	0.03	0.39	0.19	0.58	0.62	5.85	12.34
Eel River															0	0.0
ER01	1.04	1.11	94%	26.87	3.64	38.41	0.01	0.02	0.01	0.03	0.38	0.35	0.73	0.76	14.00	25.90
ER02	1.21	1.28	95%	28.49	4.69	65.20	0.01	0.00	0.00	0.01	0.31	0.32	0.62	0.63	2.85	23.76
ER03	btm	1.10	100%	29.52	6.02	79.50	0.01	0.01	0.00	0.01	0.23	0.14	0.37	0.38	2.99	8.59
Waquoit Bay															0	0.0
WB01	1.45	2.68	54%	26.90	3.13	62.61	0.02	0.05	0.00	0.05	0.43	0.30	0.73	0.77	4.65	15.29
WB02	btm	1.18	100%	27.60	4.01	63.89	0.02	0.05	0.00	0.05	0.35	0.18	0.52	0.58	5.01	8.69
WB03	2.10	2.26	93%	28.01	4.95	73.23	0.02	0.04	0.00	0.04	0.36	0.14	0.49	0.53	4.06	6.86
WB04	btm	1.31	100%	28.03	3.62	59.80	0.02	0.03	0.00	0.03	0.39	0.15	0.54	0.57	2.84	7.03
WB05	ND	ND	ND	0.10	ND	ND	0.02	0.02	0.01	0.03	0.55	0.15	0.69	0.72	2.66	10.46
WB06	ND	ND	ND	0.10	ND	ND	0.01	0.02	0.32	0.34	0.31	0.06	0.36	0.70	78.40	3.71
WB07	btm	0.44	100%	4.55	1.57	17.10	0.02	0.06	0.19	0.25	0.47	1.42	1.90	2.15	23.55	107.25
WB08	0.57	0.71	81%	7.43	2.30	28.00	0.02	0.03	0.13	0.16	0.38	1.54	1.92	2.08	21.42	126.81
WB09	0.80	1.01	80%	19.20	4.84	70.00	0.02	0.02	0.01	0.03	0.37	0.34	0.71	0.74	4.01	19.51
WB10	ND	ND	ND	27.95	ND	ND	0.03	0.06	0.00	0.06	0.39	0.16	0.55	0.61	4.79	9.25
WB11	1.49	1.85	81%	27.84	4.99	65.10	0.01	0.01	0.00	0.01	0.31	0.21	0.52	0.53	3.79	11.41
WB12	1.60	2.04	79%	27.59	2.97	42.00	0.01	0.01	0.00	0.01	0.31	0.20	0.51	0.52	1.74	10.27
WB13	1.85	2.25	82%	29.37	4.89	68.20	0.01	0.01	0.00	0.01	0.27	0.14	0.41	0.42	2.46	6.92

Secchi as % of WC is the % of the watercolumn above the secchi depth, values of 100% means that the Secchi was at or below the bottom.

Lowest 20% of D.O. records for a site over the project period.

Btm means that Secchi Disk as on bottom and therefore the depth of disk diappearance could not be determined (never disappears)

Table 4b. Summary of water quality parameters in Waquoit Bay. Summer 2016.

2016 Station	Secchi Depth (m)	Total Depth (m)	Secchi as % W.C.	Salinity (ppt)	20% Low D.O. (mg/L)	20% Low D.O. (% Sat)	PO4 (mg/L)	NH4 (mg/L)	NOx (mg/L)	DIN (mg/L)	DON (mg/L)	PON (mg/L)	TON (mg/L)	TN (mg/L)	DIN/DIP Molar	T-Pig (ug/L)
Childs River																
CR01	Btm	0.67	100%	17.07	0.80	9.10	0.04	0.05	0.35	0.40	0.81	1.45	2.26	2.67	20.38	115.37
CR02	1.07	1.40	79%	26.03	1.83	13.50	0.01	0.01	0.01	0.01	0.39	0.47	0.86	0.88	4.42	50.61
CR03	1.33	1.99	78%	29.72	3.96	58.10	0.02	0.03	0.01	0.04	0.37	0.25	0.61	0.65	3.82	25.98
Eel River															0	0.0
ER01	1.05	1.30	82%	27.08	3.08	42.60	0.01	0.01	0.00	0.01	0.46	0.58	1.04	1.06	5.62	36.00
ER02	1.14	1.26	90%	30.01	3.12	44.60	0.01	0.01	0.00	0.01	0.34	0.33	0.67	0.68	2.76	24.17
ER03	Btm	1.22	100%	30.97	4.37	61.40	0.01	0.02	0.00	0.02	0.35	0.13	0.48	0.50	3.34	7.92
Waquoit Bay															0	0.0
WB01	2.21	2.58	86%	30.97	1.50	25.70	0.04	0.01	0.00	0.01	0.48	0.16	0.64	0.65	0.72	8.87
WB02	Btm	1.27	100%	30.28	3.65	64.70	0.03	0.03	0.01	0.03	0.51	0.15	0.65	0.69	2.74	7.77
WB03	1.96	2.12	92%	30.92	3.97	70.00	0.02	0.06	0.01	0.07	0.40	0.16	0.56	0.62	8.53	7.95
WB04	Btm	1.22	100%	30.66	4.02	68.80	0.02	0.02	0.00	0.02	0.43	0.21	0.64	0.66	2.93	10.97
WB05	ND	ND	ND	0.10	ND	ND	0.01	0.02	0.00	0.02	0.74	0.41	1.15	1.17	3.62	19.63
WB06	ND	ND	ND	0.13	ND	ND	0.01	0.02	0.15	0.18	0.26	0.29	0.55	0.72	40.97	7.32
WB07	0.58	0.60	96%	5.44	2.38	33.00	0.02	0.10	0.13	0.24	0.47	0.47	0.94	1.18	34.11	51.94
WB08	0.79	0.89	89%	8.46	2.17	26.40	0.02	0.06	0.06	0.11	0.33	0.44	0.77	0.88	11.36	46.39
WB09	1.01	1.06	96%	21.43	2.45	30.00	0.03	0.04	0.02	0.06	0.37	0.33	0.70	0.76	5.25	22.87
WB10	ND	ND	ND	30.33	ND	ND	0.02	0.05	0.06	0.11	0.35	0.19	0.54	0.65	13.31	10.46
WB11	1.49	1.83	83%	29.79	5.41	79.10	0.02	0.02	0.00	0.03	0.37	0.22	0.58	0.61	2.95	11.65
WB12	1.66	1.93	86%	30.25	5.33	78.30	0.02	0.01	0.00	0.02	0.35	0.21	0.56	0.57	2.20	10.24
WB13	2.01	2.05	98%	30.95	5.97	8.20	0.02	0.01	0.00	0.02	0.35	0.18	0.52	0.54	1.93	7.22

Secchi as % of WC is the % of the watercolumn above the secchi depth, values of 100% means that the Secchi was at or below the bottom.
Lowest 20% of D.O. records for a site over the project period.

