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

(summary of summer 2016 results)

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&
Town of Mashpee Waterways Commission
&
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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 developing nitrogen management plans 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 occurs. 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, Nantucket and Vineyard Sound.

Both the Waquoit Bay and Popponesset Bay Estuarine Systems are highly nitrogen enriched and show impaired nutrient related water quality 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. The present Technical Memorandum is an update to the water quality baseline to include the results of each summer's sampling program, 2010-2016.

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 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 is nearly completed (CWMP) 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 from sources 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 has been partitioned into 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). 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

[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.

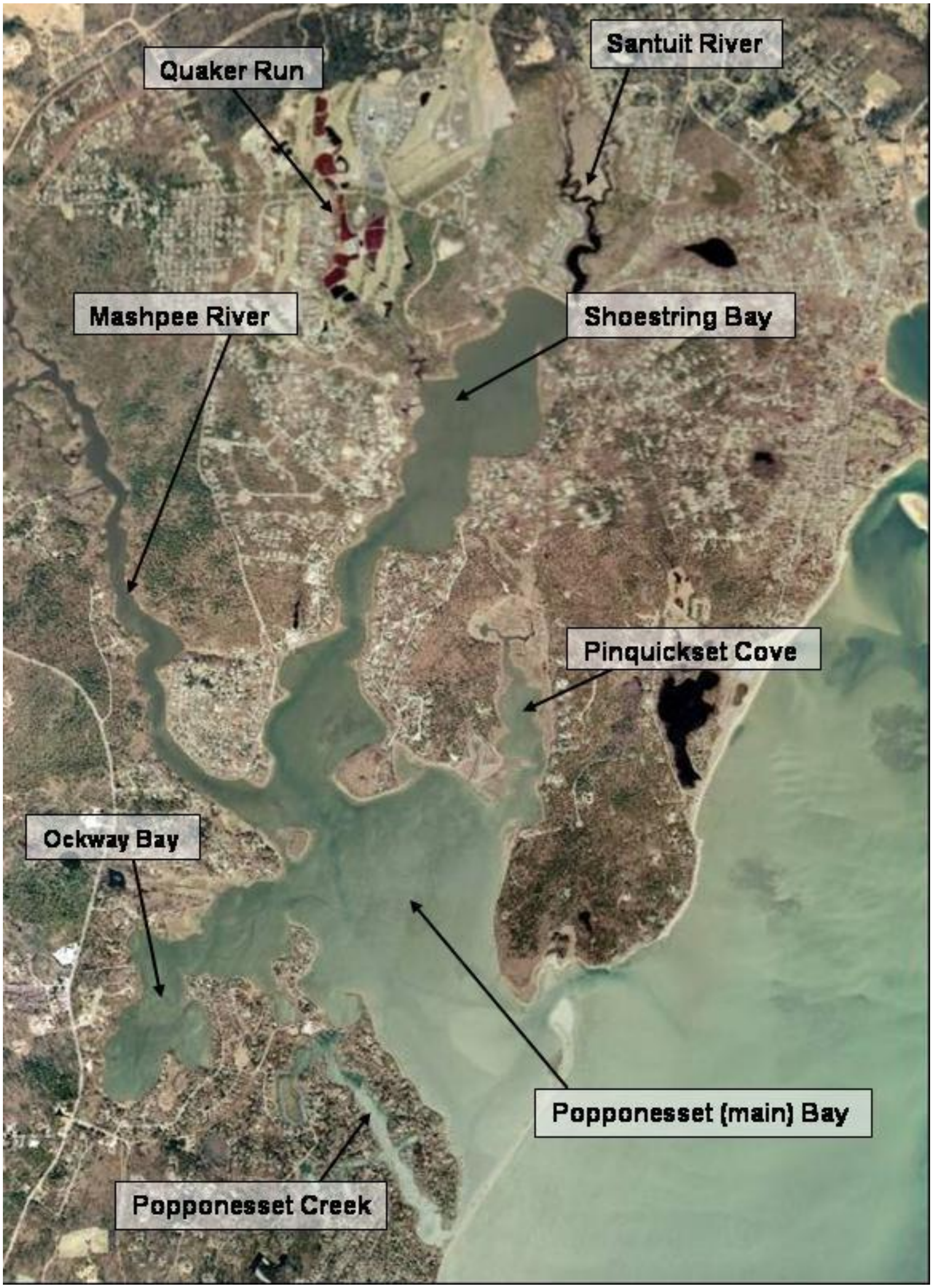

Figure. 2 Popponesset Bay System component basins. Tidal waters enter the Bay through the single inlet from Nantucket Sound. Freshwaters enter from the watershed primarily through 3 surface water discharges (Mashpee River, Santuit River, Quaker Run) and direct groundwater discharge.

component systems is generated from Nantucket Sound. Nantucket Sound, 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 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 is operating efficiently, possibly 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 tidal characteristics within the component sub-embayments.

Nitrogen loading to the Popponesset Bay System has been assessed by the Massachusetts Estuaries Project and partitioned relative to 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.

As management alternatives are being developed and evaluated, 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 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, 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 main openings to Nantucket Sound, a historically open inlet in the main bay and an ephemeral 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 recently 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. The 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

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.

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 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 where the tide range is 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 tidal damping.

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 Program (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
    - Jehu Pond
    - Main Bay
    - Childs River
    - Eel Pond
    - Quashnet River
    - Red Brook
    - Great River

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, and compliance monitoring associated with the TMDL (Clean Water Act). The present monitoring effort is significantly reduced over prior sampling efforts for these estuaries, 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

[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.

lowered making the program sustainable over the long-term. The stream-lined program builds upon the more intensive efforts conducted previously.

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 L. Howes, Director of the Coastal Systems Program at SMAST-UMD and Sara Sampieri Horvet, the Coastal Systems Analytical Facility Manager (ssampieri@umassd.edu). Volunteers came 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 (2015) monitoring effort, the 2016 Mashpee Water Quality Monitoring Program was very successful from the organizational aspect (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 2016: July6, July 22, August 5, and August 22. 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 2010-2016 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. A total of 37 water samples for nutrients (includes 2 QA samples) were collected in 2015 and 2016 field seasons per each combined (both systems) sampling event: 20 in the Waquoit Bay system and 17 in the Popponesset Bay system. The offshore station is used as one gauge of the boundary conditions in nearshore Nantucket Sound (Table 2 and 3).

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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	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

