SMAST 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 2020 results)

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For:

<u>Mashpee Water Quality Monitoring Consortium</u>:

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&
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) to 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 and Popponesset Bays 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 have declined in ecological health since 2010 and now show moderate to significant impairment throughout. While overall the systems continue to support impaired habitat quality there are localized areas of improvement where management actions have been taken (e.g. dredging Popponesset Inlet and deployment of bivalves). However, in general Waquoit Bay appears to have more nitrogen impairment in recent years compared to the long-term baseline and Popponesset Bay varies from year to year, but generally shows significant impairment through nitrogen enrichment in all of its basins. Analysis of the full record for each estuary indicates that while conditions in 2016 and 2017 were generally similar to or slightly improved over the long term baseline, the improvements observed during 2010-2015 had 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. In 2019 and 2020 high phytoplankton levels due to nitrogen enrichment are now pervasive and both systems are showing lower water quality than 2010-2015 and the measurements now show no high water quality areas remaining in either Bay

The Upper Childs and Quashnet Rivers (and to a lesser extent the Mashpee River) in 2016 through 2020 were among 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 monitoring program results, 2010-2020.

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] The MEP Technical Team is still active through SMAST in conducting assessments and modeling in New England estuaries and conducting “what if” scenarios for Town’s developing management actions.

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. This appears to have been the case for Mashpee’s estuaries.

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) and initial funds voted to begin its implementation. The goal being to reduce 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]

[1] Massachusetts Estuaries Project Nutrient Threshold Reports can be accessed via the Web at http://www.smast.umassd.edu/estuaries/. This site is maintained by the SMAST MEP Technical Team 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.

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).

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 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 bay 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 3 surface water inflow and decrease the travel time of groundwater from the watershed recharge areas to bay waters. 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.

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 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 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. Almost all 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 than estuaries adjacent 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 documented for 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 generate the major nitrogen load to bay waters.

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 Monitoring 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
    - Popponesset Creek
    - 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 the Natural Resources Department, Rick York (2009-2019) and Ashley Fisher (2019-present), including the recruiting of volunteers. The Mashpee Wampanoag Tribe Natural Resources Staff 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, wave 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 Stations CR, ER and WB	X	X	X	X
Popponesset Bay				
All Stations PB and SR	X	X	X	X

As was the case with prior year's monitoring efforts, the 2019 and 2020 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 2019: July 8, July 19, August 5, August 19 and in 2020: July 8, July 23, August 6, and August 21. Samples were collected at each station at mid water depth on an early morning 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 2010-2020 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, Figures 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 previous seasons, a total of 148 water samples for nutrients (includes QA samples) were collected in the 2019 and 2020 field seasons: 80 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 2018; * 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 16	3*	3	3	4	2	1	2	1	1	20
July 31	3*	3	3	4	2	1	2	1	1	20
Aug 14	3*	3	3	4	2	1	2	1	1	20
Aug 28	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,	Shoestring Bay PB05,0 6, 07	Ockway Bay PB09, 10	Popp Bay PB08, 11, 12,	Off Shore PB 14	Pinquickset Cove PB15	Santuit River SR05	Total
July 16	4	3	2	5*	1	1	1	17
July 31	4	3	2	5*	1	1	1	17
Aug 14	4	3	2	5*	1	1	1	17
Aug 28	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 2019* 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 8	3*	3	3	4	2	1	2	1	1	20
July 19	3*	3	3	4	2	1	2	1	1	20
Aug 5	3*	3	3	4	2	1	2	1	1	20
Aug 19	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 8	4	3	2	5*	1	1	1	17
July 19	4	3	2	5*	1	1	1	17
Aug 5	4	3	2	5*	1	1	1	17
Aug 19	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 2020; * 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 8	3*	3	3	4	2	1	2	1	**1**	**20**
July 23	3*	3	3	4	2	1	2	1	**1**	**20**
Aug 6	3*	3	3	4	2	1	2	1	**1**	**20**
Aug 21	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 8	4	3	2	5*	1	1	1	**17**
July 23	4	3	2	5*	1	1	1	**17**
Aug 6	4	3	2	5*	1	1	1	**17**
Aug 21	4	3	2	5*	1	1	1	**17**
Total	**16**	**12**	**8**	**20**	**4**	**4**	**4**	**68**

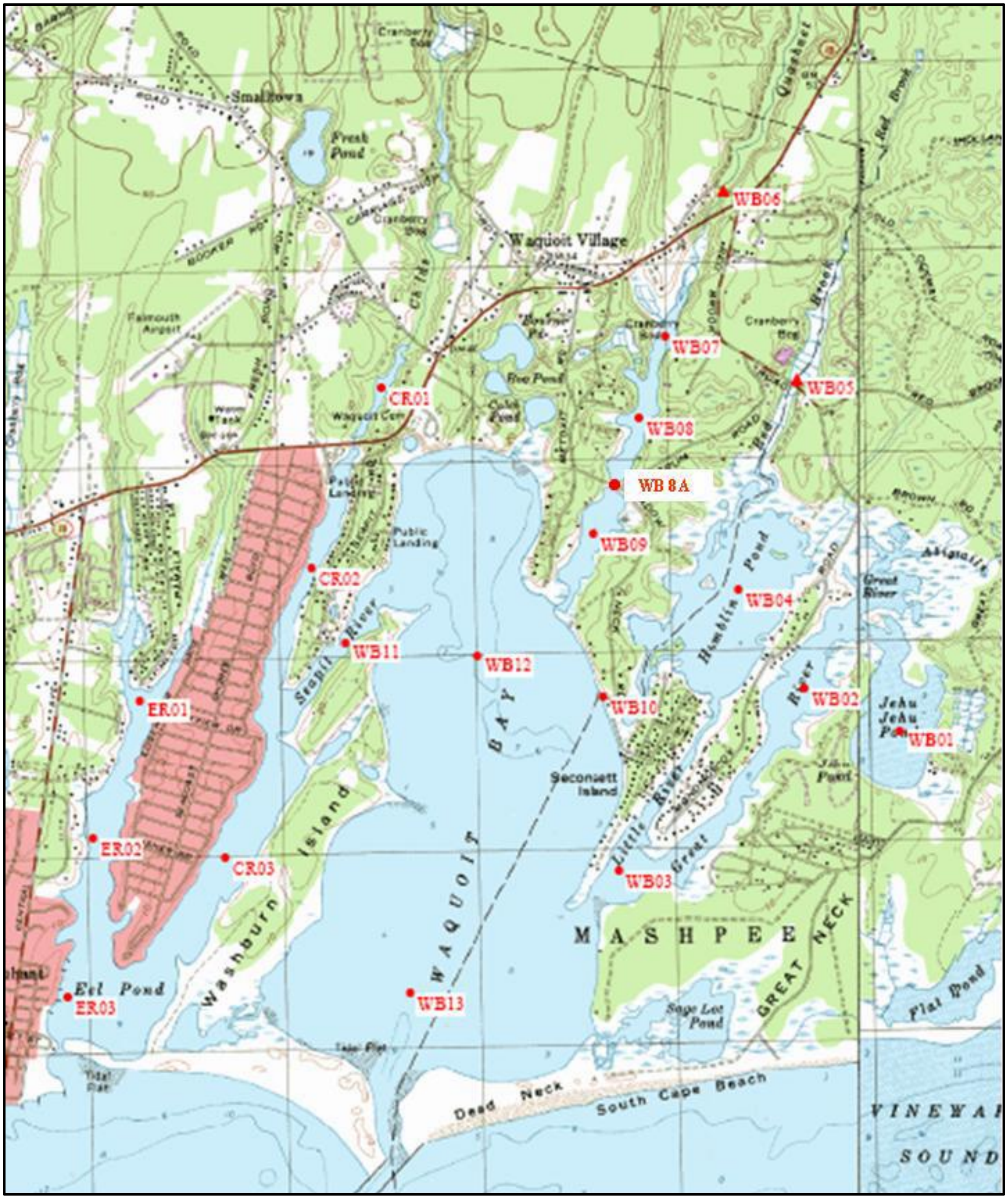

Figure 4. Water quality sampling stations associated with the Waquoit Bay System (2001-2020). Samples were collected synoptically between 5:30 - 8:30 AM on ebbing tides.

Figure 5. Water quality sampling stations associated with the Popponesset Bay System (1997-2020). 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 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 and quahogs). As implementation is still in its early stages, it is not surprising that the results of the 2010-2020 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 that were showing some improved water quality through 2015 with moderately impaired areas being relatively stable, have now declined (2016-2020) and there are currently (2019-2020) no high quality areas remaining in either estuary (see below). Unfortunately, both bays experienced large blooms and an associated decline in water quality in summers of 2016 – 2018, with high phytoplankton levels throughout. Although in Popponesset and Waquoit Bay, levels were still high in summers of 2019 and 2020, they were more in line with the general baseline, indicative of continuing eutrophic conditions.

Both Waquoit and Popponesset Bays support impaired habitats throughout their tidal reaches and remain below the water quality levels set by the MassDEP/EPA. This is consistent with the fact that the Threshold Nitrogen Level specified in the TMDL was not attained within any basin in 2019 and 2020, indicating that the impairments are caused by nitrogen enrichment.

The overall salinity gradients within each estuary in 2010-2020 are generally consistent with historical patterns (Figures 6 and 10), but with slightly lower levels observed in upper tidal reaches of both estuaries in the high rainfall year of 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 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 2019 and 2020 the salinity of the Mashpee River was at below baseline levels (2 ppt in 2020) with a clear gradient of near freshwater at the headwaters at Rt. 28 and increasing to the mouth. It is interesting to note that the freshwater outflow from the Mashpee River can be seen in surface samples at PB08 adjacent Gooseberry Island where there is frequently a surface fresher water layer overlying more saline bottom waters derived from bottom waters at the mouth of the Mashpee River and outflowing waters from Shoestring Bay.