Btm means that Secchi Disk as on bottom and therefore the depth of disk diappearance could not be determined (never disappears)

Table 5a. Summary of water quality parameters in Popponesset Bay. Summer 2017.

2017 Station	Secchi Depth (m)	Total Depth (m)	Secchi as % W.C.	Salinity (ppt)	20% Low D.O. (mg/L)	20% Low D.O. (% Sat)	PO4 uM	NH4 uM	NOx uM	DIN uM	DON uM	PON uM	TON uM	TN uM	DIN/DIP Molar	T-Pig ug/L
Mashpee River/Popponesset Bay																
PB01	ND	ND	ND	0.10	ND	ND	0.27	3.00	34.14	37.14	23.13	3.76	26.89	64.03	136.25	1.99
PB02	btm	0.57	100%	3.26	2.52	30.70	0.37	3.36	20.03	23.39	42.57	79.06	121.63	145.02	62.38	75.97
PB03	btm	0.58	100%	10.95	3.26	40.67	0.33	3.69	6.66	10.35	32.38	40.46	72.84	83.19	31.43	40.62
PB04	btm	0.79	100%	17.36	3.53	45.60	0.28	3.69	2.32	5.54	23.03	32.42	55.45	61.00	19.71	29.74
PB05	0.87	1.33	85%	22.31	3.15	45.20	0.31	1.18	0.11	1.29	28.79	39.96	68.75	70.05	4.22	30.56
PB06	0.96	1.34	87%	22.12	3.31	45.30	0.37	1.04	0.20	1.24	23.74	29.35	53.09	54.33	3.37	23.00
PB07	0.73	0.75	98%	24.53	3.10	43.00	0.35	2.70	0.03	2.73	21.96	28.68	50.64	53.37	7.88	20.67
PB09	0.98	1.28	76%	27.36	3.41	44.60	0.19	0.66	0.03	0.68	20.62	40.76	61.38	62.06	3.67	22.93
PB10	0.95	1.00	95%	28.16	4.24	56.50	0.30	0.71	0.10	0.80	13.60	18.07	31.67	32.48	2.69	13.22
PB08	1.19	1.43	84%	23.72	4.77	66.80	0.25	0.57	0.29	0.86	20.18	16.48	36.67	37.53	3.44	12.37
PB11	btm	1.24	100%	28.93	4.53	63.20	0.40	0.79	0.03	0.82	19.54	10.38	29.92	30.74	2.05	8.81
PB12	1.49	1.58	96%	28.04	4.89	74.80	0.29	1.83	0.07	1.90	19.07	11.37	30.44	32.34	6.50	13.85
PB13	1.46	1.63	92%	29.08	4.69	65.70	0.42	1.48	0.15	1.63	19.08	9.14	28.22	29.85	3.93	8.69
PB15	btm	0.63	100%	24.53	3.43	46.70	0.33	1.01	0.05	1.06	21.96	14.81	36.77	37.83	3.27	12.98
PB14	btm	1.48	100%	30.21	5.67	78.70	0.35	0.74	0.03	0.77	16.53	11.67	28.19	28.96	2.21	5.10
Santuit River																
SR5	ND	ND	ND	7.43	ND	ND	0.89	4.81	30.79	35.59	30.73	36.69	67.42	103.01	40.16	29.42

Table 5b. Summary of water quality parameters in Popponesset Bay. Summer 2016.

2016 Station	Secchi Depth (m)	Total Depth (m)	Secchi as % W.C.	Salinity (ppt)	20% Low D.O. (mg/L)	20% Low D.O. (% Sat)	PO4 (mg/L)	NH4 (mg/L)	NOx (mg/L)	DIN (mg/L)	DON (mg/L)	PON (mg/L)	TON (mg/L)	TN (mg/L)	DIN/DIP Molar	T-Pig (ug/L)
Mashpee River/Popponesset Bay																
PB01	ND	ND	ND	0.18	ND	ND	0.006	0.042	0.580	0.622	0.232	0.090	0.322	0.945	345.35	2.75
PB02	btm	0.53	100%	2.81	1.15	14.70	0.010	0.030	0.243	0.273	0.321	0.492	0.797	1.152	58.88	45.42
PB03	btm	0.77	100%	15.81	2.27	28.00	0.011	0.028	0.113	0.141	0.357	0.522	0.879	1.021	28.20	48.00
PB04	btm	0.74	100%	18.58	3.71	36.80	0.013	0.027	0.047	0.074	0.343	0.369	0.712	0.786	12.95	18.88
PB05	0.83	0.87	97%	25.20	4.22	60.50	0.012	0.012	0.006	0.018	0.403	0.456	0.859	0.877	3.33	28.83
PB06	0.74	0.81	91%	25.69	4.04	57.00	0.018	0.014	0.004	0.018	0.429	0.407	0.835	0.854	2.17	26.93
PB07	btm	0.60	100%	27.28	4.98	69.95	0.021	0.019	0.004	0.023	0.360	0.292	0.652	0.675	2.39	20.84
PB09	1.02	1.26	81%	29.26	3.02	37.80	0.008	0.008	0.004	0.012	0.428	0.419	0.847	0.859	3.35	24.19
PB10	btm	0.95	100%	29.70	4.31	56.40	0.011	0.007	0.003	0.010	0.337	0.526	0.863	0.874	2.06	19.73
PB08	1.38	2.13	64%	26.48	3.63	49.00	0.023	0.011	0.004	0.016	0.387	0.376	0.762	0.778	1.50	25.02
PB11	1.15	1.19	97%	29.95	4.14	59.90	0.020	0.025	0.004	0.029	0.361	0.187	0.548	0.577	3.18	10.45
PB12	1.61	1.88	86%	30.96	4.14	60.60	0.021	0.036	0.005	0.041	0.300	0.144	0.444	0.485	4.44	9.07
PB13	1.92	2.50	77%	31.23	4.00	59.00	0.016	0.025	0.006	0.031	0.359	0.131	0.490	0.521	4.31	8.98
PB15	btm	0.63	100%	28.13	2.62	38.00	0.018	0.018	0.004	0.022	0.389	0.270	0.659	0.681	2.64	16.04
PB14	btm	1.53	100%	31.86	4.56	66.70	0.016	0.011	0.003	0.014	0.337	0.098	0.435	0.449	1.87	4.48
Santuit River																
SR5	ND	ND	ND	15.98	ND	ND	0.035	0.084	0.388	0.472	0.387	0.292	0.678	1.151	31.56	35.93

Table 6a. Trophic Health Index Scores and status for marine water quality monitoring stations in Waquoit Bay, 2017 and Long-Term, based upon open water embayment (not salt marsh) habitat quality scales (described in Howes et al. 1999) at (www.savebuzzardsbay.org).