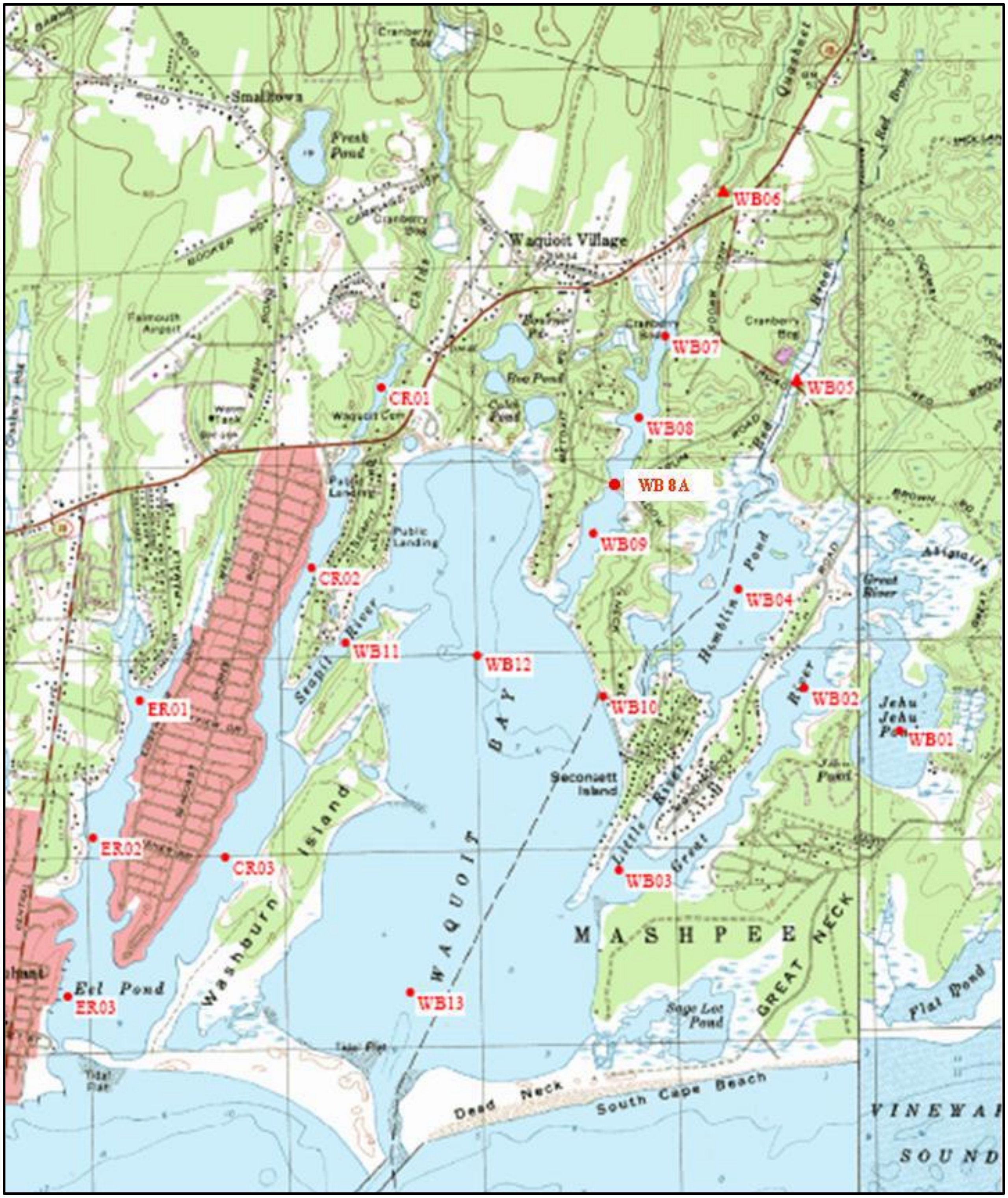

Figure 4. Water quality sampling stations associated with the Waquoit Bay System (2001-2016). Samples were collected synoptically between 5:30 - 8:30 AM on ebbing tides.

Figure 5. Water quality sampling stations associated with the Popponesset Bay System (1997-2015). 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 initial stages, it is not surprising that the results of the 2010-2016 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. 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 2014, while the higher quality areas appear to be stable (see below). Unfortunately both bays experienced large blooms and an associated decline in water quality in summer 2016 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 recent blooms in Mashpee estuaries.

The salinity gradients within each estuary in 2010-2016 are generally consistent with historical levels (Figures 6 and 10). The gradients show the concentration of freshwater discharges at 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 upper reaches of the Quashnet River and the Mashpee River showed salinities generally ~5 ppt (Figures 6 and 10) and the long term salinity at the head of the Childs River was generally around 10 ppt, however, in recent years, 2010-2016, the salinity levels in the headwaters have risen to ~16-18 ppt, which appears to be a real shift. This likely results from lower freshwater inflows allowing more saline water to push higher up into the Childs River estuary. These freshwater inflows are rich in nitrogen from terrestrial sources and support much of the eutrophication in the more estuarine areas downstream. Interestingly, the corresponding average TN levels at the Childs River head station have remained relatively constant from historic levels through 2015, with only 2016 showing a major increase in TN, apparently associated with the very large phytoplankton bloom.

It should be noted that the Quashnet River above the Meadow Neck Road bridge 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), an increase of more than 12 ppt, was thought to result from a restriction in tidal flow in this region. However, no significant tidal restriction was found in a follow-up study completed by the Coastal Systems Program (SMAST) in collaboration with the Town of Mashpee. 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. Upon return to average annual rainfall conditions, if this basin further freshens, phosphorus management may need to be evaluated (Figure 18). The Mashpee River upper basin also supports brackish salinities (3-5 ppt) 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 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.

Monitoring results from summers 2010-2016, show that total nitrogen levels throughout the Waquoit Bay and Popponesset Bay Systems are significantly enriched over the high quality waters of Nantucket Sound (0.28 mg/L TN) entering during flooding tides and are generally consistent with prior historical data (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 and 2016 TN averages, there is a very high average TN value at the head of the Quashnet River, much higher than in the long-term historical data or the 2013-2015 average results (Figure 7). The higher TN years are caused by elevated PON levels associated with major phytoplankton blooms. The observed inter-annual variability results from the higher average PON (total chlorophyll a) and TN values for the 2010-12 and 2016 seasons. These “peaks” in TN were not repeated in 2013, 2014, 2015 or 2016. The cause of the blooms is a combination of temperature, sunlight and circulation which allows a bloom to develop, possibly related to elevated inorganic nitrogen inputs in streamflows. The variation itself indicates the need to establish 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.

In general, the 2010-2016 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. In addition, TN levels in the pond 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.

Popponesset Bay has a completed system-wide Massachusetts Estuaries Project analysis and 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 2010-2016 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 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, which is generally associated with habitat decline. In contrast, the main basin has remained relatively constant due to its volume, flushing rate and continuation of maintenance of the tidal inlet.

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 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 are significantly higher, supporting the contention that these estuaries are presently nitrogen enriched, resulting in high levels of phytoplankton production. In addition to the amount of phytoplankton, it is important to note the large and prolonged bloom in summer 2016, 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. Chlorophyll-a levels within the tidal rivers of both systems and in particular Childs River, Quashnet River and upper Eel Pond in the Waquoit Bay System and Shoestring Bay and the Mashpee River in the Popponesset Bay System are all showing significantly impaired conditions (Figures 8 and 12). Okway Bay and the main basin of Popponesset show lower chlorophyll levels than elsewhere, however, total pigment levels from 2016 seem uniformly high compared to the average levels from 2010-2012 and 2013-2015. While the western basins of Waquoit Bay tend to have relatively high chlorophyll-a levels, 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 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 is also 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 or darkness adding to oxygen depletion and loss of fish, shellfish and bottom dwelling animals and the other 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 in specific. 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 2010-2016 and were generally consistent with historical data, however, DO was generally lower in 2016 across the Waquoit Bay and Popponesset Bay stations with the exception of Shoestring Bay and Okway Bay which showed less summer DO depletion in 2016 compared to the 2013-2015. Interestingly, the generally lower DO in the Waquoit and Popponesset Bay systems follows the distribution of higher total chlorophyll-a and TN levels (Figures 9, 13) with the exception of stations in Okway Bay and Shoestring Bay. The linkage of oxygen depletion to nitrogen enrichment is seen in each year's results with higher oxygen levels at lower levels of nitrogen enrichment and greater depletion in basins with higher nitrogen enrichment. In 2016 oxygen depletion tended to be greater than in previous years with the exception of the more well flushed tidal basins of the Popponesset Estuary, particularly Okway Bay and Shoestring Bay. More specifically, 8 of the 13 stations sampled in Popponesset Bay in 2016 recorded lower D.O. than the 2013-2015 average and only 1 station showed higher DO levels. Similarly, DO conditions in Waquoit Bay were generally worse in 2016 compared to the average levels for 2013-2015. In 2016, 10 stations showed lower DO concentrations compared to the 2013-2015 average and only 3 stations were higher. The depressed DO levels likely result from the large, prolonged phytoplankton bloom in 2016, 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 2016 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 in 2016 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 summer 2016, it may be associated with lower freshwater inflows due to the below average precipitation in 2016. It is likely that results from 2017 will help evaluate this effect. Note that even if conditions improve in 2017, it is the nutrient and organic enrichment of these estuarine basins which keep them poised for low oxygen when other external factors become operative (storms, low light, wind, temperature, etc).

NUTRIENT RELATED WATER QUALITY INDEX

Integrating the various nutrient related parameters collected as part of the monitoring program in order to provide a simple view of the general nutrient related water quality of the Waquoit Bay and Popponesset Bay Estuarine Systems, the Bay Health Index was constructed based on the monitoring results (long-term, 2010-2012, 2013-2014 and 2015-2016). 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. Since clear temporal trends have not been observed in the time-series data (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). 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 that they are similar to the long-term pattern (Figures 14, 16). The overall pattern is similar to that of the separate parameters used in calculating the Index. Both embayment systems show poor nutrient related water quality within the tidal rivers and tributary basins, with modest improvement within the main basins and with the only regions showing moderate to high quality being adjacent to the tidal inlets to Nantucket Sound. The region adjacent the tidal inlet is typically the last reach of an estuary to show impairments 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, 2013-14 and 2015-16 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 has been a general improvement in regions of significant impairment (Index <30), small recent improvements in the moderately impaired areas from 2013-2016 and no change (1 site) to a worsening of water quality (1 site) in the highest quality sites (>60). It should be noted that the declines seen in the 2015-2016 data are driven significantly by the large phytoplankton bloom in 2016. The importance of this event will depend on if it was a rare event spawned by low flows due to the 2016 drought 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. In comparison, water quality in the Popponesset Bay System showed more stability between years than Waquoit Bay, with the only clear result being the small improvement in the poorest quality areas (long term index<30). However, Popponesset Bay also had a moderately large phytoplankton bloom in 2016, 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. 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 14 and 16) 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, 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 compared to historical levels and experienced a moderately large phytoplankton bloom (which also occurred in Three Bays) with associated bottom water oxygen depletions. A single year is not a trend and more analysis is needed to determine the importance of the 2016 regional phytoplankton bloom 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 2010-2016, 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. Only the main basins of Waquoit Bay and Popponesset Bay continue to show moderate - high water quality, but with lower Eel Pond and lower Waqouit Bay showing a decline in 2016. The major water quality event of 2016 was the 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. The extent to which this phytoplankton bloom was 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 is underway to reduce 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 was a poor water quality year due to the large phytoplankton bloom, and overall the systems continue to support impaired habitat quality. 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 2013-2016 and either stable or variable conditions in the high quality areas (Health Index >60) in the lower main basins. It should be noted that the declines associated with summer 2016 data are driven significantly by the large phytoplankton bloom. The importance to this event will depend on if it was a rare event spawned by low flows due to the drought or if it is part of a trend toward increasing bloom frequency and duration due to continued nitrogen enrichment. Overall, in both bays there is a trend of improving water quality in the poorest quality (most nitrogen enriched) areas, which is a positive sign for both estuaries. 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 2014-2016, 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.