Both the Upper Mashpee and Childs Rivers show significant inter-annual variation in salinity in response to rainfall and groundwater levels, although salinity and rainfall are only weakly correlated. There is not a clear relationship between salinity in the upper reaches of these tidal rivers and their Total Nitrogen (TN) level found in the monitoring data. This almost certainly relates to the finding that while high discharges typically carry more nitrogen load, the concentration does not generally vary much with flow.

It should be noted that the head of Quashnet River has been consistently very brackish, ≤5 ppt, declining to 3 ppt in some years (e.g. 2020). At the mid-station of Quashnet River the salinity appears to have returned to long-term level or even slightly higher after lower salinities in 2015-2020. The abrupt increase in salinity from the mid station to the lower basin (~5-8 ppt to ~20 ppt over the complete record) is mainly due to lower tidal exchange in the mid versus lower basin. This increase from mid to low station 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 and through 2020. It appears that currently the mid basin is still functioning as an estuarine basin, but the upper most basin has sufficiently depressed salinities in some years that phosphorus management may need to be evaluated (Figure 18). It should be noted that this uppermost basin typically has very large phytoplankton blooms and although less frequent, so does the mid basin. The mid to upper Quashnet support some of the largest blooms in both estuaries, exceeding 50 ug/L chlorophyll-a in some years (over 10 ug/L indicates eutrophic conditions).

Like the Childs and Quashnet Rivers within Waquoit Bay, in Popponesset Bay, the Mashpee River upper basin also continues to support brackish salinities very similar to the upper Quashnet River Basin. However, the Mashpee River has generally supported a stable salinity structure of 3-5 ppt in all previous years, except in 2020 where salinity declined to 2 ppt. The Mashpee River continues to support no tidal restrictions within the tidal river itself. It is worth noting that the salinity at the upper Mashpee River station indicates slightly lower salinities in 2019 & 2020 than in most previous years and the mid and mouth stations also appear to have lower salinities 2016-2020 (Figure 10). Notably, the Mashpee River upper and mid stations frequently support higher TN concentrations than at the head or the mouth of the river, with the upper station now showing the highest TN in the Popponesset Bay System, 2016-2020 (Figure 11). The observed TN levels in the upper and mid Mashpee River are consistent with summer average phytoplankton chlorophyll levels exceeding 30 ug/L in most years (>10 ug/L indicates eutrophic conditions). The Mashpee River supports larger blooms than all the other basins comprising the Popponesset Bay system (Figure 12).

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. In 2019 and 2020, salinity in these open basin stations were similar to previous years with no salinity variations of ecological importance in these larger open water basins.

Monitoring results from summers 2010-2020 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, 2016-2018 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 2013-2015 or 2019-2020. 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 in Popponesset Bay are higher in the 2010-2020 period than historically, particularly in the Mashpee River and Shoestring Bay, but are less clear in Ockway Bay and the Bay’s main basin. However, all stations in all years of monitoring indicate high TN levels (greater than the TMDL threshold) consistent with impairment by nitrogen enrichment. The effects of the high TN levels can be seen in the algal blooms and periodic low oxygen levels. Similarly, Waquoit Bay appears to have higher TN levels in the past 5 years than historically in the Child River head and lower basin, upper and mid Quashnet River, Jehu and Hamblin mid stations with possibly slight increases in the main bay, although there is year to year variation. 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 appear to have increased over the past 5 years and apparent continuing declines in water quality in some basins are troubling as they appear to represent a new trend (2016-2020).

In general, the 2010-2020 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. However, in 2019 and 2020 TN levels in Jehu and

Hamblin Ponds have returned to pre-2015 levels. 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 2010-2020 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 2016-2020 TN levels have significantly increased over historic (pre-2010) conditions (particularly in the Mashpee River, Shoestring Bay, and Quashnet River), 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 also appears to be showing some 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 2016-2019 (Mashpee River, Shoestring Bay, and Quashnet River), and associated depletion of bottom water oxygen. It is worth noting that 2020 showed unusually high DO levels for many of the Popponesset Bay stations, the cause of which is unclear. It is possible that the relatively high light levels in the days preceding sampling was in part the cause. However, event oxygen levels were elevated in Shoestring Bay and the main basin, the levels generally failed to meet the Massachusetts water quality standard for 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 and Popponesset Bay systems, 2016-2020 chlorophyll-a levels are generally higher than the long-term historical data in some basins (Waquoit Bay: Childs River, Quashnet River, Seapit River, Jehu Pond; Popponesset Bay:Mashpee River, Shoestring Bay, Ockway Bay and portions of the main Popponesset Bay basin), supporting the contention that each overall estuary is presently nitrogen enriched, resulting in high levels of phytoplankton production and blooms when environmental conditions are right and conditions appear to be declining. In addition to the amount of phytoplankton, it is important to note the large and prolonged bloom in summers 2016, 2017, 2018 and 2019, to levels not previously observed. The effects of continuing nitrogen enrichment are 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 (note some basins frequently >20 ug/L). 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) typically support only moderate levels (consistent with moderate TN levels). But again, increasing total chlorophyll-a levels in 2016-2018 and 2020 were higher levels than the long-term average in the eastern basins, with the period 2016-2018 being the highest levels recorded at most stations, generally exceeding the 10 ug/L threshold 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. Overall, most waters of both estuarine systems have total chlorophyll-a averages greater than 5 ug L^{-1}.

The observed levels of phytoplankton biomass in both estuaries 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, a shift to 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 decades in Popponesset Bay and has been reduced in Waquoit Bay to a few remaining patches in Hamblin Pond and Jehu Pond in the 1990's (Short and Burdick, 1996) and currently only Jehu Pond. 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). With eelgrass loss there is frequently a shift to macroalgal growth and accumulations stimulated by high nitrogen inputs have been significant across Waquoit Bay and large areas within the Popponesset Bay Estuary. In Popponesset Bay macroalgal accumulations have become significant throughout Ockway and Shoestring Bays, the lower Mashpee River and the upper main basin. 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.

Oxygen depletion of bottom waters was variable but still not meeting water quality standards within both systems in 2010-2020 and were generally consistent with historical data, however, except for the low 2018 DO levels in Shoestring Bay (and upper Childs River), there were no exceptionally low DO levels observed. Anomalously high DO levels were found in lower Mashpee River, Shoestring Bay and portions of Popponesset Bay in 2020, the cause of which is likely periods of high light prior to each sampling event. The elevated DO was also seen in some Waquoit Bay stations but was less intense. Generally, the observed low DO at specific stations in the Waquoit Bay system (Childs River, Eel River) and Popponesset Bay systems (Mashpee River and Shoestring Bay) follow the distribution of higher total chlorophyll-a and TN levels (Figures 9, 13) and the high DO in 2020 at some stations was associated with slightly lower chlorophyll-a levels at those stations. Note that in 2020 the DO still did not meet Massachusetts Standards at almost all stations and the chlorophyll levels still indicated impairment. 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 oxygen depletion in basins with higher nitrogen enrichment. In the Popponesset Bay Estuary, significant oxygen depletion was observed at all 13 estuarine station in samples from 2010-2020, except for 3 stations in 2020. The significant depletions created bottom water DO levels below the MassDEP water quality standard and to levels deemed stressful to estuarine organisms. DO conditions in Waquoit Bay show the same general pattern as seen in Popponesset Bay, with most basins with DO declines to below 5 mg/L each year and below 4 mg/L in some years even in the main basin. The more depressed DO levels in the eastern basins of Waquoit Bay, 2016-2018 are likely the result of the large, prolonged phytoplankton blooms that occurred during that period, which resulted in higher organic loading to the sediments and elevated water column night-time respiration, however, 2019-2020 showed a return to typical DO and chlorophyll levels. It is likely that the basins of these estuaries remain generally nutrient and organic matter enriched to the point where oxygen depletion will 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.

It is clear from the Mashpee Water Quality Monitoring Program Results that both Popponesset Bay and Waquoit Bay are nitrogen enriched, have frequent phytoplankton blooms and oxygen depletion throughout their basins. While each Bay supports a gradient of highly impaired (upper tidal reaches) conditions to moderately impaired conditions close to their tidal inlets, the areas of high water quality near their inlets are now showing impairment (2019-2020) such that there are no high water quality areas remaining in either system. In addition, both estuaries are showing the same responses to nitrogen enrichment, with higher chlorophyll-a and lower DO levels. 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, the observed levels observed in 2016-2019 suggest that these estuaries have declined after a period of slight improvement 2010-2015, which was due to implementation of localized management actions. While the exact cause of the large blooms and increased total chlorophyll pigment levels throughout the both bays in the period 2016-2020 is not certain, it may be associated with higher TN loading from higher freshwater inflows due to variations in spring-summer precipitation. 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 2016-2018, 2019-2020). 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 Waquoit and Popponesset Bay systems which continued through 2019 and 2020 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. While historically the waters in the region of the tidal inlet showed high water quality in 2019 & 2020 they showed moderately impaired water quality. This is a negative finding 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 remaining eelgrass habitat were found there (now lost), although there may be some high quality benthic animal habitat remaining still.

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, 2016-18 and 2019-2020 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 compared to the baseline years of 1997-2009 taken as a whole (not significant at p=0,05). However, results from 2016-2020 indicate a decline in some basins. On a finer scale, regions of significant impairment (Index <30) did show some improved conditions (but still poor conditions) 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 2016-2018 and 2019 and 2020 yielded a significant reduction ($p<0.05$) in the water quality Index from 2010-2015 to 2016-2019 and a return to the baseline conditions of 1997-2009. It should be noted that the declines seen in the 2016-2019 data are driven significantly by the large phytoplankton blooms in 2016-19. Most significant is the loss of the high water quality area in Waquoit Bay nearest the inlet, such that in 2019-2020 there are no high water quality areas remaining in either Bay. The importance of these events will depend on if they are transitory or rare events spawned by unique environmental conditions (streamflows, wind, precipitation, light) or if it is part of a permanent shift toward increasing bloom frequency and duration due to continued nitrogen enrichment. At this time there is significant impairment of water and habitat quality throughout the tidal reaches of both the Popponesset and Waquoit Bay Systems.