Sample ID	Secchi Depth (m)	20% Low D.O. (% Sat)	DIN (mg/L)	TON (mg/L)	Total Pigments (ug/L)	Secchi SCORE	Low20% Oxsat SCORE	DIN SCORE	TON SCORE	T-Pig SCORE	2017 EUTRO Index	2017 Health Status	Long-Term EUTRO Index	Long-Term Health Status
CR01	0.66	19%	0.590	1.088	40.260	5.4	0.0	0.0	0.0	0.0	1.1	Fair/Poor	1.1	Fair/Poor
CR02	1.27	38%	0.056	0.853	28.144	46.7	0.0	39.7	0.0	0.0	17.3	Fair/Poor	15.8	Fair/Poor
CR03	1.66	68%	0.033	0.585	12.338	63.3	65.8	63.0	3.4	0.0	39.1	Moderate/Fair	46.0	Moderate
ER01	1.0	38%	0.032	0.727	25.902	34.0	0.0	64.1	0.0	0.0	19.6	Fair/Poor	21.9	Fair/Poor
ER02	1.2	65%	0.007	0.622	23.758	43.7	60.2	100.0	0.0	0.0	40.8	Moderate/Fair	35.9	Moderate
ER03	btm	80%	0.012	0.370	8.590	Btm	84.7	100.0	63.6	12.6	65.2	High/Moderate	63.8	High
WB01	1.5	63%	0.050	0.725	15.290	54.8	55.3	45.1	0.0	0.0	31.0	Moderate/Fair	31.9	Moderate
WB02	btm	64%	0.054	0.525	8.686	Btm	57.7	41.4	17.5	11.7	32.1	Moderate/Fair	39.1	Moderate
WB03	2.1	73%	0.040	0.491	6.856	77.8	74.6	54.3	26.2	31.4	52.9	Moderate	49.4	Moderate
WB04	btm	60%	0.027	0.541	7.028	Btm	49.6	71.2	13.5	29.3	40.9	Moderate/Fair	44.5	Moderate
WB05	ND	ND	0.030	0.693	10.457	Btm	ND	67.2	0.0	0.0	22.4	Fair/Poor	19.9	Fair/Poor
WB06	ND	ND	0.339	0.362	3.707	Btm	ND	0.0	66.1	82.4	49.5	Moderate	30.8	Fair/Poor
WB07	btm	17%	0.250	1.898	107.254	Btm	0.0	0.0	0.0	0.0	0.0	Fair/Poor	0.0	Fair/Poor
WB08	0.6	28%	0.163	1.920	126.808	Btm	0.0	0.0	0.0	0.0	0.0	Fair/Poor	6.7	Fair/Poor
WB09	0.8	70%	0.028	0.713	19.510	Btm	69.0	70.2	0.0	0.0	34.8	Moderate/Fair	16.3	Fair/Poor
WB10	ND	ND	0.060	0.548	9.252	Btm	ND	36.6	12.0	6.5	18.3	Fair/Poor	19.1	Fair/Poor
WB11	1.5	65%	0.014	0.516	11.408	56.4	60.1	100.0	19.7	0.0	47.2	Moderate	38.5	Moderate
WB12	1.6	42%	0.007	0.511	10.265	60.9	6.0	100.0	21.0	0.0	37.6	Moderate	50.3	Moderate
WB13	1.9	68%	0.014	0.410	6.924	70.0	65.8	100.0	49.9	30.5	63.2	High/Moderate	72.2	High
					High Quality = >69; High/Moderate = 61-69; Moderate = 39-61; Moderate/Fair = 31-39; Fair/Poor = <31									

Table 6b. Trophic Health Index Scores and status for marine water quality monitoring stations in Waquoit Bay, 2016 and Long-Term, based upon open water embayment (not salt marsh) habitat quality scales (described in Howes et al. 1999) at (www.savebuzzardsbay.org).

2016 Station	Secchi Depth (m)	20% Low).O. (% Sat	DIN mg/L	TON mg/L	T-Pig (ug/L)	Secchi SCORE	Low20% Oxsat SCORE	DIN SCORE	TON SCORE	T-Pig SCORE	**2016** EUTRO Index	**2016** HEALTH STATUS	**Longterm 2001-09** EUTRO Index	HEALTH STATUS
CR01		9.10	0.402	2.264	115.37		0	0	0	0	0	Fair/Poor	1.1	Fair/Poor
CR02	1.07	13.50	0.015	0.863	50.61	36	0	98	0	0	27	Fair/Poor	15.8	Fair/Poor
CR03	1.33	58.10	0.037	0.613	25.98	49	46	57	0	0	31	Mod/Fair	46.0	Moderate
ER01	1.05	42.60	0.013	1.044	36.00	35	8	100	0	0	29	Fair/Poor	21.9	Fair/Poor
ER02	1.14	44.60	0.012	0.668	24.17	40	13	100	0	0	31	Mod/Fair	35.9	Mod/Fair
ER03	2	61.40	0.022	0.476	7.92	75	53	79	30	19	51	Moderate	63.8	High/Mod
WB01	2.21	25.70	0.013	0.638	8.87	81	0	100	0	10	38	Mod/Fair	31.9	Mod/Fair
WB02	2	64.70	0.034	0.655	7.77	75	59	61	0	21	43	Moderate	39.1	Moderate
WB03	1.96	70.00	0.065	0.560	7.95	73	69	33	9	19	41	Moderate	49.4	Moderate
WB04	1.8	68.80	0.020	0.638	10.97	68	67	84	0	0	44	Moderate	44.5	Moderate
WB05			0.017	1.153	19.63			Freshwater						
WB06			0.180	0.545	7.32			Freshwater						
WB07	0.58	33.00	0.236	0.943	51.94	0	0	0	0	0	0	Fair/Poor	0.0	Fair/Poor
WB08	0.79	26.40	0.112	0.767	46.39	17	0	10	0	0	5	Fair/Poor	6.7	Fair/Poor
WB09	1.01	30.00	0.060	0.698	22.87	33	0	37	0	0	14	Fair/Poor	16.3	Fair/Poor
WB10			0.109	0.541	10.46			11	13	0	8	Fair/Poor	19.1	Fair/Poor
WB11	1.49	79.10	0.025	0.583	11.65	56	84	74	4	0	44	Moderate	38.5	Moderate
WB12	1.66	78.30	0.016	0.557	10.24	63	83	95	10	0	50	Moderate	50.3	Moderate
WB13	2.01	82.91	0.015	0.524	7.22	75	90	97	18	27	61	High/Mod	72.2	High

Table 7a. Trophic Health Index Scores and status for marine water quality monitoring stations in Popponesset Bay, 2017 and long- term, based upon open water embayment (not salt marsh) habitat quality scales (described in Howes et al. 1999) at www.savebuzzardsbay.org).