(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 in 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 bloom in summer 2016 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, 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 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 is becoming 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, we have made some recommendations 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, 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.

In addition, due to the habitat impairments related to 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.

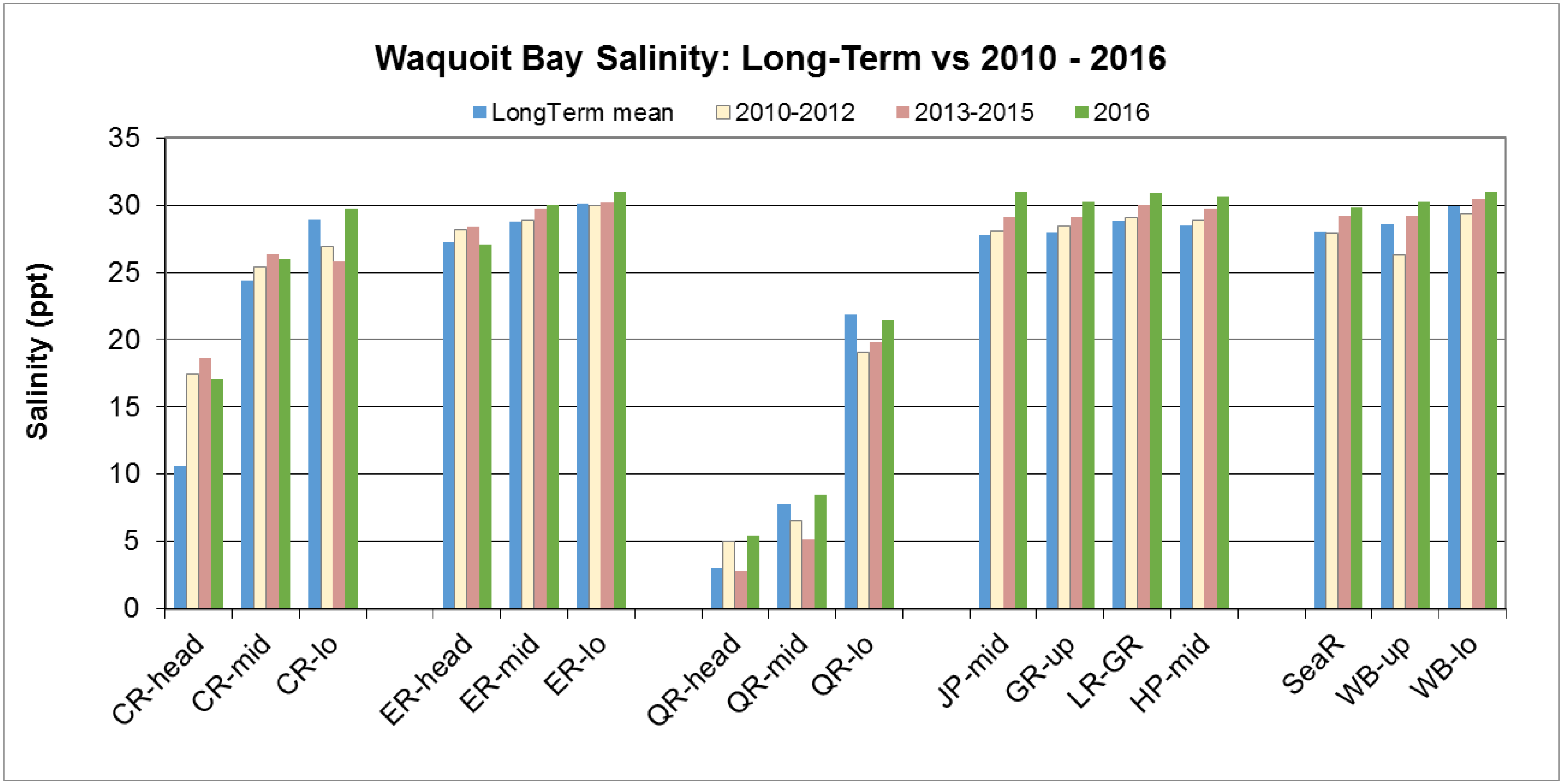

Figure 6. Salinity Distribution throughout the Waquoit Bay Estuarine System long-term and in the summers of 2010-2016. Freshwater enters through groundwater all along the shoreline, with additional "point" inflows from the Moonakis River, Childs River, and Red Brook. These freshwaters mix with the saline 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.

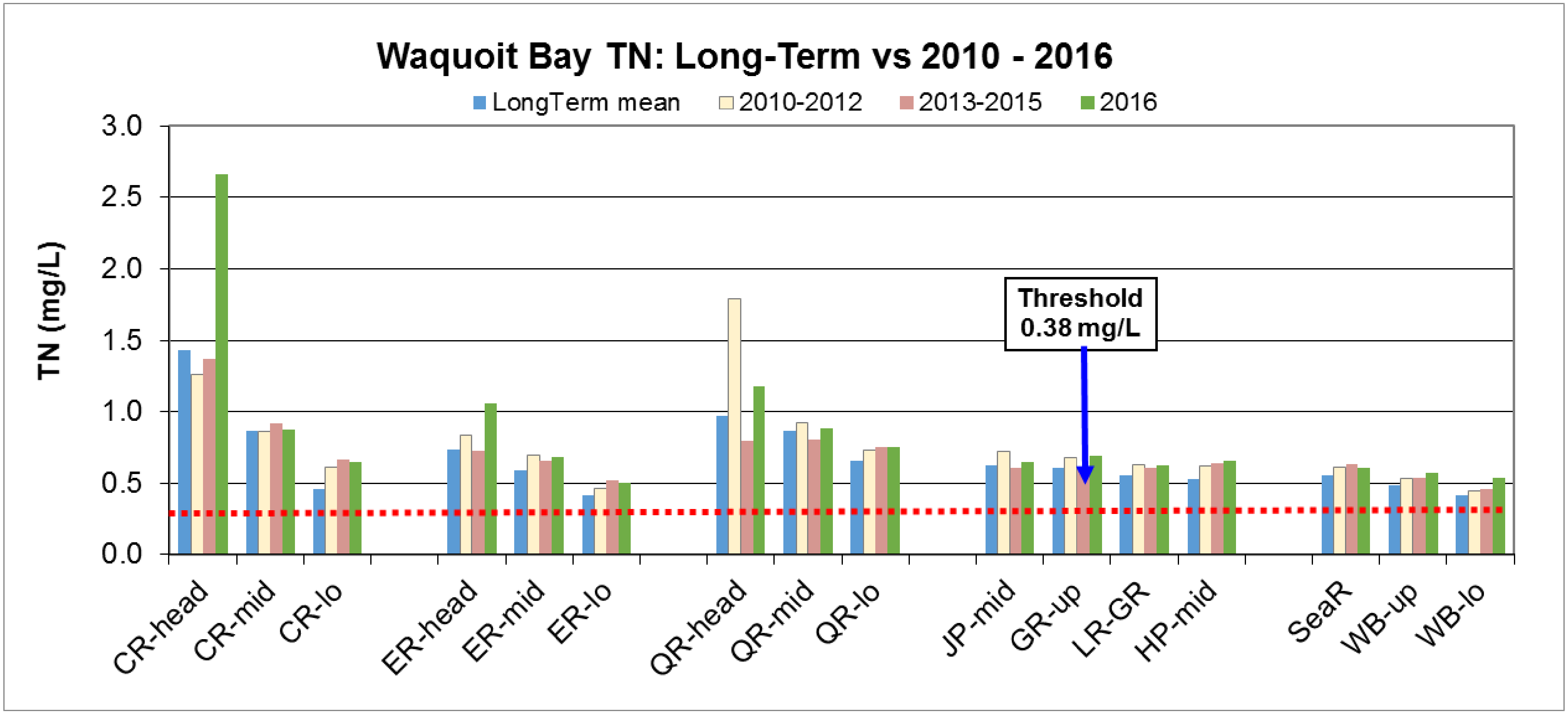

Figure 7. Distribution of Total Nitrogen within the Waquoit Bay Estuarine System, long-term and during the summers of 2010 through 2016. Nitrogen enters through groundwater inflows all along the shoreline, with additional "point" loads from the upper regions of the watershed via Moonakis River, Childs 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.