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 2016-2019, which impacted water quality. Overall, the trend of improving water quality in the poorest quality areas compared to historic records, but the improvement is not continuing and some areas are declining to historic levels as seen in the impairment levels in recent years, 2016-2020. The moderately impaired areas appear to be relatively stable continuing the historic level of impairment. Analysis of macroalgal accumulations in these areas suggests that the "improvement" is related to a diversion of nitrogen to different primary producer (macroalgae versus phytoplankton), which would actually add another stress to the benthic habitat quality.

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 2016-2020, 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 2016-2020 compared to historical levels due to periodic phytoplankton blooms 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 2016-2020 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. However, it is clear that the Popponesset Bay system is impaired by nitrogen loading and has not improved and may be getting worse as macroalgal accumulations expand.

MONITORING CONCLUSIONS AND RECOMMENDATIONS

Overall, both the Waquoit Bay and Popponesset Bay Estuarine Systems remain highly nitrogen enriched and showed impaired nutrient related water quality in 2010-2020, 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 which may be becoming more frequent. 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 possible declines 2016-2020. 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 which have continued (measure of phytoplankton levels). In both estuaries it is the tidal rivers that receive significant freshwater inflows from the watershed dischage to their headwaters and it appears that average freshwater inputs in wet years (carrying nitrogen and other constituents) can depress salinities and cause localized blooms and poor water quality. However, since the freshwater discharges still occur in dry years and carry watershed nitrogen to the estuary, these tidal rivers (Quashnet River, Childs River, Mashpee River) typically support the poorest water quality in each estuary. Given the apparent growing trend toward more frequent phytoplankton blooms monitoring should include tracking bloom events in summers 2021-2023. 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 Waquoit Bay deployment of bivalves is also underway. These actions appeared to show some improvement, but it appears that more action is needed. 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. In a positive critical action Town Meeting Voters unanimously passed (May 2020) a $54 million article to fund Phase I of the Town's implementation of its estuarine restoration plan. Therefore, monitoring should hopefully begin documenting improvements in estuarine water quality rather than its continuing decline.

Specific findings:

(1) Both Waquoit Bay and Popponesset Bay appear to be showing some additional impairments, mainly associated with the increased frequency and magnitude of phytoplankton blooms 2016-2020. Blooms are difficult to capture as they can be patchy last only a few weeks so there is some variability in the results. The blooms are clearly associated with nitrogen enrichment and are generated within each estuary each summer. Some of the largest blooms in the past 20 years have been seen in the past 5 years in each of the component basins to both estuaries. The result is that both systems continue to support impaired habitat quality. Unfortunately, there apparent general gradual improvement in overall Waquoit Bay and Popponesset Bay in 2010-2015 compared to 1997-2009 has now diminished in the 2016-2020 and the water quality is at the lowest on record. However, examination station by station indicates that regions which have historically shown significantly impaired water quality (Health Index <30) have possibly improved slightly but with little ecogical impact as they remain severely degraded. In contrast, regions in the main basins with little to moderate impairment now support impaired water and habitat quality. Based upon the composite index, all high water quality areas within either estuary have been gone since 2016. In 2016 there was the possibility that the observed water quality decline was due to unique environmental conditions, but it now appears that it is 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. Unfortunately, each of the component sub-basins comprising each estuary now support impaired habitats and remain below the water quality levels and above the TN 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 2016-2020, with levels in the mid basin nearly double those in prior years (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 2012-2019 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 complete record, 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) 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.

2) To determine the cause of the high variability in oxygen depletion and phytoplankton blooms, deploy continuously recording dissolved oxygen and chlorophyll mooring at critical location(s) in the Waquoit and Popponesset Bays systems (min. 30-day deployment) and to determine there is new process associated with macroalgae in that resulted in the elevated oxygen levels in 2020.

Based upon the recent increase in large phytoplankton blooms that may 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 equilibrium or if we are only seeing the responses to rainfall cycles.

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.

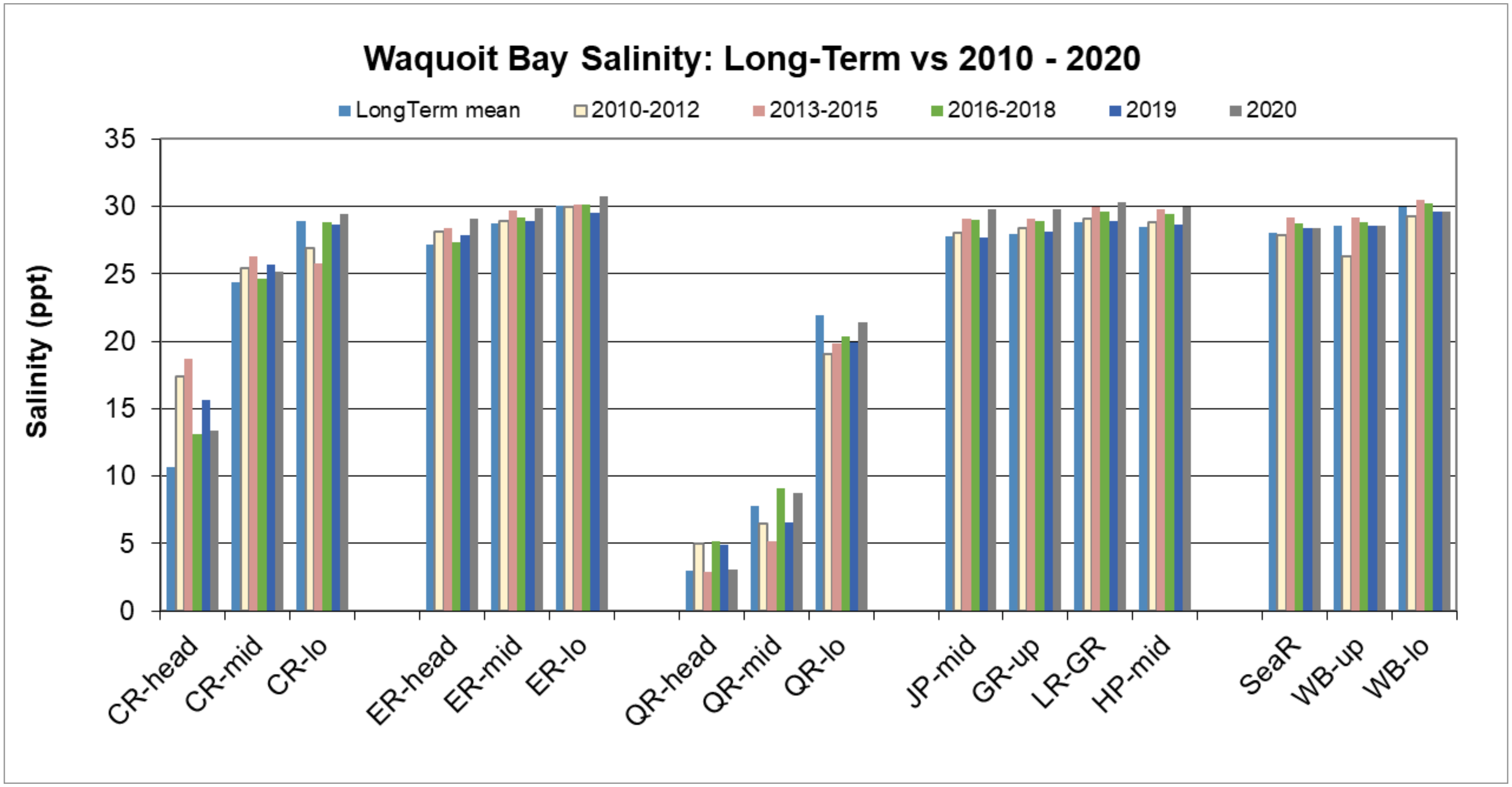

Figure 6. Salinity Distribution throughout the Waquoit Bay Estuarine System long-term and in the summers of 2010-2020. Freshwater enters through groundwater all along the shoreline, with additional "point" inflows from the Moonakis River, Childs River, and Red Brook. These freshwaters mix with the saline 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.