Station	Secchi Depth (m)	20% Low D.O. (% Sat)	DIN (mg/L)	TON (mg/L)	T-Pig (ug/L)	Secchi SCORE	Low20% Oxsat SCORE	DIN SCORE	TON SCORE	T-Pig SCORE	2017 EUTRO Index	2017 Health Status	97-09 EUTRO Index	97-09 Health Status
PB01	ND	ND	0.52	0.38	1.99	ND	ND	0.0	61.09	100.00	53.7	Moderate	36.4	Mod/Fair
PB02	btm	30.70%	0.33	1.70	75.97	ND	0.0	0.0	0.00	0.00	0.00	Fair/Poor	2.2	Fair/Poor
PB03	btm	40.67%	0.14	1.02	40.62	100.0	2.0	0.0	0.00	0.00	20.4	Fair/Poor	4.0	Fair/Poor
PB04	btm	45.60%	0.08	0.78	29.74	100.0	16.2	25.6	0.00	0.00	28.3	Fair/Poor	24.3	Fair/Poor
PB05	0.87	45.20%	0.02	0.96	30.56	23.1	15.1	88.9	0.00	0.00	25.4	Fair/Poor	18.2	Fair/Poor
PB06	0.96	45.30%	0.02	0.74	23.00	29.2	15.3	90.8	0.00	0.00	27.1	Fair/Poor	21.4	Fair/Poor
PB07	0.73	43.00%	0.04	0.71	20.67	12.3	8.9	56.4	0.00	0.00	15.5	Fair/Poor	31.3	Mod/Fair
PB08	1.19	66.80%	0.01	0.51	12.37	42.4	63.2	100.0	20.40	0.00	45.2	Moderate	46.4	Moderate
PB09	0.98	45%	0.01	0.86	22.93	30.2	13.4	100.0	0.00	0.00	28.7	Fair/Poor	22.8	Fair/Poor
PB10	0.95	57%	0.01	0.44	13.22	on btm	42.6	100.0	39.61	0.00	45.6	Moderate	30.6	Fair/Poor
PB11	btm	63.20%	0.01	0.42	8.81	on btm	56.4	100.0	47.1	10.5	53.5	Moderate	43.1	Moderate
PB12	1.49	74.80%	0.03	0.43	13.85	on btm	ND	72.1	44.8	0.0	39.0	Moderate/Fair	46.6	Moderate
PB13	1.46	65.70%	0.02	0.40	8.69	55.4	61.2	78.7	54.8	11.7	52.3	Moderate	54.2	Moderate
PB14	btm	78.70%	0.01	0.39	5.10	100.0	83.5	100.0	54.9	55.9	78.8	High	75.2	High
PB15	btm	46.70%	0.01	0.51	12.98	100.0	19.1	97.3	20.0	0.0	47.3	Moderate/Fair	20.7	Fair/Poor
High Quality = >69; High/Moderate = 61-69; Moderate = 39-61; Moderate/Fair = 31-39; Fair/Poor = <31														
SR05			0.47	0.68	35.93	ND	ND	0.0	0.0	0.0	0.0		0.7	

Table 7b. Trophic Health Index Scores and status for marine water quality monitoring stations in Popponesset Bay, 2016 and long- term, based upon open water embayment (not salt marsh) habitat quality scales (described in Howes et al. 1999) at www.savebuzzardsbay.org).

2016							Low20%				2016		Longterm 2001-2009	
	Secchi	20% Low	DIN	TON	T-Pig	Secchi	Oxsat	DIN	TON	T-Pig	EUTRO	HEALTH	EUTRO	HEALTH
Station	Depth (m)	D.O. (% Sat)	mg/L	mg/L	(ug/L)	SCORE	SCORE	SCORE	SCORE	SCORE	Index	Status	Index	Status
PB01			0.622	0.322	2.7							Freshwater		Freshwater
PB02		14.70	0.273	0.797	45.4		0.0	0.0	0.0	0.0	0.0	Fair/Poor	2.2	Fair/Poor
PB03		28.00	0.141	0.879	48.0		0.0	0.0	0.0	0.0	0.0	Fair/Poor	4.0	Fair/Poor
PB04		36.80	0.074	0.712	18.9		0.0	27.7	0.0	0.0	6.9	Fair/Poor	24.3	Fair/Poor
PB05	0.83	60.50	0.018	0.859	28.8	20.5	51.0	88.5	0.0	0.0	32.0	Mod/Fair	18.2	Mod/Fair
PB06	0.74	57.00	0.018	0.835	26.9	13.2	43.7	88.7	0.0	0.0	29.1	Fair/Poor	21.4	Fair/Poor
PB07		69.95	0.023	0.652	20.8		68.9	79.1	0.0	0.0	37.0	Mod/Fair	31.3	Mod/Fair
PB09	1.02	37.80	0.012	0.847	24.2	33.0	0.0	100.0	0.0	0.0	26.6	Fair/Poor	22.8	Fair/Poor
PB10		56.40	0.010	0.863	19.7		42.4	100.0	0.0	0.0	35.6	Mod/Fair	30.6	Mod/Fair
PB08	1.38	49.00	0.016	0.762	25.0	51.8	25.0	95.0	0.0	0.0	34.4	Mod/Fair	46.4	Mod/Fair
PB11	1.15	59.90	0.029	0.548	10.4	40.3	49.8	68.3	12.0	0.0	34.1	Mod/Fair	43.1	Mod/Fair
PB12	1.61	60.60	0.041	0.444	9.1	61.1	51.2	53.0	39.6	8.2	42.6	Moderate	46.6	Moderae
PB13	1.92	59.00	0.031	0.490	9.0	72.3	47.9	65.4	26.6	8.9	44.2	Moderate	54.2	Moderae
PB15		38.00	0.022	0.659	16.0		0.0	80.4	0.0	0.0	20.1	Fair/Poor	20.7	Fair/Poor
PB14	2	66.70	0.014	0.435	4.5	74.8	63.1	100.0	42.1	66.6	69.3	High	75.2	High
SR5			0.472	0.678	35.9			0.0	0.0	0.0	0.0		0.7	

Table 8. Reference values used in the Bay Health Index. Scores are generated for each parameter and the mean score computed. In some cases where Secchi data is not available, the mean of the other 4 parameters may be used.

Score	Secchi Depth M	Oxygen Saturation %	Inorganic N mg/L	Total N mg/L	Total Chlorophyll-a Pigments ug/L
%	0.6	0.40	0.140	0.600	10.0
100%	3.0	0.90	0.014	0.280	3.0
The relationship between 0% to 100% for each parameter is logarithmic.					