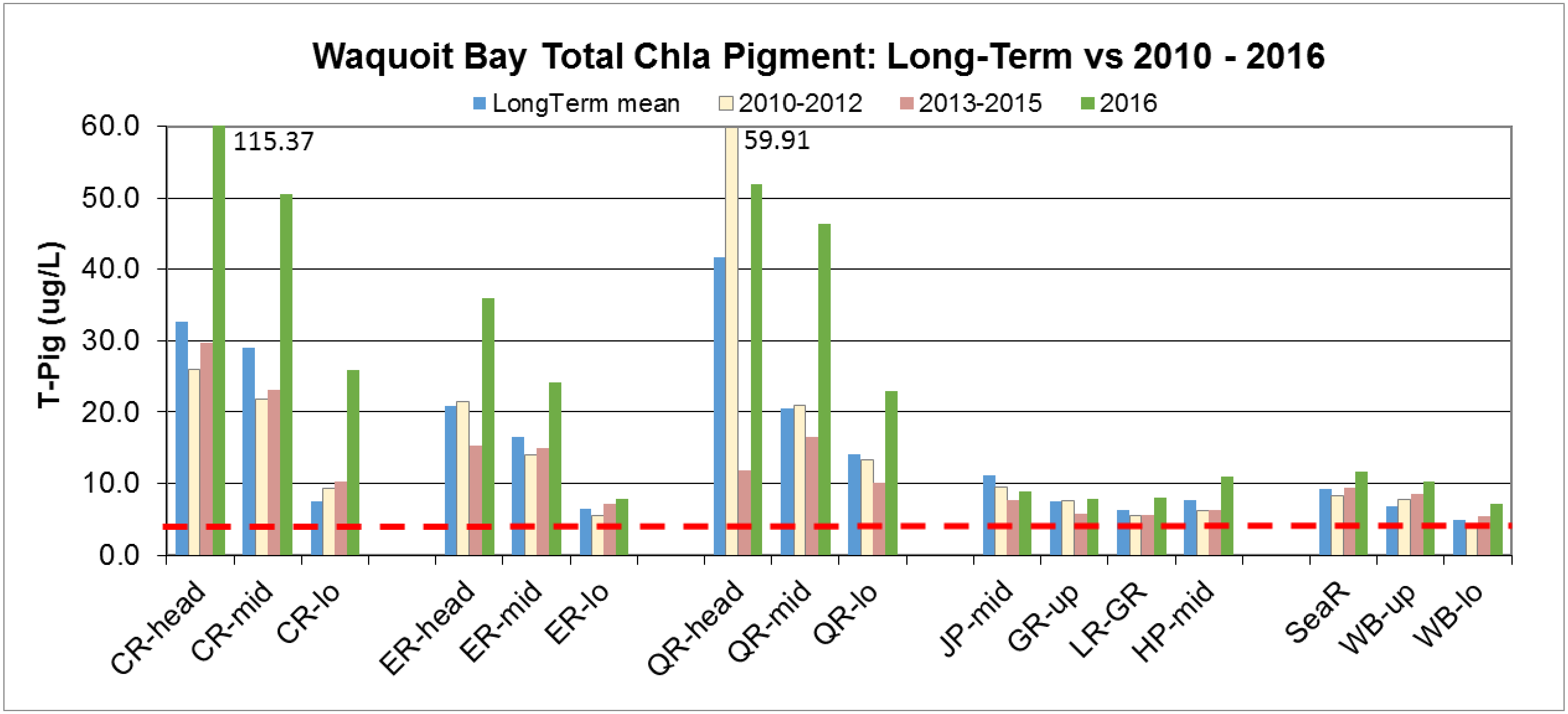

Figure 8. Total Chlorophyll a pigment levels throughout the Waquoit Bay Estuarine System over the long-term and in summers of 2009 through 2016. Phytoplankton pigment levels are a gauge of phytoplankton biomass, which is a response to nitrogen loading. Values over 10 indicate nitrogen enrichment, values <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.

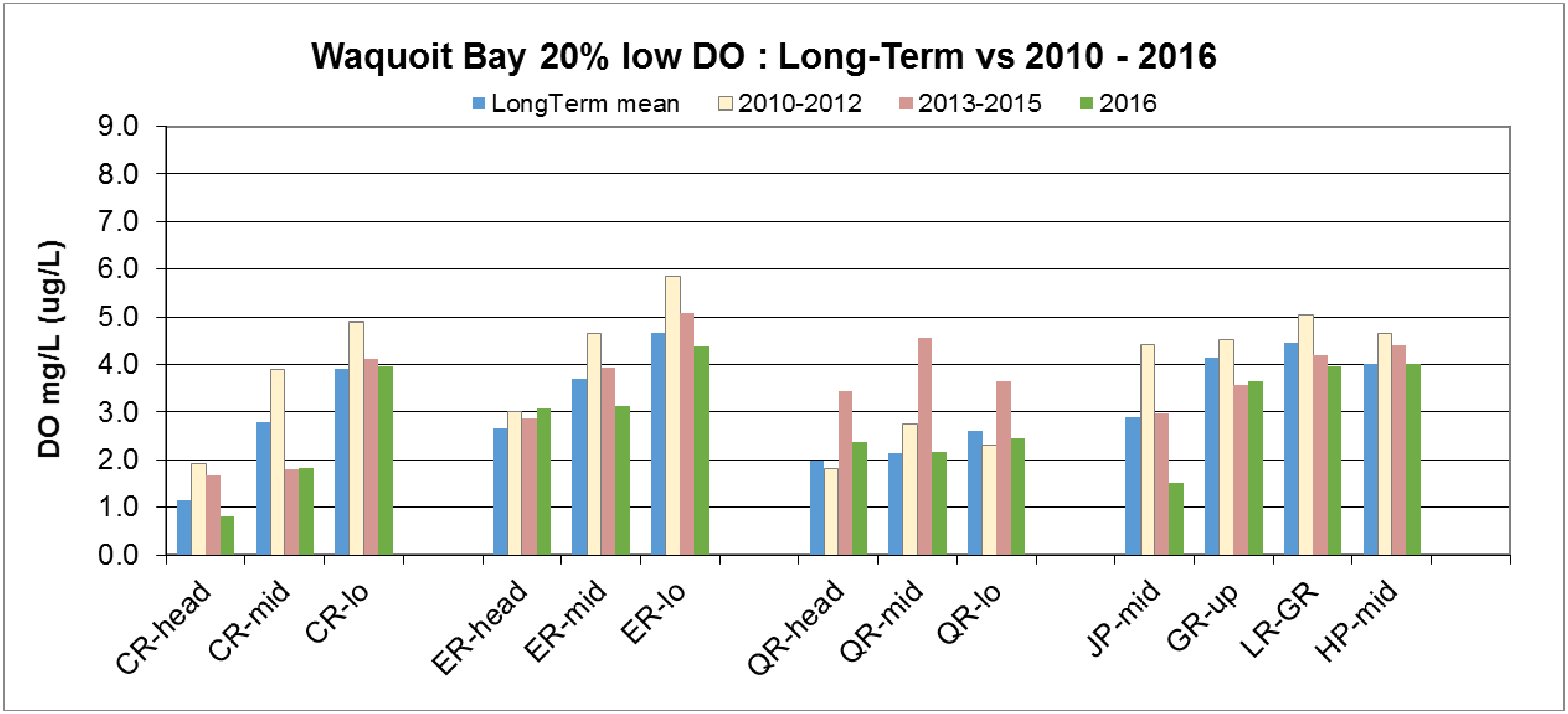

Figure 9. Minimum Dissolved Oxygen (D.O.) levels throughout the Waquoit Bay Estuarine System over the long-term and in the summers of 2010-2016. CR - Childs River, ER - Eel River, QR - Quashnet River, JP - Jehu Pond, GR - Great River, LR-GR - Little River-Great River confluence, HP - Hamblin Pond, SeaR - Seapit River, WB - Waquoit Bay main basin; head - uppermost reach, mid - middle reach, lo - lower basin near mouth or inlet.