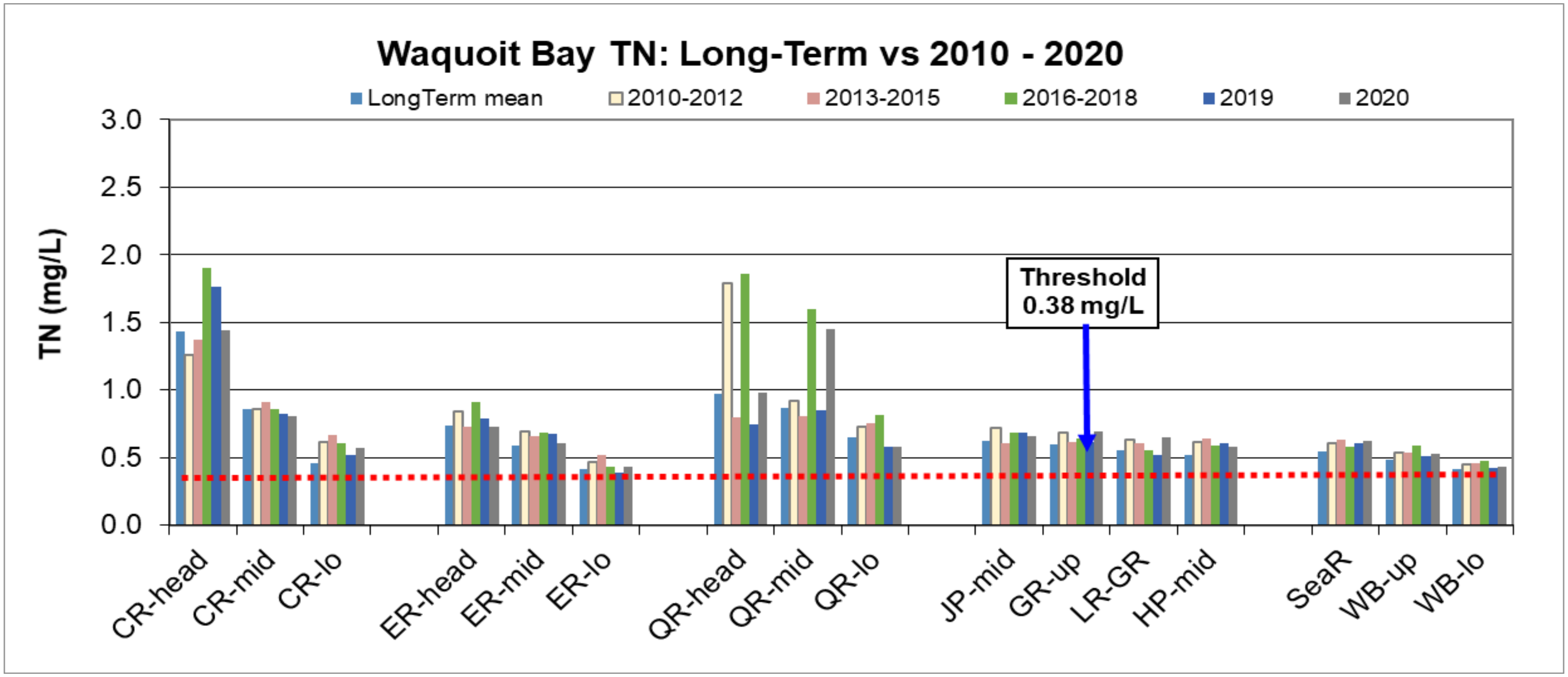

Figure 7. Distribution of Total Nitrogen within the Waquoit Bay Estuarine System, long-term and during the summers of 2010 through 2020. Nitrogen enters through groundwater inflows all along the shoreline, with additional "point" loads from the upper regions of the watershed via Moonakis River, Childs 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.

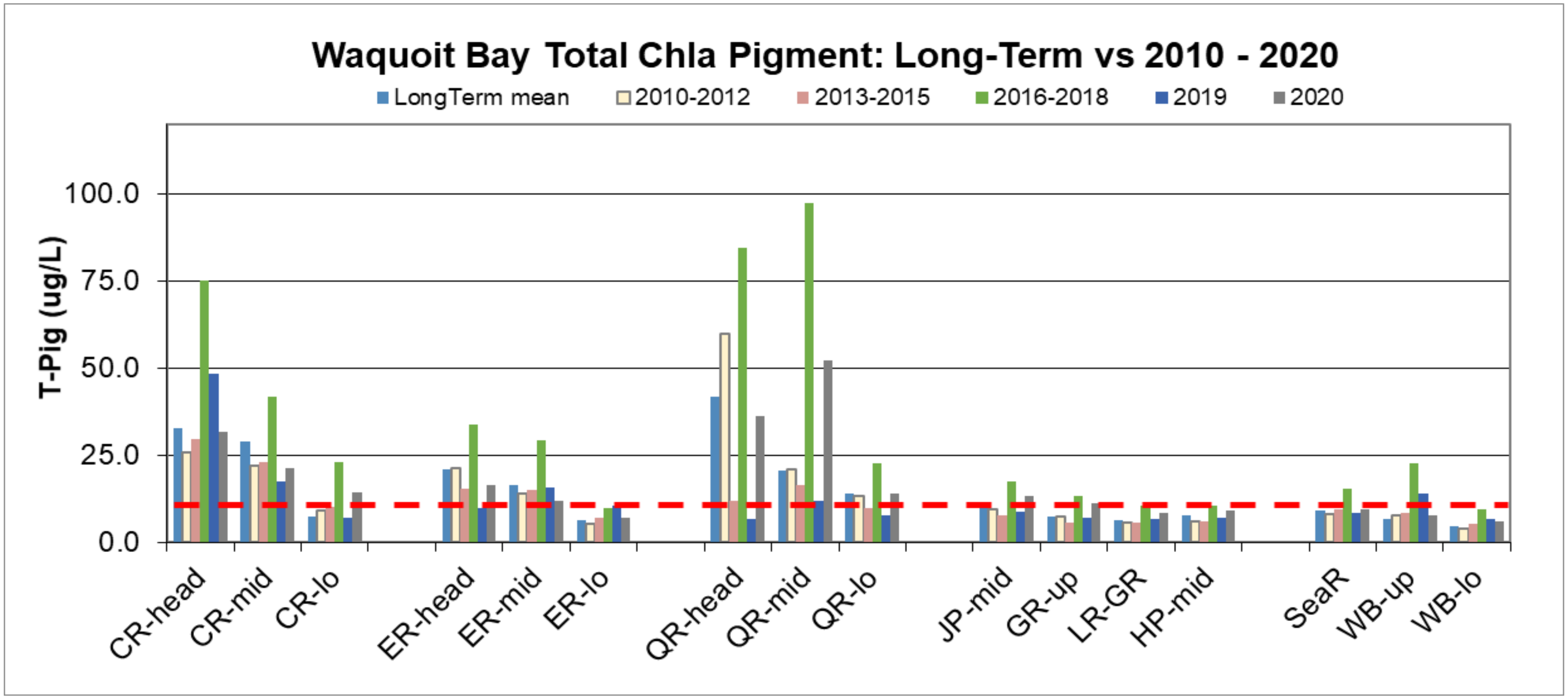

Figure 8. Total Chlorophyll-a pigment levels throughout the Waquoit Bay Estuarine System over the long-term and in summers of 2009 through 2020. Phytoplankton pigment levels are a gauge of phytoplankton biomass, which is a response to nitrogen loading. Values over 10 indicate nitrogen enrichment, values <3 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.

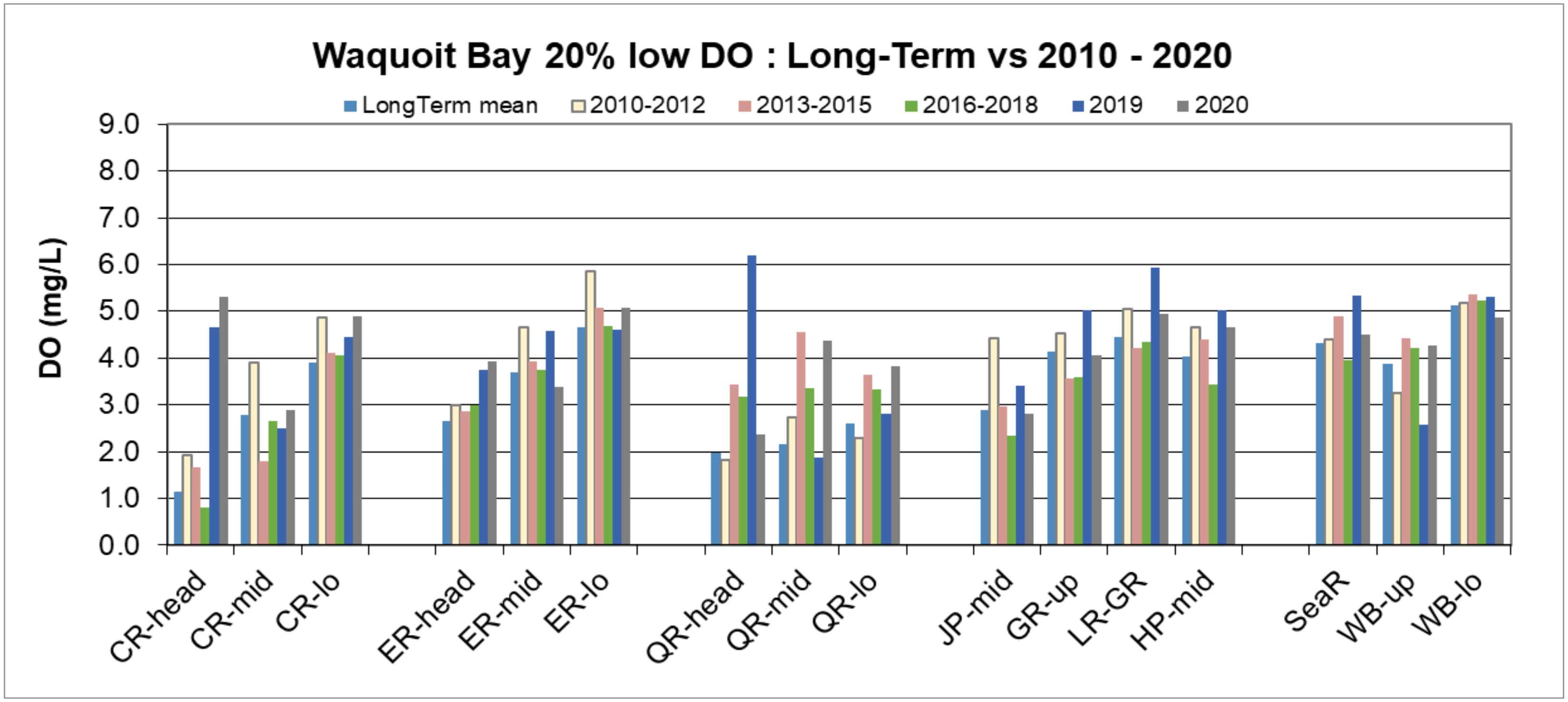

Figure 9. Minimum Dissolved Oxygen (D.O.) levels throughout the Waquoit Bay Estuarine System over the long-term and in the summers of 2010-2020. CR - Childs River, ER - Eel River, QR - Quashnet River, JP - Jehu Pond, GR - Great River, LR-GR - Little River-Great River confluence, HP - Hamblin Pond, SeaR - Seapit River, WB - Waquoit Bay main basin; head - uppermost reach, mid - middle reach, lo - lower basin near mouth or inlet. Values below 6 mg/L do not meet the Commonwealth's water quality standard, and below 4 mg/L cause stress to benthic animals. Almost all sites fail to meet even 5 mg/L in most years and Upper Childs and Eel Rivers, Quashnet River, Jehu Pond and Upper Waquoit Bay approach or fall below 4 mg/L in most years.