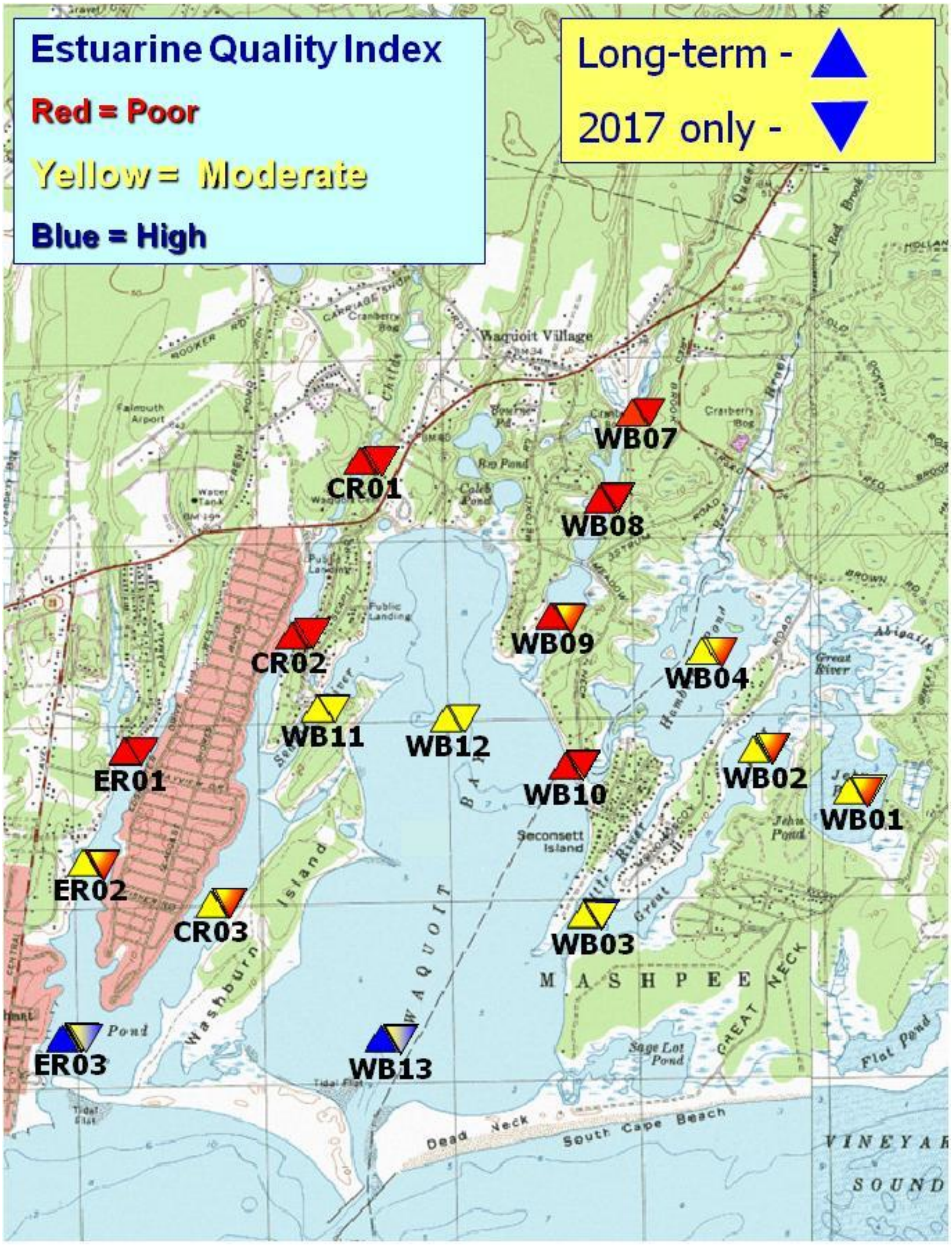

Figure 14a. 2017 Nutrient related water quality of the Waquoit Bay system, based upon monitoring data (Table 4) from stations in Figure 4. The Health Index was developed for Buzzards Bay open water embayments. Note the gradient in nitrogen related water quality with lowest quality within the inland tidal reaches and highest nearest the tidal inlets. The Index colors are red=poor, yellow=moderate decline, blue high quality.

▲ Long-Term Data ▼ 2017 Data

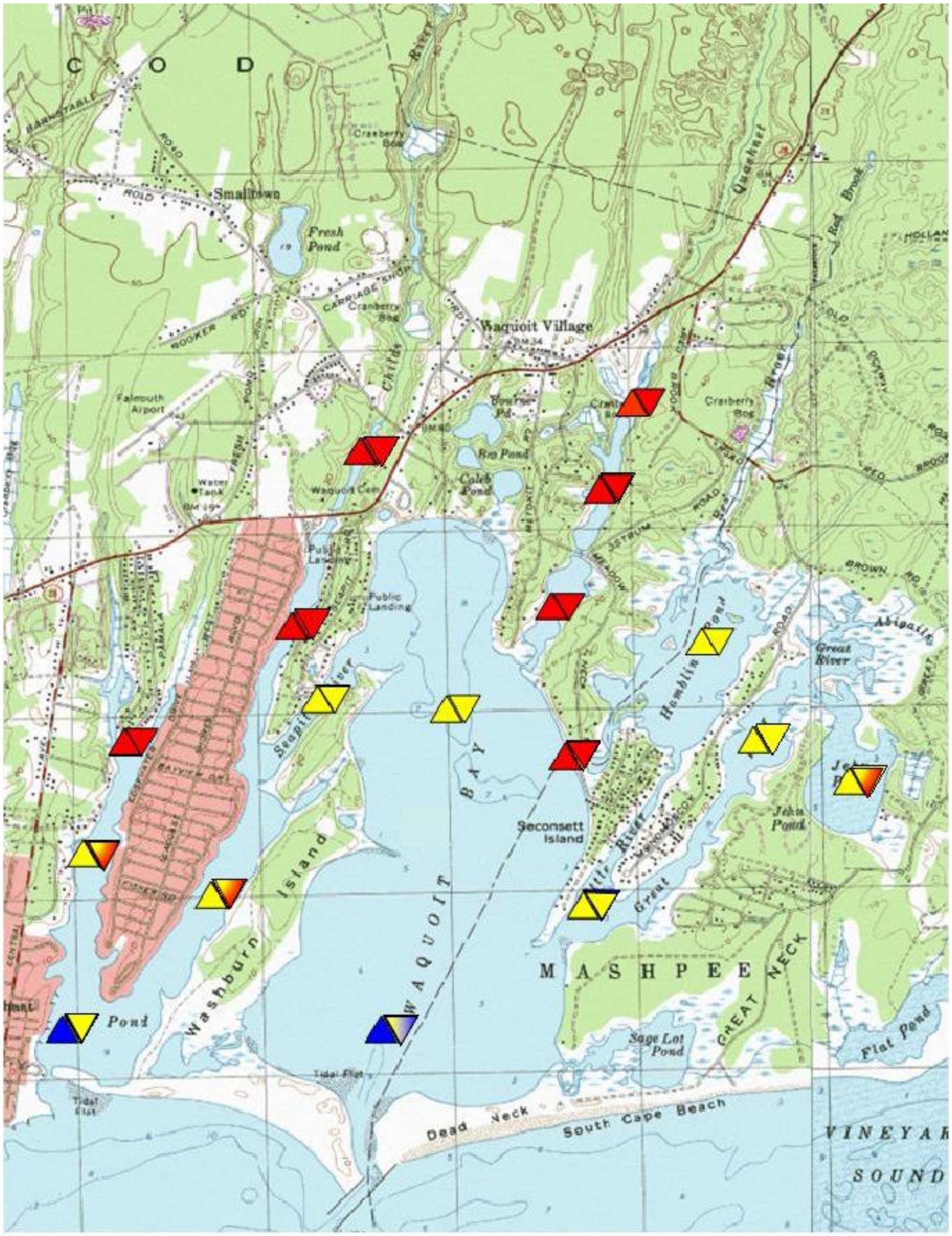

Figure 14b. 2016 Nutrient related water quality of the Waquoit Bay system, based upon monitoring data (Table 4) from stations in Figure 4. The Health Index was developed for Buzzards Bay open water embayments. Note the gradient in nitrogen related water quality with lowest quality within the inland tidal reaches and highest nearest the tidal inlets. The Index colors are red=poor, yellow=moderate decline, blue high quality.