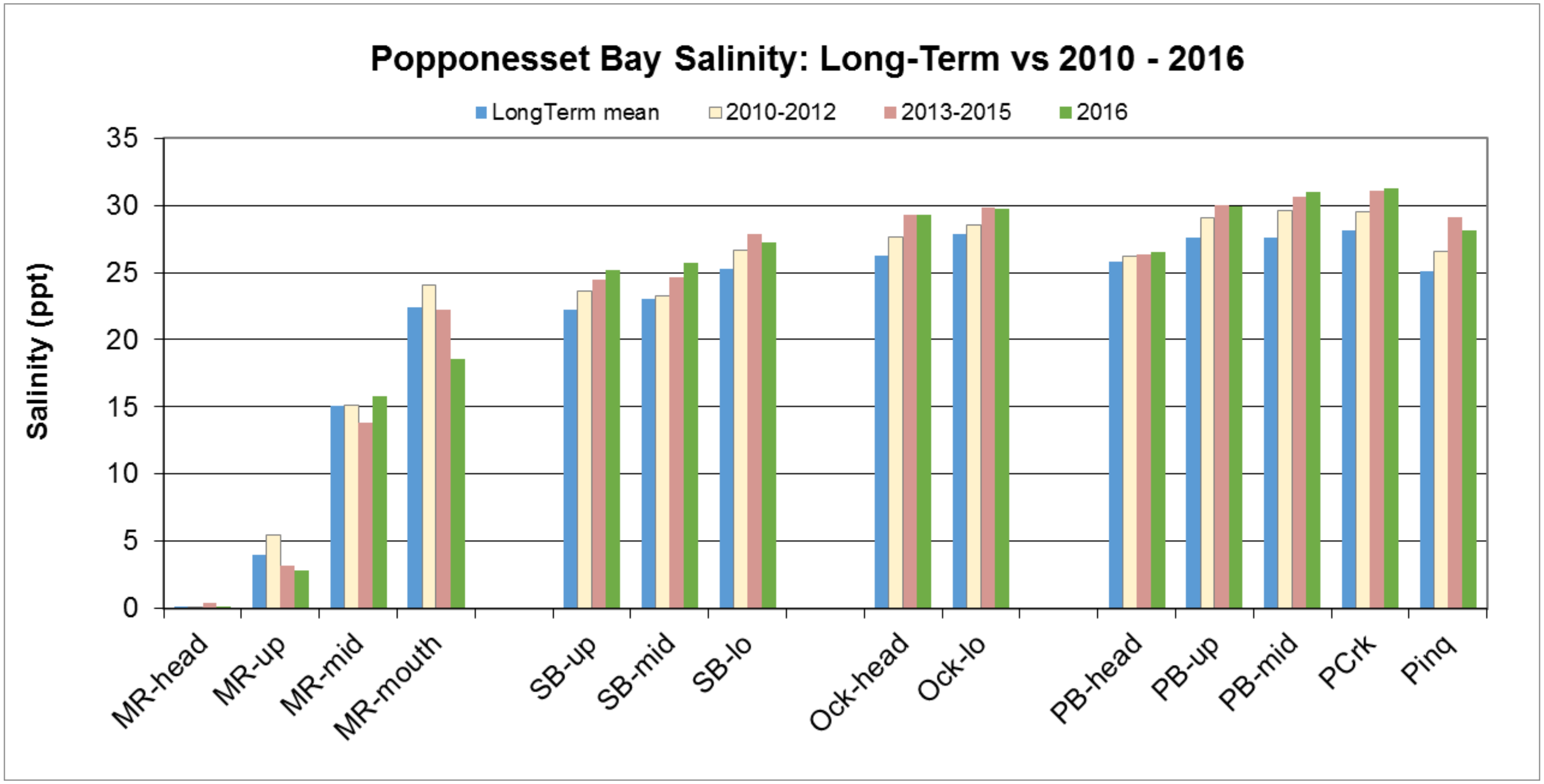

Figure 10. Salinity Distribution throughout the Popponesset Bay Estuarine System. Freshwater enters through groundwater all along the shoreline, with additional "point" inflows from the freshwater reach of the Mashpee River and from the Santuit River to Shoestring Bay. These freshwaters mix with the 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.

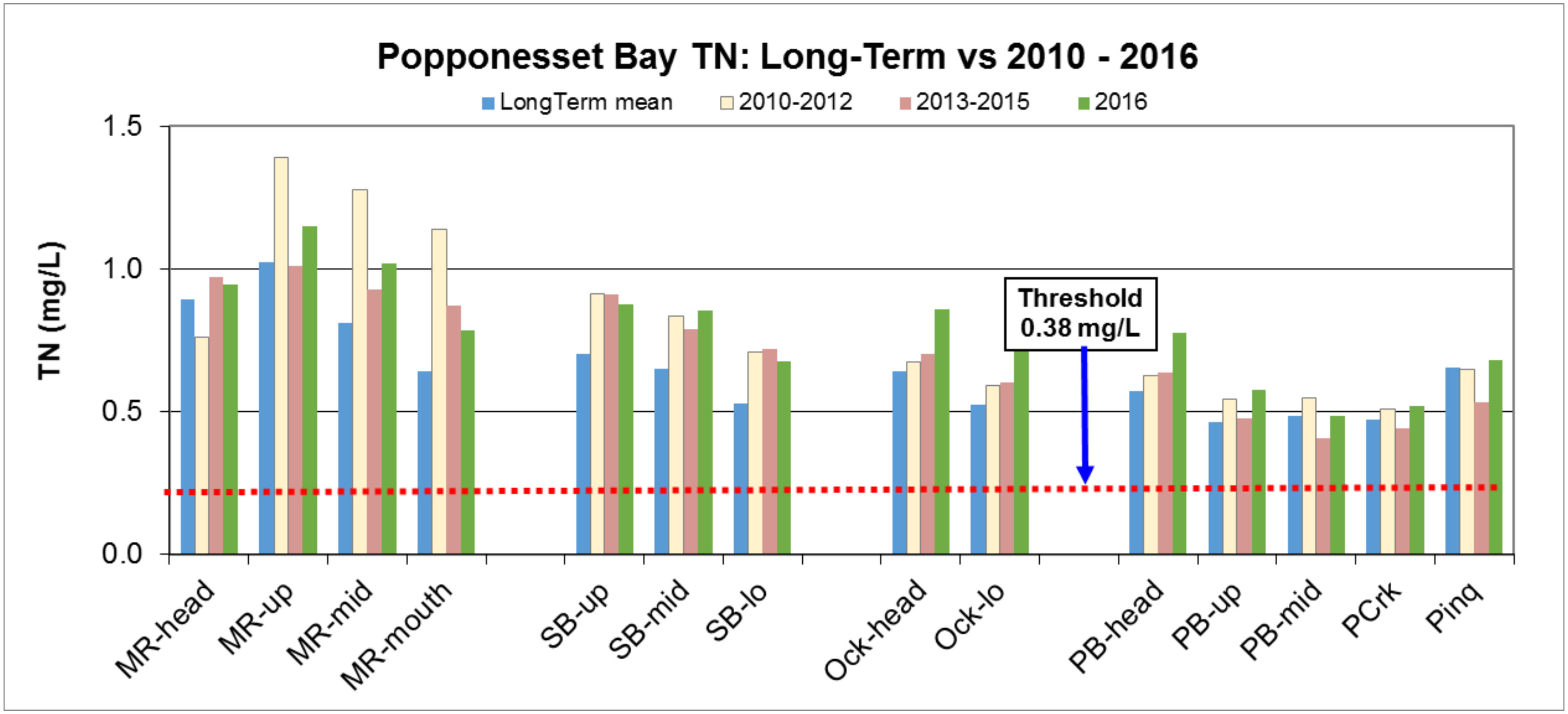

Figure 11. Distribution of Total Nitrogen within the Popponesset Bay Estuarine System. Nitrogen enters through groundwater inflows all along the shoreline, with additional "point" loads from the upper regions of the watershed via the Mashpee River and Santuit River to Shoestring Bay. These nitrogen loads 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 2010-2015 are compared to the long-term average.