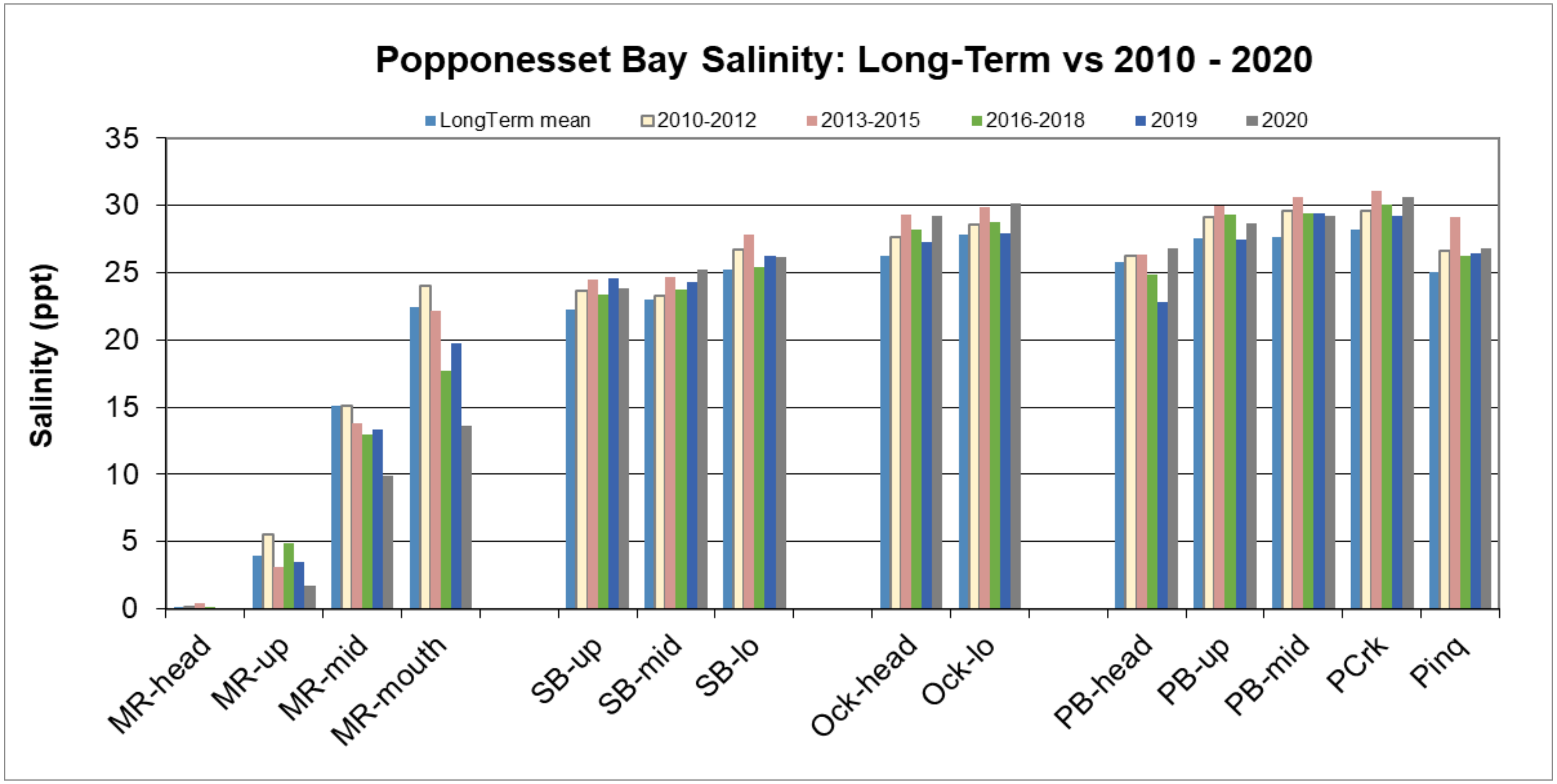

Figure 10. Salinity Distribution throughout the Popponesset Bay Estuarine System (2010-2020). Freshwater enters through groundwater all along the shoreline, with additional "point" inflows from the freshwater reach of the Mashpee River and from the Santuit River to Shoestring Bay. These freshwaters mix 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.

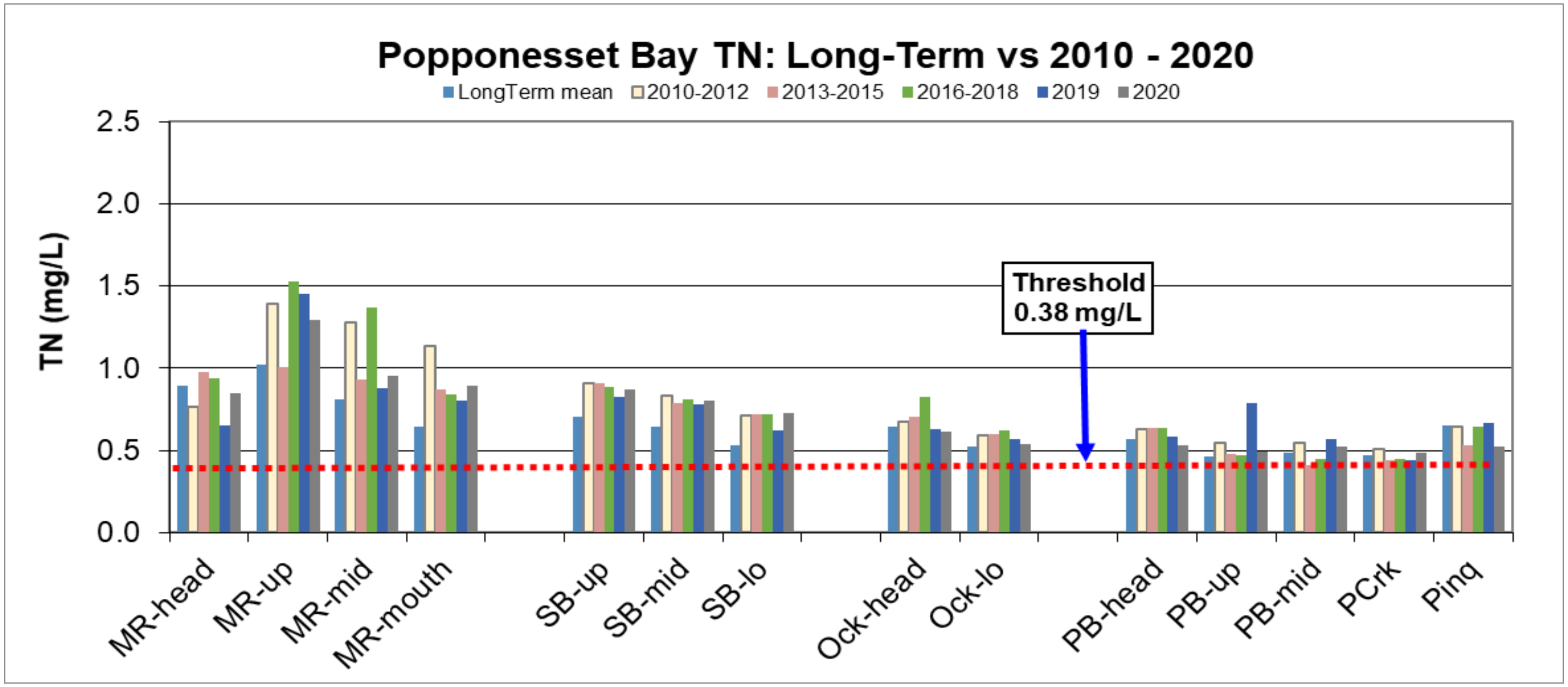

Figure 11. Distribution of Total Nitrogen within the Popponesset Bay Estuarine System. Nitrogen enters through groundwater inflows all along the shoreline, with additional "point" loads from the upper regions of the watershed via the Mashpee River and Santuit River to Shoestring Bay. These nitrogen loads 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 2010-2020 are compared to the long-term average.