▲ Long-Term Data ▼ 2016 Data

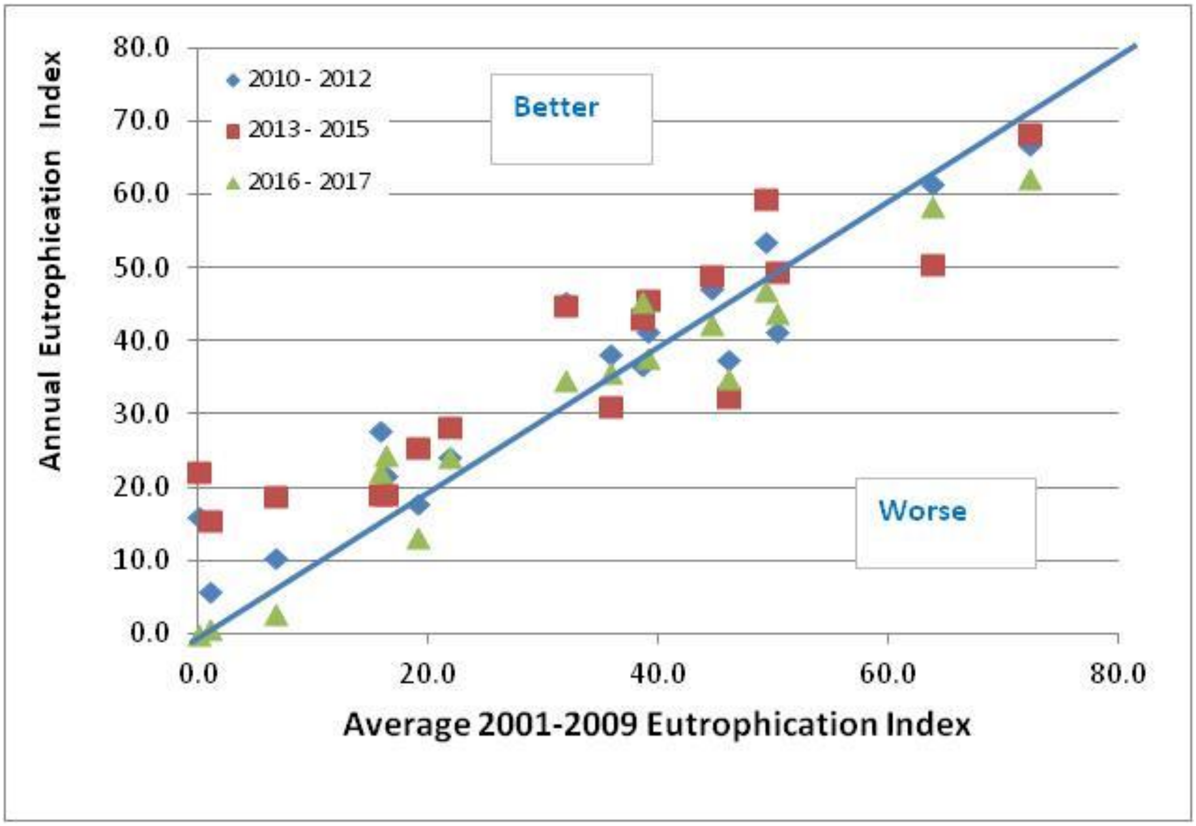

Figure 15. Eutrophication Index for each Waquoit Bay site averaged 2010-12, 2013-15 and 2016-17 (Y axis) compared to the longer term average (2001-2009) for the same sites (X axis). Freshwater sites are not included. The 1:1 line represents "No Change", points above the line indicate improved conditions and points below the line indicate increased impairment.