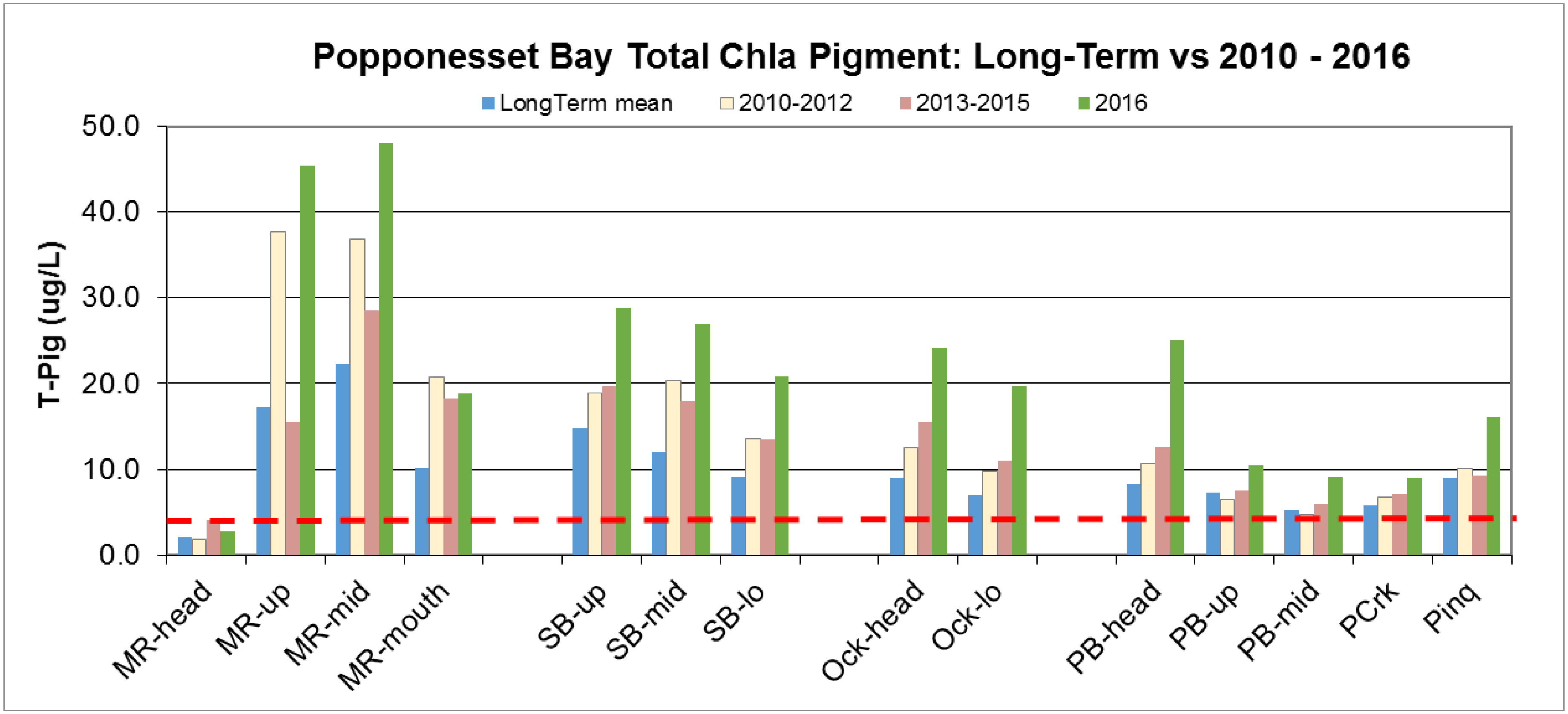

Figure 12. Total Chlorophyll a pigment levels throughout the Popponesset Bay Estuarine System over the long-term and in summer 2010-2015. Phytoplankton pigment levels are a gauge of phytoplankton biomass, which is a response to nitrogen loading. Values over 10 indicate nitrogen enrichment, values <u><</u>3 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.

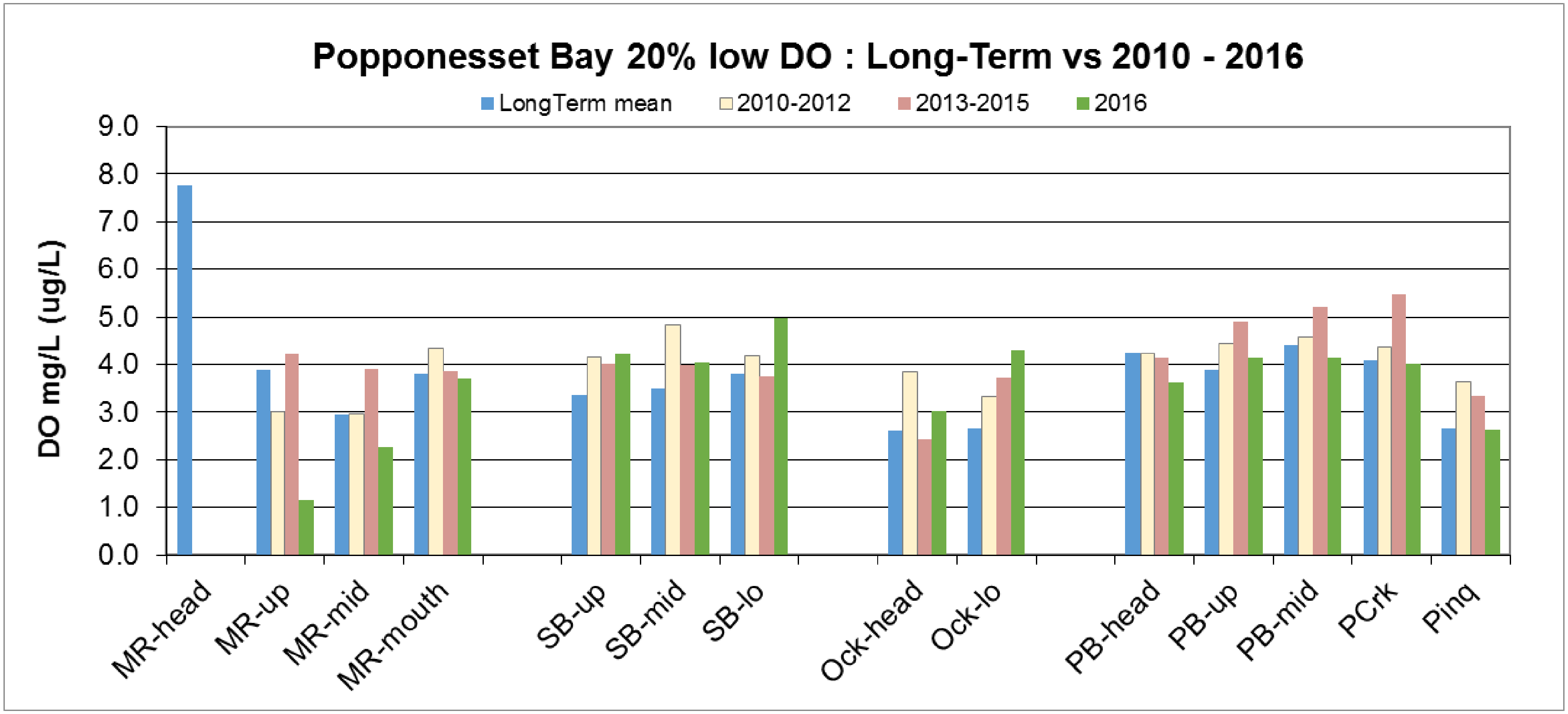

Figure 13. Minimum Dissolved Oxygen levels throughout the Popponesset Bay Estuarine System over the long-term and in the summers of 2010 through 2015. MR - Mashpee River, SB - Shoestring Bay, Ock - Ockway Bay, PB - Popponesset Bay, PCrk - Poppenesset Creek, Pinq - Pinquickset Cove.

Table 4. 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 5. 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 6. 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							Low20%				**2016**	**2016**	**Longterm 2001-09**	
	Secchi	20% Low	DIN	TON	T-Pig	Secchi	Oxsat	DIN	TON	T-Pig	EUTRO	HEALTH	EUTRO	HEALTH
Station	Depth (m)	).O. (% Sat	mg/L	mg/L	(ug/L)	SCORE	SCORE	SCORE	SCORE	SCORE	Index	STATUS	Index	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 7. 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.					