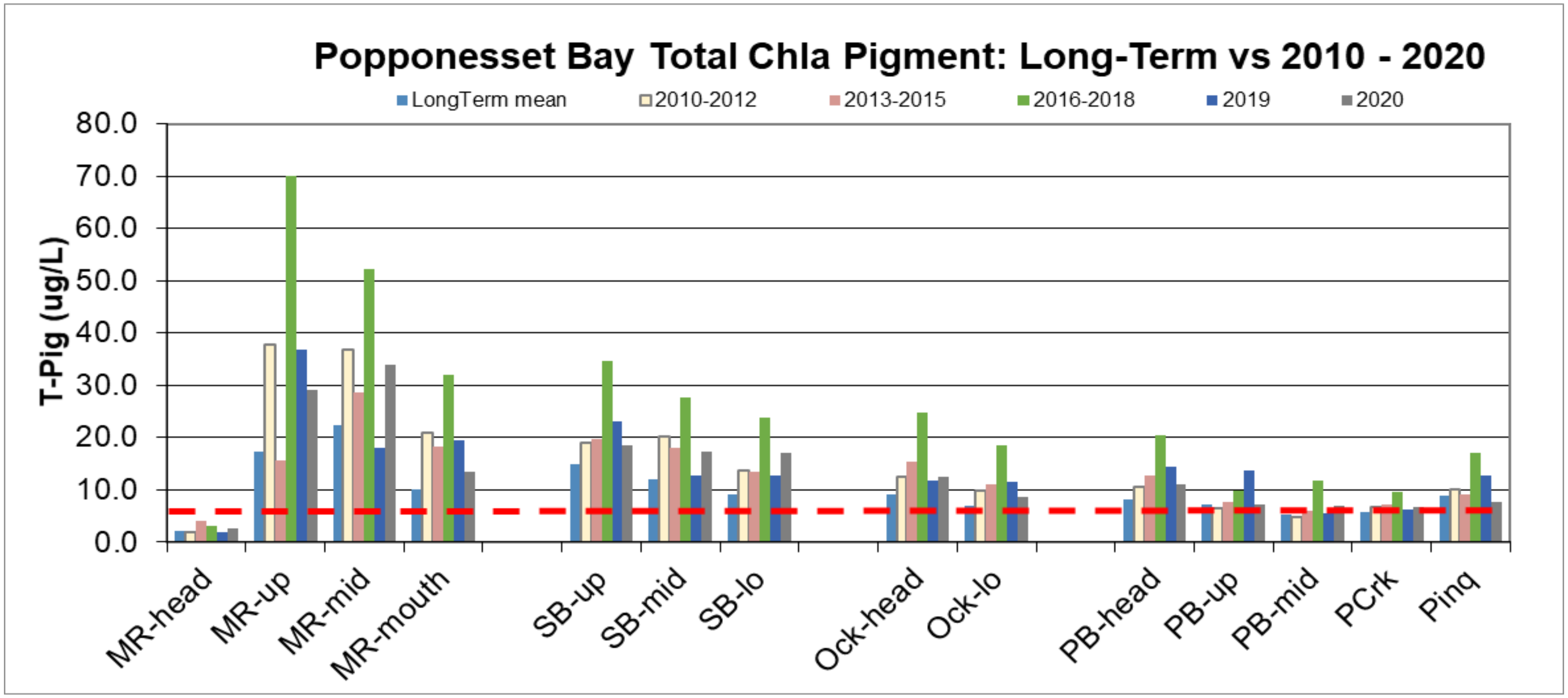

Figure 12. Total Chlorophyll-a pigment levels throughout the Popponesset Bay Estuarine System over the long-term and in summer 2010-2018. Phytoplankton pigment levels are a gauge of phytoplankton biomass, which is a response to nitrogen loading. Values over 10 indicate nitrogen enrichment, values <3 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.

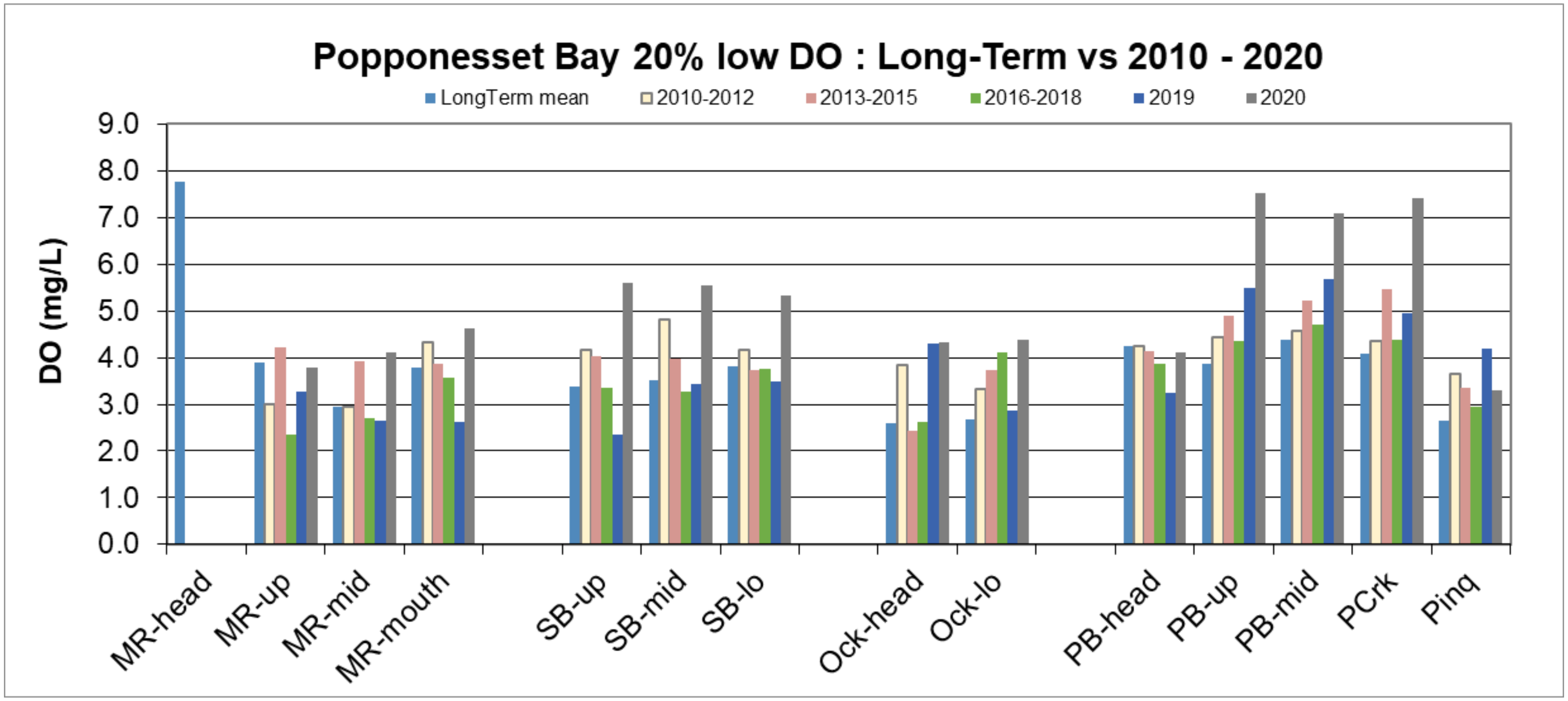

Figure 13. Minimum Dissolved Oxygen levels throughout the Popponesset Bay Estuarine System over the long-term and in the summers of 2010 through 2018. MR - Mashpee River, SB - Shoestring Bay, Ock - Ockway Bay, PB - Popponesset Bay, PCrk - Poppenesset Creek, Pinq - Pinquickset Cove. Values below 6 mg/L do not meet the Commonwealth's water quality standard, and below 4 mg/L cause stress to benthic animals. Almost all sites fail to meet even 5 mg/L in most years and approach or fall below 4 mg/L in most years except in the main Popponesset Bay basin.

Table 4a. Summary of water quality parameters in Waquoit Bay. Summer 2019.

2019 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	0.84	0.94	92%	15.67	4.65	66.10	0.04	0.04	0.07	0.11	0.60	1.06	1.65	1.77	5.84	48.38
CR02	1.04	1.71	60%	25.69	2.50	36.00	0.01	0.02	0.01	0.03	0.36	0.44	0.80	0.82	4.43	17.37
CR03	1.45	3.23	45%	28.70	4.45	65.30	0.02	0.04	0.00	0.04	0.26	0.22	0.48	0.52	4.33	6.98
Eel River																
ER01	1.00	1.15	88%	27.90	3.76	56.70	0.00	0.01	0.01	0.03	0.34	0.42	0.76	0.79	15.50	9.88
ER02	1.04	1.34	77%	28.94	4.57	65.30	0.01	0.01	0.00	0.01	0.27	0.39	0.66	0.67	3.64	15.74
ER03	1.25	1.43	89%	29.51	4.61	70.90	0.02	0.02	0.00	0.02	0.20	0.16	0.36	0.39	3.43	10.43
Waquoit Bay																
WB01	1.40	2.65	52%	27.72	3.40	50.20	0.02	0.02	0.00	0.02	0.42	0.24	0.67	0.69	2.16	8.91
WB02	1.28	1.41	89%	28.18	5.03	73.40	0.02	0.02	0.00	0.02	0.35	0.25	0.60	0.62	2.76	7.07
WB03	1.26	2.09	60%	28.91	5.92	86.70	0.01	0.03	0.00	0.03	0.28	0.22	0.49	0.52	5.04	6.83
WB04	1.33	1.46	90%	28.68	5.03	74.20	0.01	0.01	0.00	0.01	0.33	0.26	0.59	0.60	2.72	7.00
WB05	btm	0.75	0.75	0.10	ND	ND	0.02	0.01	0.01	0.01	0.37	0.11	0.48	0.50	1.96	2.76
WB06	btm	0.23	1.00	0.10	ND	ND	0.01	0.02	0.23	0.26	0.20	0.08	0.29	0.54	57.28	3.54
WB07	btm	0.51	100%	4.92	6.20	65.40	0.01	0.05	0.13	0.17	0.23	0.35	0.58	0.75	49.83	6.74
WB08	btm	0.85	100%	6.58	1.88	19.60	0.01	0.04	0.09	0.13	0.21	0.51	0.72	0.85	34.04	11.82
WB09	btm	1.15	100%	19.97	2.81	40.40	0.02	0.02	0.01	0.03	0.27	0.27	0.55	0.58	3.86	7.86
WB10	btm	0.25	1.00	28.15	ND	ND	0.02	0.03	0.01	0.04	0.34	0.27	0.62	0.66	5.84	10.49
WB11	1.48	2.13	70%	28.38	5.34	75.40	0.02	0.04	0.01	0.05	0.34	0.22	0.56	0.61	6.65	8.49
WB12	1.43	2.14	67%	28.61	2.56	35.80	0.01	0.01	0.00	0.01	0.23	0.26	0.49	0.51	2.86	13.89
WB13	1.59	2.28	70%	29.59	5.30	86.70	0.01	0.02	0.00	0.02	0.25	0.15	0.40	0.42	3.78	6.70

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 2020.