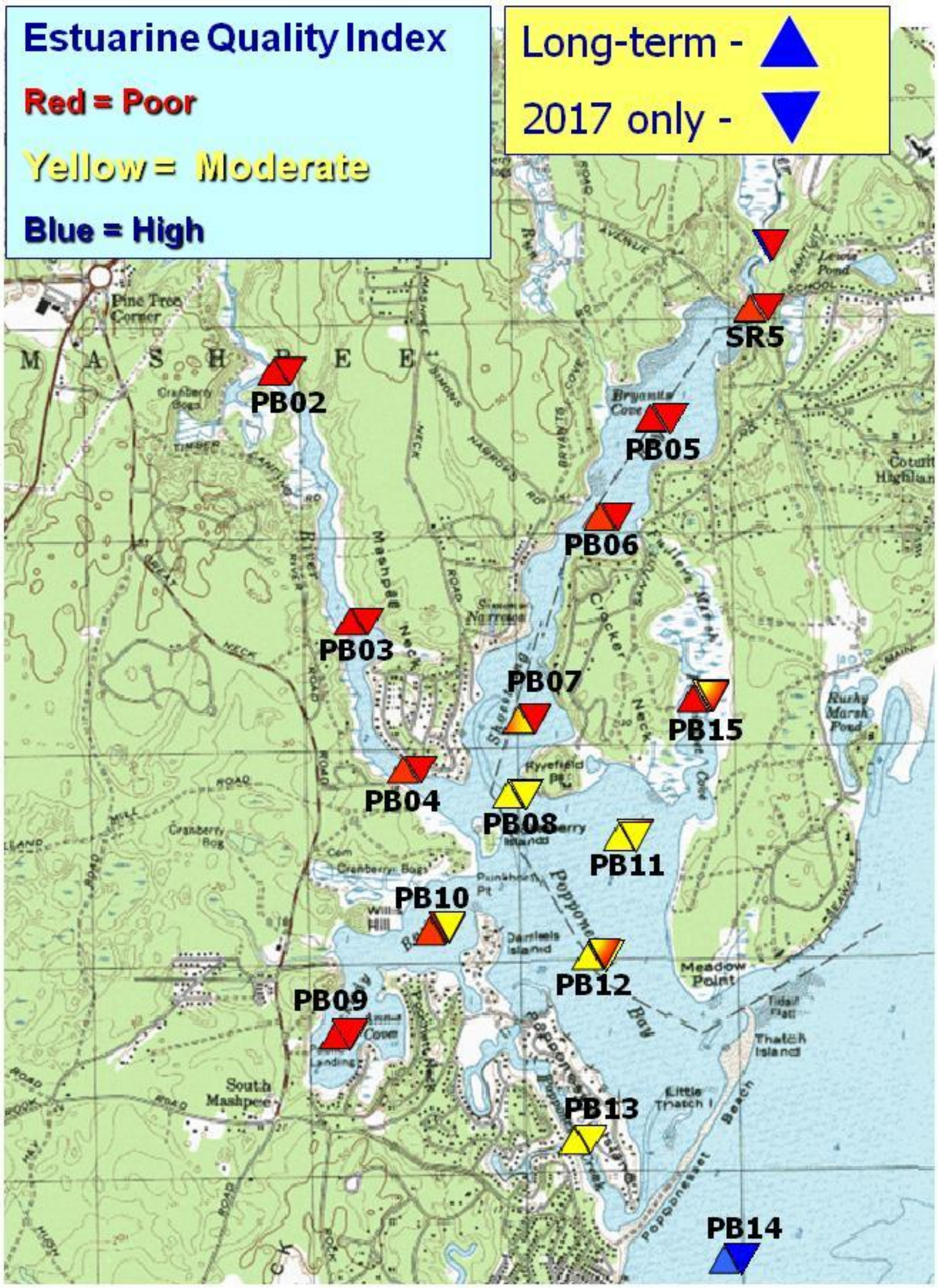

Figure 16a. 2017 Nutrient related water quality of the Popponesset Bay system, based upon monitoring data (Table 5) from stations in Figure 5. The Health Index was developed for Buzzards Bay open water embayments. Note the gradient in nitrogen related water quality with lowest quality within the inland tidal reaches and highest nearest the tidal inlets. The Index colors are red=poor, yellow=moderate decline, blue high quality.

▲ Long-Term Data ▼ 2017 Data

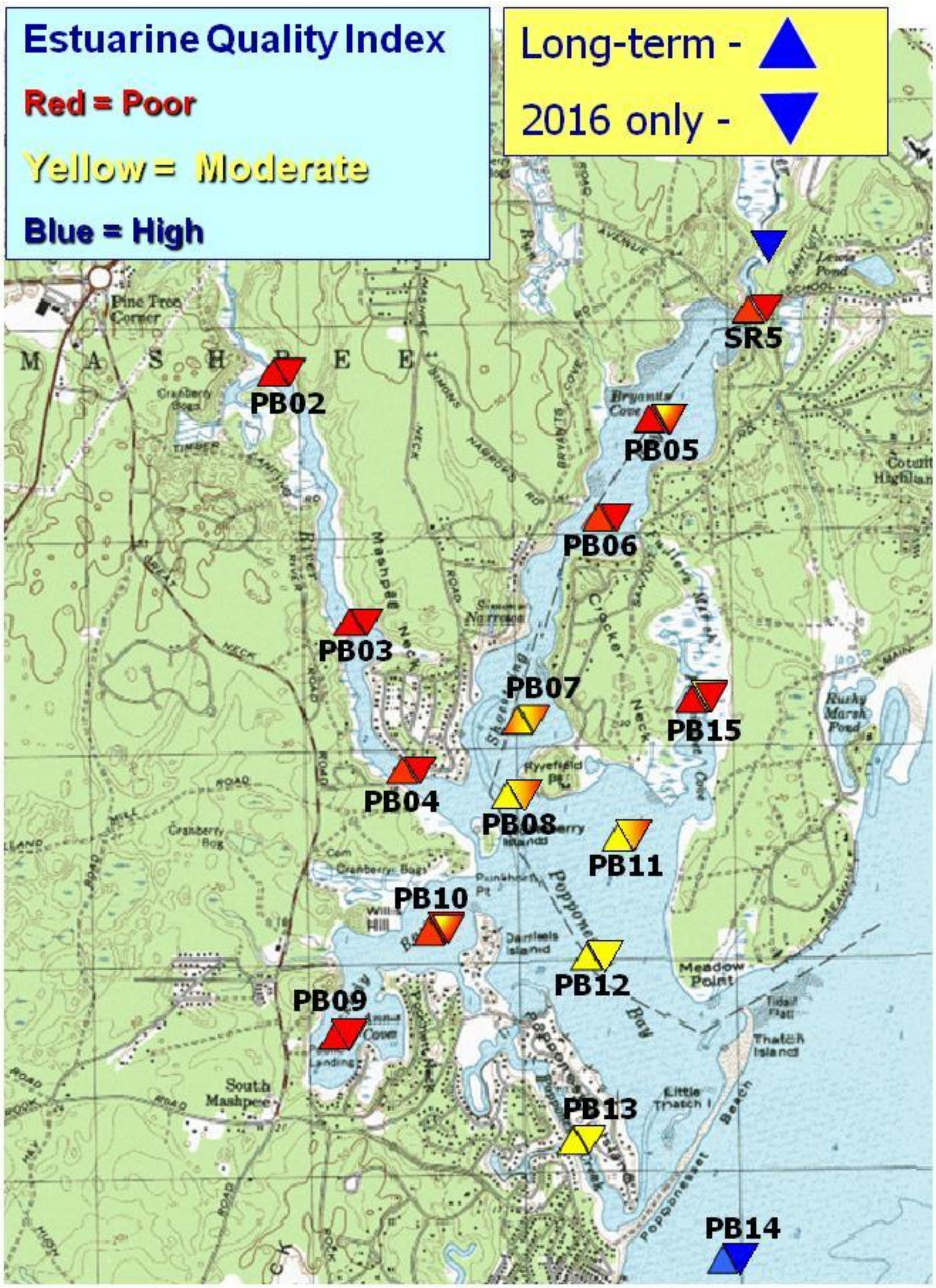

Figure 16b. 2016 Nutrient related water quality of the Popponesset Bay system, based upon monitoring data (Table 5) from stations in Figure 5. The Health Index was developed for Buzzards Bay open water embayments. Note the gradient in nitrogen related water quality with lowest quality within the inland tidal reaches and highest nearest the tidal inlets. The Index colors are red=poor, yellow=moderate decline, blue high quality.