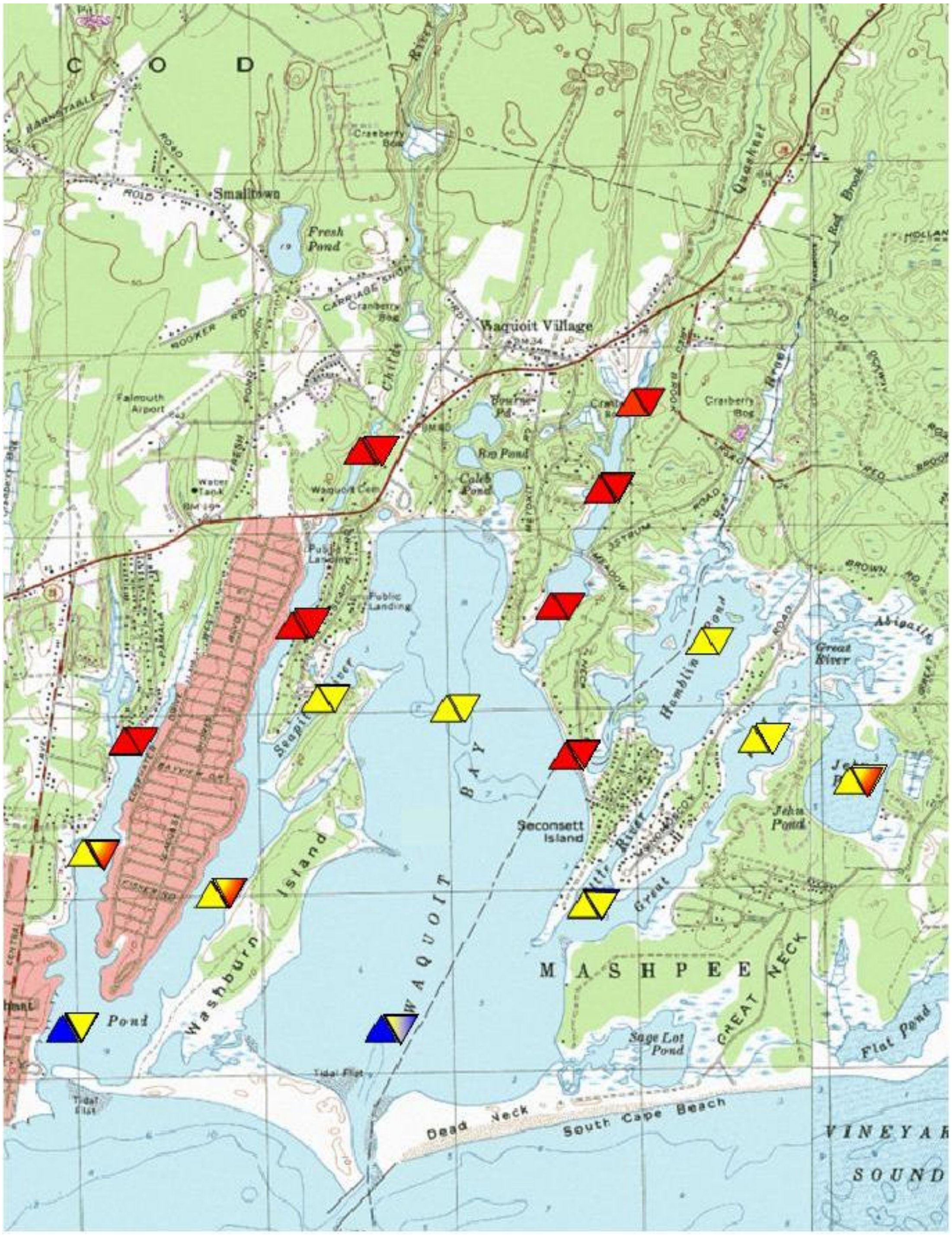

Figure 14. Nutrient related water quality of the Waquoit Bay system, based upon monitoring data (Table 4) from stations in Figure 4. The Health Index was developed for Buzzards Bay open water embayments. Note the gradient in nitrogen related water quality with lowest quality within the inland tidal reaches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

▲ Long-Term Data ▼ 2016 Data

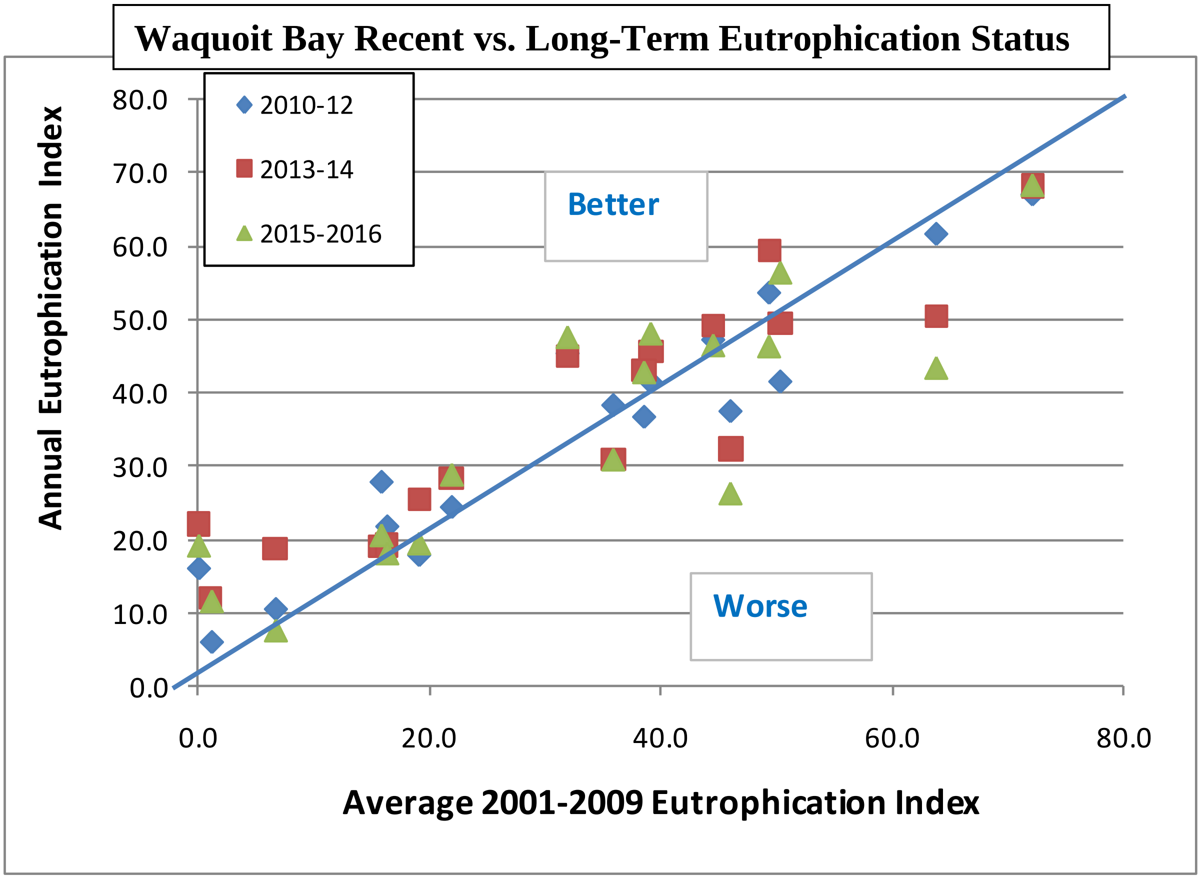

Figure 15. Eutrophication Index for each Waquoit Bay site averaged 2010-12, 2013-14 and 2015-16 (Y axis) compared to the longer term average (2001-2009) for the same sites (X axis). Freshwater sites are not included. The 1:1 line represents "No Change", points above the line indicate improved conditions and points below the line indicate increased impairment.

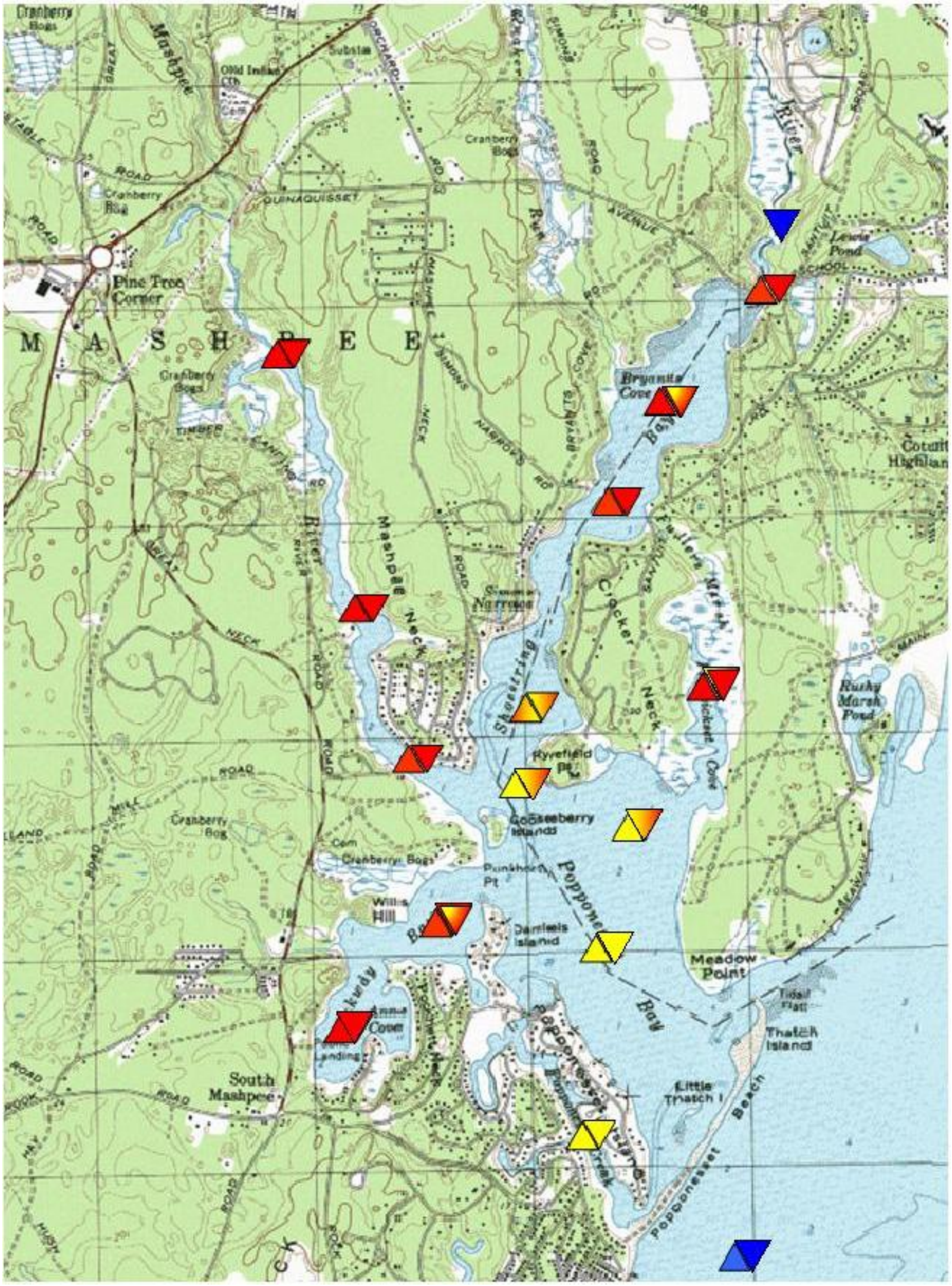

Figure 16. Nutrient related water quality of the Popponesset Bay system, based upon monitoring data (Table 5) from stations in Figure 5. The Health Index was developed for Buzzards Bay open water embayments. Note the gradient in nitrogen related water quality with lowest quality within the inland tidal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