2020 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	0.85	0.85	1.00	13.34	5.32	79.50	0.02	0.03	0.22	0.25	0.54	0.65	1.19	1.44	36.98	31.76
CR02	0.93	1.75	0.53	25.17	2.88	48.50	0.01	0.01	0.01	0.02	0.40	0.39	0.79	0.81	6.05	21.13
CR03	1.13	2.40	0.48	29.46	4.89	76.80	0.01	0.02	0.00	0.02	0.33	0.22	0.55	0.57	3.66	14.27
Eel River																
ER01	0.77	1.25	0.62	29.08	3.94	69.10	0.00	0.00	0.00	0.00	0.37	0.35	0.72	0.73	5.70	16.48
ER02	1.00	1.33	0.75	29.92	3.37	56.70	0.00	0.01	0.00	0.01	0.32	0.28	0.60	0.61	7.93	11.87
ER03	1.00	1.40	0.71	30.76	5.07	88.20	0.01	0.03	0.00	0.03	0.26	0.15	0.41	0.44	7.56	7.13
Waquoit Bay																
WB01	1.17	2.81	0.41	29.81	2.81	47.20	0.00	0.01	0.00	0.01	0.38	0.27	0.65	0.66	12.94	13.22
WB02	1.08	1.35	0.80	29.82	4.05	67.50	0.00	0.01	0.00	0.01	0.41	0.26	0.68	0.69	6.90	11.22
WB03	1.33	2.23	0.60	30.30	4.94	82.80	0.01	0.02	0.00	0.02	0.39	0.24	0.63	0.65	4.80	8.59
WB04	1.16	1.46	0.80	30.02	4.67	78.30	0.00	0.02	0.00	0.02	0.33	0.23	0.56	0.58	13.89	9.27
WB05	0.27	0.40	1.00	0.25	ND	ND	0.02	0.12	0.16	0.28	0.49	0.25	0.74	1.02	27.33	16.13
WB06	btm	0.20	1.00	0.10	ND	ND	0.01	0.04	0.28	0.33	0.19	0.07	0.26	0.59	95.08	5.19
WB07	0.47	0.58	1.00	3.10	2.36	38.80	0.01	0.04	0.20	0.24	0.27	0.47	0.74	0.98	85.82	36.33
WB08	0.73	0.94	0.84	8.74	4.36	58.50	0.00	0.01	0.07	0.07	0.29	1.09	1.37	1.45	34.97	52.31
WB09	0.98	1.14	0.91	21.41	3.81	54.00	0.00	0.02	0.01	0.04	0.28	0.27	0.55	0.58	17.93	14.05
WB10	btm	0.23	1.00	29.08	ND	ND	0.01	0.02	0.02	0.04	0.45	0.28	0.74	0.77	7.46	15.27
WB11	1.35	1.55	0.87	29.51	4.50	66.00	0.01	0.03	0.01	0.05	0.36	0.22	0.58	0.63	7.42	9.54
WB12	1.52	2.18	0.70	29.42	4.26	58.00	0.01	0.01	0.00	0.02	0.30	0.21	0.52	0.53	4.93	7.85
WB13	1.34	1.56	0.91	30.86	4.87	81.30	0.01	0.01	0.00	0.01	0.26	0.16	0.42	0.44	2.49	6.04

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 2019.

2019 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	0.84	0.94	92%	15.67	4.65	66.10	0.04	0.04	0.07	0.11	0.60	1.06	1.65	1.77	5.84	48.38
CR02	1.04	1.71	60%	25.69	2.50	36.00	0.01	0.02	0.01	0.03	0.36	0.44	0.80	0.82	4.43	17.37
CR03	1.45	3.23	45%	28.70	4.45	65.30	0.02	0.04	0.00	0.04	0.26	0.22	0.48	0.52	4.33	6.98
Eel River																
ER01	1.00	1.15	88%	27.90	3.76	56.70	0.00	0.01	0.01	0.03	0.34	0.42	0.76	0.79	15.50	9.88
ER02	1.04	1.34	77%	28.94	4.57	65.30	0.01	0.01	0.00	0.01	0.27	0.39	0.66	0.67	3.64	15.74
ER03	1.25	1.43	89%	29.51	4.61	70.90	0.02	0.02	0.00	0.02	0.20	0.16	0.36	0.39	3.43	10.43
Waquoit Bay																
WB01	1.40	2.65	52%	27.72	3.40	50.20	0.02	0.02	0.00	0.02	0.42	0.24	0.67	0.69	2.16	8.91
WB02	1.28	1.41	89%	28.18	5.03	73.40	0.02	0.02	0.00	0.02	0.35	0.25	0.60	0.62	2.76	7.07
WB03	1.26	2.09	60%	28.91	5.92	86.70	0.01	0.03	0.00	0.03	0.28	0.22	0.49	0.52	5.04	6.83
WB04	1.33	1.46	90%	28.68	5.03	74.20	0.01	0.01	0.00	0.01	0.33	0.26	0.59	0.60	2.72	7.00
WB05	btm	0.75	0.75	0.10	ND	ND	0.02	0.01	0.01	0.01	0.37	0.11	0.48	0.50	1.96	2.76
WB06	btm	0.23	1.00	0.10	ND	ND	0.01	0.02	0.23	0.26	0.20	0.08	0.29	0.54	57.28	3.54
WB07	btm	0.51	100%	4.92	6.20	65.40	0.01	0.05	0.13	0.17	0.23	0.35	0.58	0.75	49.83	6.74
WB08	btm	0.85	100%	6.58	1.88	19.60	0.01	0.04	0.09	0.13	0.21	0.51	0.72	0.85	34.04	11.82
WB09	btm	1.15	100%	19.97	2.81	40.40	0.02	0.02	0.01	0.03	0.27	0.27	0.55	0.58	3.86	7.86
WB10	btm	0.25	1.00	28.15	ND	ND	0.02	0.03	0.01	0.04	0.34	0.27	0.62	0.66	5.84	10.49
WB11	1.48	2.13	70%	28.38	5.34	75.40	0.02	0.04	0.01	0.05	0.34	0.22	0.56	0.61	6.65	8.49
WB12	1.43	2.14	67%	28.61	2.56	35.80	0.01	0.01	0.00	0.01	0.23	0.26	0.49	0.51	2.86	13.89
WB13	1.59	2.28	70%	29.59	5.30	86.70	0.01	0.02	0.00	0.02	0.25	0.15	0.40	0.42	3.78	6.70

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 5b. Summary of water quality parameters in Popponesset Bay. Summer 2020.

2020 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	0.85	0.85	1.00	13.34	5.32	79.50	0.02	0.03	0.22	0.25	0.54	0.65	1.19	1.44	36.98	31.76
CR02	0.93	1.75	0.53	25.17	2.88	48.50	0.01	0.01	0.01	0.02	0.40	0.39	0.79	0.81	6.05	21.13
CR03	1.13	2.40	0.48	29.46	4.89	76.80	0.01	0.02	0.00	0.02	0.33	0.22	0.55	0.57	3.66	14.27
Eel River																
ER01	0.77	1.25	0.62	29.08	3.94	69.10	0.00	0.00	0.00	0.00	0.37	0.35	0.72	0.73	5.70	16.48
ER02	1.00	1.33	0.75	29.92	3.37	56.70	0.00	0.01	0.00	0.01	0.32	0.28	0.60	0.61	7.93	11.87
ER03	1.00	1.40	0.71	30.76	5.07	88.20	0.01	0.03	0.00	0.03	0.26	0.15	0.41	0.44	7.56	7.13
Waquoit Bay																
WB01	1.17	2.81	0.41	29.81	2.81	47.20	0.00	0.01	0.00	0.01	0.38	0.27	0.65	0.66	12.94	13.22
WB02	1.08	1.35	0.80	29.82	4.05	67.50	0.00	0.01	0.00	0.01	0.41	0.26	0.68	0.69	6.90	11.22
WB03	1.33	2.23	0.60	30.30	4.94	82.80	0.01	0.02	0.00	0.02	0.39	0.24	0.63	0.65	4.80	8.59
WB04	1.16	1.46	0.80	30.02	4.67	78.30	0.00	0.02	0.00	0.02	0.33	0.23	0.56	0.58	13.89	9.27
WB05	0.27	0.40	1.00	0.25	ND	ND	0.02	0.12	0.16	0.28	0.49	0.25	0.74	1.02	27.33	16.13
WB06	btm	0.20	1.00	0.10	ND	ND	0.01	0.04	0.28	0.33	0.19	0.07	0.26	0.59	95.08	5.19
WB07	0.47	0.58	1.00	3.10	2.36	38.80	0.01	0.04	0.20	0.24	0.27	0.47	0.74	0.98	85.82	36.33
WB08	0.73	0.94	0.84	8.74	4.36	58.50	0.00	0.01	0.07	0.07	0.29	1.09	1.37	1.45	34.97	52.31
WB09	0.98	1.14	0.91	21.41	3.81	54.00	0.00	0.02	0.01	0.04	0.28	0.27	0.55	0.58	17.93	14.05
WB10	btm	0.23	1.00	29.08	ND	ND	0.01	0.02	0.02	0.04	0.45	0.28	0.74	0.77	7.46	15.27
WB11	1.35	1.55	0.87	29.51	4.50	66.00	0.01	0.03	0.01	0.05	0.36	0.22	0.58	0.63	7.42	9.54
WB12	1.52	2.18	0.70	29.42	4.26	58.00	0.01	0.01	0.00	0.02	0.30	0.21	0.52	0.53	4.93	7.85
WB13	1.34	1.56	0.91	30.86	4.87	81.30	0.01	0.01	0.00	0.01	0.26	0.16	0.42	0.44	2.49	6.04