▲ Long-Term Data ▼ 2016 Data

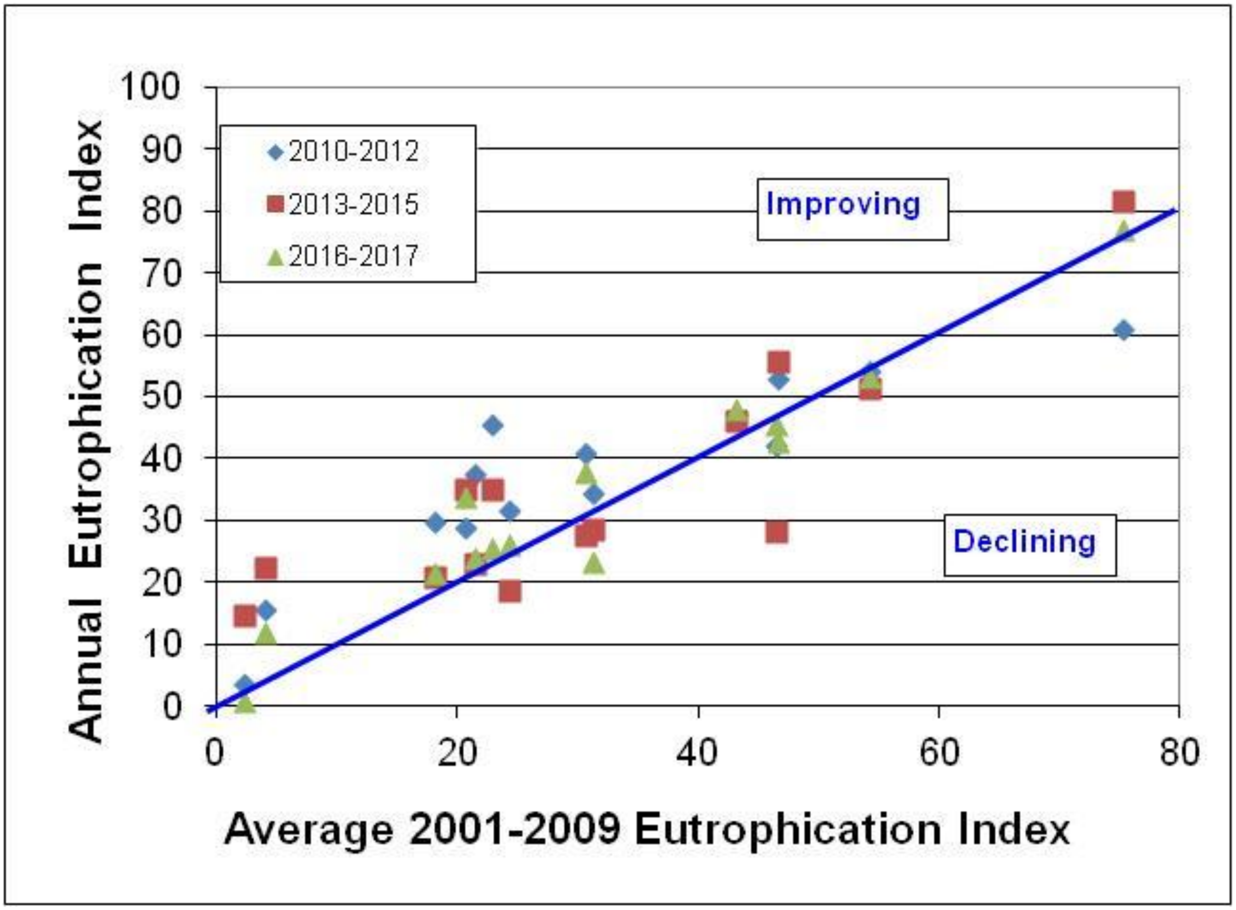

Figure 17. Eutrophication Index for each Popponesset Bay site averaged 2010-12, 2013-15 and 2016-17 (Y axis) compared to the longer term average (2001-2009) for the same sites (X axis). Freshwater sites are not included. The 1:1 line represents "No Change", points above the line indicate improved conditions and points below the line indicate increased impairment.

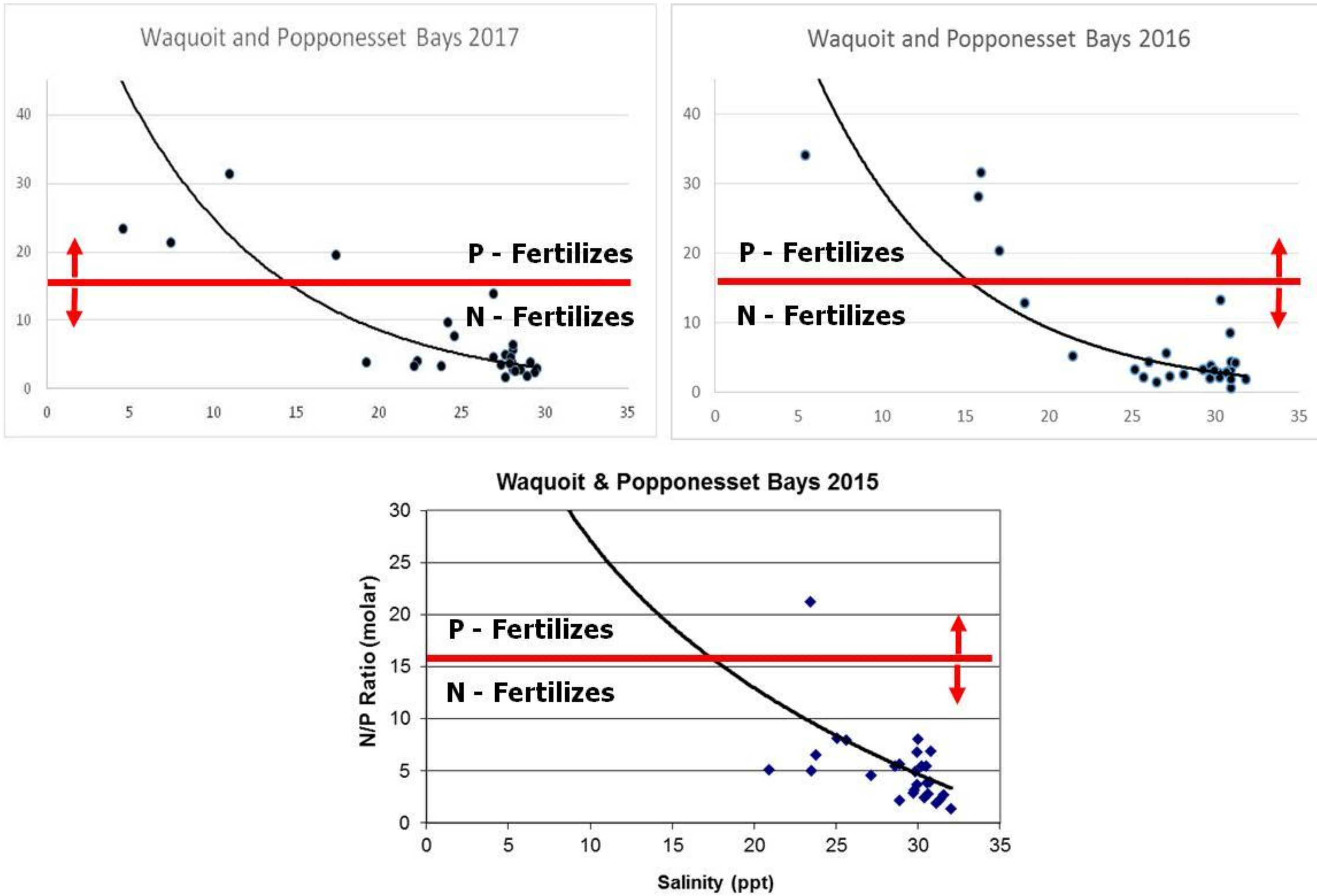

Figure 18. Changes in the nutrient causing eutrophication with water column salinity (2015 and 2016). Typically phosphorus is the nutrient to be managed in freshwater systems and nitrogen in marine systems. The indications of phosphorus limitation are all within or adjacent discharging streams within either the Waquoit Bay or Popponesset Bay Estuaries. It appears that saline waters of both estuaries are nitrogen limited. (N/P<16).