▲ Long-Term Data ▼ 2016 Data

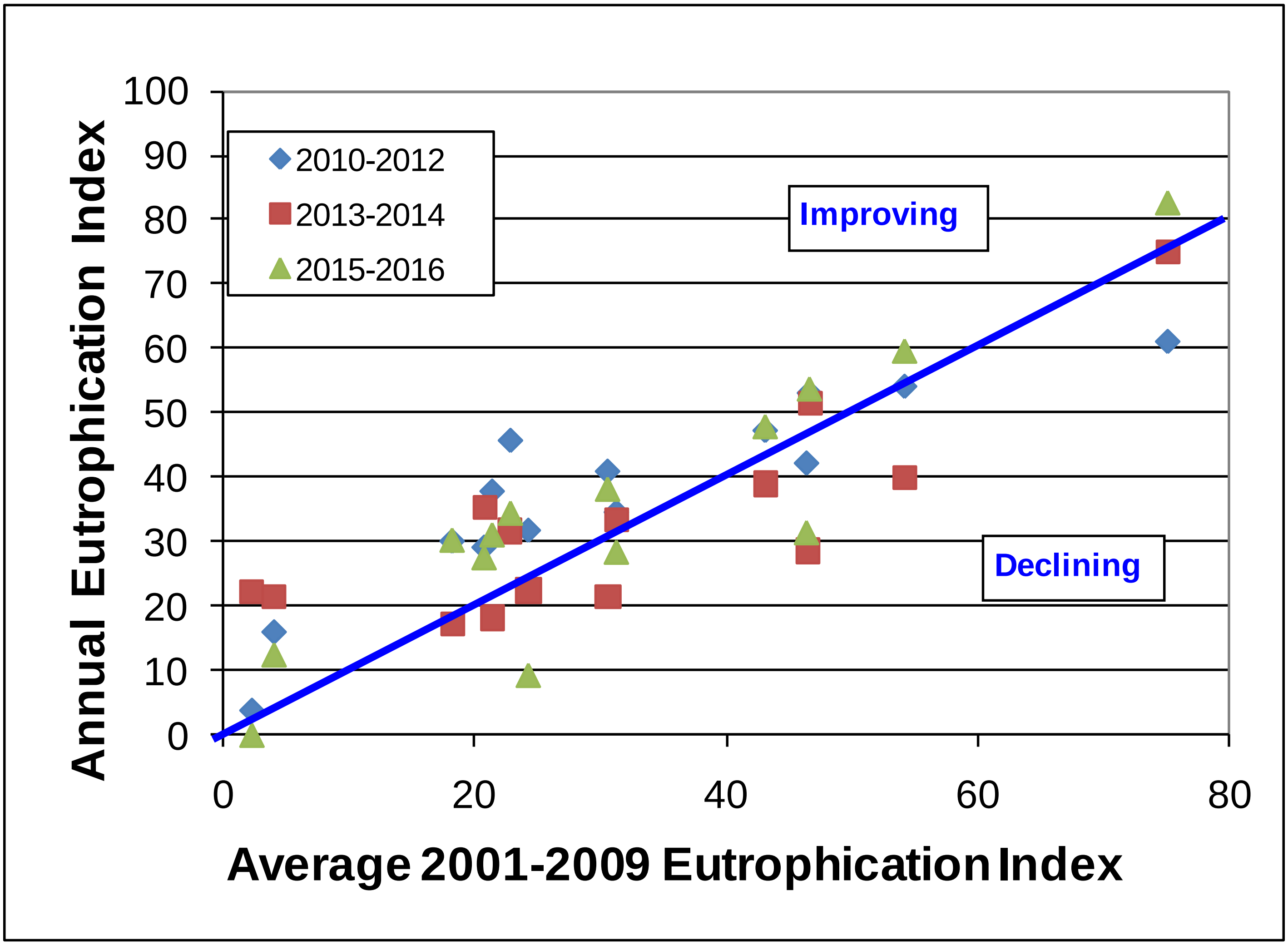

Figure 17. Eutrophication Index for each Popponesset Bay site averaged 2010-12, 2013-14 and 2015-16 (Y axis) compared to the longer term average (2001-2009) for the same sites (X axis). Freshwater sites are not included. The 1:1 line represents "No Change", points above the line indicate improved conditions and points below the line indicate increased impairment.

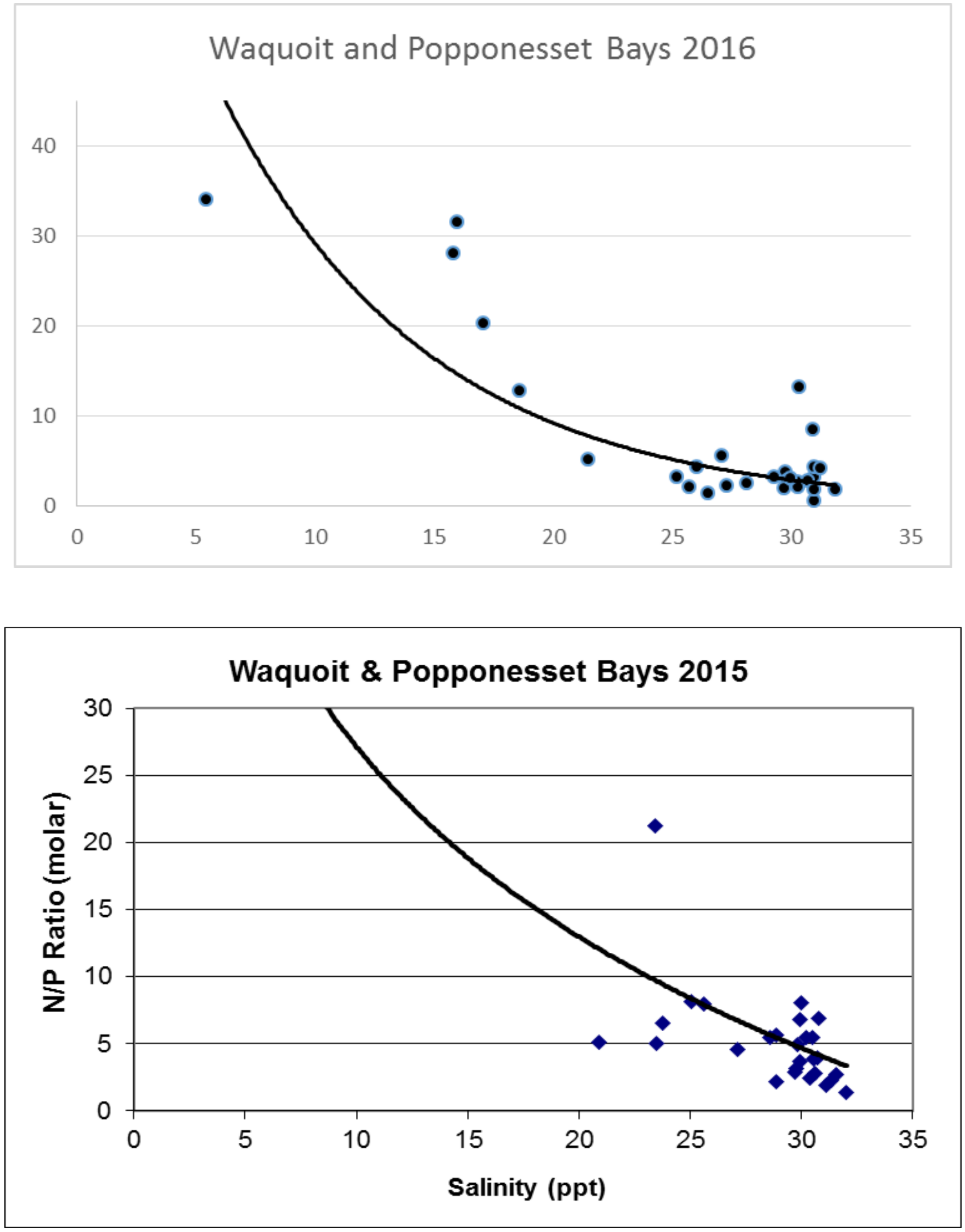

Figure 18. Changes in the nutrient causing eutrophication with water column salinity (2015 and 2016). Typically phosphorus is the nutrient to be managed in freshwater systems and nitrogen in marine systems. The indications of phosphorus limitation are all within or adjacent discharging streams within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