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 6a. Trophic Health Index Scores and status for marine water quality monitoring stations in Waquoit Bay, 2019 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	2019 EUTRO Index	2019 Health Status	Long-Term EUTRO Index	Long-Term Health Status
CR01	0.84	19%	0.114	1.653	48.4	20.7	0.0	9.1	0.0	0.0	6.0	Fair/Poor	1.1	Fair/Poor
CR02	1.04	38%	0.028	0.796	17.4	34.0	0.0	70.1	0.0	0.0	20.8	Fair/Poor	15.8	Fair/Poor
CR03	1.45	68%	0.041	0.481	7.0	54.8	65.8	53.3	29.0	29.9	46.6	Moderate	46.0	Moderate
ER01	1.0	38%	0.027	0.761	9.9	31.7	0.0	70.9	0.0	1.0	20.7	Fair/Poor	21.9	Fair/Poor
ER02	1.0	65%	0.010	0.663	15.7	34.0	60.2	100.0	0.0	0.0	38.9	Moderate/Fair	35.9	Moderate
ER03	1.3	80%	0.023	0.363	10.4	Btm	84.7	77.7	66.1	0.0	57.1	Moderate	63.8	High
WB01	1.4	63%	0.020	0.667	8.9	52.8	55.3	85.1	0.0	9.6	40.5	Moderate	31.9	Moderate
WB02	1.3	64%	0.022	0.597	7.1	Btm	57.7	80.3	0.7	28.8	41.9	Moderate	39.1	Moderate
WB03	1.3	73%	0.029	0.493	6.8	46.3	74.6	68.9	25.8	31.6	49.4	Moderate	49.4	Moderate
WB04	1.3	60%	0.014	0.589	7.0	Btm	49.6	98.6	2.5	29.6	45.1	Moderate	44.5	Moderate
WB07	btm	17%	0.173	0.577	6.7	Btm	0.0	0.0	5.1	32.7	9.4	Fair/Poor	0.0	Fair/Poor
WB08	btm	28%	0.128	0.720	11.8	Btm	0.0	3.8	0.0	0.0	1.0	Fair/Poor	6.7	Fair/Poor
WB09	btm	70%	0.032	0.545	7.9	Btm	69.0	64.2	12.5	20.0	41.4	Moderate	16.3	Fair/Poor
WB10	btm	ND	0.041	0.619	10.5	Btm	ND	53.5	0.0	0.0	17.8	Fair/Poor	19.1	Fair/Poor
WB11	1.5	65%	0.053	0.558	8.5	55.9	60.1	42.5	9.4	13.6	36.3	Moderate/Fair	38.5	Moderate
WB12	1.4	42%	0.013	0.495	13.9	53.7	6.0	100.0	25.3	0.0	37.0	Moderate/Fair	50.3	Moderate
WB13	1.6	68%	0.022	0.399	6.7	60.4	65.8	81.1	53.6	33.3	58.8	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, 2020 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	2020 EUTRO Index	2020 Health Status	Long-Term EUTRO Index	Long-Term Health Status
CR01	btm	19%	0.251	1.188	31.761	100.0	0.0	0.0	0.0	0.0	20.0	Fair/Poor	1.1	Fair/Poor
CR02	0.93	38%	0.015	0.790	21.135	27.5	0.0	96.1	0.0	0.0	24.7	Fair/Poor	15.8	Fair/Poor
CR03	1.13	68%	0.017	0.552	14.268	39.5	65.8	91.5	10.9	0.0	41.5	Moderate	46.0	Moderate
ER01	0.8	38%	0.005	0.725	16.482	15.2	0.0	100.0	0.0	0.0	23.0	Fair/Poor	21.9	Fair/Poor
ER02	1.0	65%	0.010	0.599	11.870	31.7	60.2	100.0	0.3	0.0	38.5	Moderate/Fair	35.9	Moderate
ER03	1.0	80%	0.028	0.407	7.128	Btm	84.7	70.1	50.8	28.1	58.4	Moderate	63.8	High
WB01	1.2	63%	0.009	0.649	13.224	41.4	55.3	100.0	0.0	0.0	39.3	Moderate	31.9	Moderate
WB02	1.1	64%	0.014	0.679	11.223	Btm	57.7	100.0	0.0	0.0	39.4	Moderate	39.1	Moderate
WB03	1.3	73%	0.022	0.630	8.590	49.4	74.6	81.2	0.0	12.6	43.5	Moderate	49.4	Moderate
WB04	1.2	60%	0.018	0.560	9.269	Btm	49.6	89.3	9.0	6.3	38.6	Moderate/Fair	44.5	Moderate
WB07	0.5	17%	0.241	0.739	36.325	Btm	0.0	0.0	0.0	0.0	0.0	Fair/Poor	0.0	Fair/Poor
WB08	0.7	28%	0.073	1.375	52.312	Btm	0.0	28.4	0.0	0.0	7.1	Fair/Poor	6.7	Fair/Poor
WB09	1.0	70%	0.036	0.547	14.048	Btm	69.0	59.2	12.1	0.0	35.1	Moderate/Fair	16.3	Fair/Poor
WB10	btm	ND	0.039	0.735	15.268	Btm	ND	55.8	0.0	0.0	18.6	Fair/Poor	19.1	Fair/Poor
WB11	1.3	65%	0.046	0.581	9.536	50.2	60.1	48.2	4.1	3.9	33.3	Moderate/Fair	38.5	Moderate
WB12	1.5	42%	0.016	0.516	7.851	57.8	6.0	93.1	19.9	20.1	39.4	Moderate/Fair	50.3	Moderate
WB13	1.3	68%	0.011	0.424	6.036	49.8	65.8	100.0	45.5	41.9	60.6	Moderate	72.2	High

High Quality = >69; High/Moderate = 61-69; Moderate = 39-61; Moderate/Fair = 31-39; Fair/Poor = <31

Table 7a. Trophic Health Index Scores and status for marine water quality monitoring stations in Popponesset Bay, 2019 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	2019 EUTRO Index	2019 Health Status	Long-Term EUTRO Index	Long-Term Health Status
PB01	btm	ND	0.450	0.203	1.82	100.0	ND	0.0	100.00	100.00	75.0	Moderate	36.4	Mod/Fair
PB02	btm	43.1%	0.168	1.281	36.79	100.0	9.2	0.0	0.00	0.00	21.8	Fair/Poor	2.2	Fair/Poor
PB03	0.79	31.8%	0.053	0.825	18.09	16.9	0.0	42.3	0.00	0.00	11.8	Fair/Poor	4.0	Fair/Poor
PB04	0.99	34.3%	0.031	0.773	19.42	31.3	0.0	65.5	0.00	0.00	19.4	Fair/Poor	24.3	Fair/Poor
PB05	0.86	33.6%	0.013	0.810	23.01	22.4	0.0	100.0	0.00	0.00	24.5	Fair/Poor	18.2	Fair/Poor
PB06	0.90	88.8%	0.022	0.758	12.75	25.0	98.3	80.6	0.00	0.00	40.8	Moderate	21.4	Fair/Poor
PB07	0.66	49.3%	0.020	0.600	12.62	5.4	25.8	83.9	0.00	0.00	23.0	Fair/Poor	31.3	Mod/Fair
PB08	0.84	42.0%	0.024	0.564	14.41	20.6	6.0	77.2	8.10	0.00	22.4	Fair/Poor	46.4	Moderate
PB09	1.01	58.0%	0.010	0.618	11.77	32.5	45.8	100.0	0.00	0.00	35.7	Fair/Moderate	22.8	Fair/Poor
PB10	0.93	34.0%	0.010	0.560	11.63	27.1	0.0	100.0	9.13	0.00	27.2	Fair/Poor	30.6	Fair/Poor
PB11	1.15	77.7%	0.034	0.754	13.61	40.4	81.9	61.3	0.0	0.0	36.7	Fair/Moderate	43.1	Moderate
PB12	1.68	81.0%	0.028	0.544	5.42	63.8	ND	70.3	12.8	50.9	49.4	Moderate	46.6	Moderate
PB13	1.89	69.1%	0.028	0.413	6.15	71.2	67.4	70.4	49.1	40.3	59.7	Moderate	54.2	Moderate
PB14	btm	87.2%	0.014	0.319	3.21	100.0	96.1	100.0	82.9	94.3	94.7	High	75.2	High
PB15	btm	ND	0.423	0.789	19.45	100.0	100.0	0.0	0.0	0.0	40.0	Moderate	20.7	Fair/Poor

High Quality = >69; High/Moderate = 61-69; Moderate = 39-61; Moderate/Fair = 31-39; Fair/Poor = <31

Table 7b. Trophic Health Index Scores and status for marine water quality monitoring stations in Popponesset Bay, 2020 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	2020 EUTRO Index	2020 Health Status	Long-Term EUTRO Index	Long-Term Health Status
PB01	btm	ND	0.545	0.303	2.5	na	na	0.0	89.49	100.00	63.2	Moderate	36.4	Mod/Fair
PB02	btm	43.9%	0.366	0.930	29.2	na	11.5	0.0	0.00	0.00	2.9	Fair/Poor	2.2	Fair/Poor
PB03	btm	52.2%	0.117	0.838	33.9	na	32.8	7.6	0.00	0.00	10.1	Fair/Poor	4.0	Fair/Poor
PB04	btm	61.6%	0.086	0.807	13.4	na	53.2	21.1	0.00	0.00	18.6	Fair/Poor	24.3	Fair/Poor
PB05	0.98	87.8%	0.013	0.857	18.4	30.4	96.9	100.0	0.00	0.00	45.5	Moderate	18.2	Fair/Poor
PB06	1.01	88.1%	0.011	0.793	17.2	32.6	97.4	100.0	0.00	0.00	46.0	Moderate	21.4	Fair/Poor
PB07	0.90	84.7%	0.022	0.705	17.1	24.8	92.5	80.5	0.00	0.00	39.6	Fair/Moderate	31.3	Mod/Fair
PB08	1.18	52.2%	0.016	0.516	11.1	41.8	32.8	94.2	19.91	0.00	37.7	Fair/Moderate	46.4	Moderate
PB09	0.97	53.0%	0.006	0.610	12.4	29.6	34.7	100.0	0.00	0.00	32.9	Fair/Moderate	22.8	Fair/Poor
PB10	1.11	54.1%	0.007	0.534	8.7	38.4	37.2	100.0	15.30	11.16	40.4	Fair/Moderate	30.6	Fair/Poor
PB11	btm	79.7%	0.017	0.477	7.2	na	85.0	91.3	30.2	27.0	58.4	Moderate	43.1	Moderate
PB12	1.29	79.1%	0.018	0.505	6.9	47.7	ND	88.9	22.6	30.9	47.5	Moderate	46.6	Moderate
PB13	1.76	89.2%	0.033	0.455	6.7	67.0	98.9	63.3	36.2	33.4	59.8	Moderate	54.2	Moderate
PB14	1.79	89.4%	0.010	0.302	3.5	67.8	99.2	100.0	90.1	86.4	88.7	High	75.2	High
PB15	btm	52.9%	0.029	0.498	7.6	na	34.5	67.8	24.4	22.4	37.3	Fair/Moderate	20.7	Fair/Poor

High Quality = >69; High/Moderate = 61-69; Moderate = 39-61; Moderate/Fair = 31-39; Fair/Poor = <31

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%	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.					

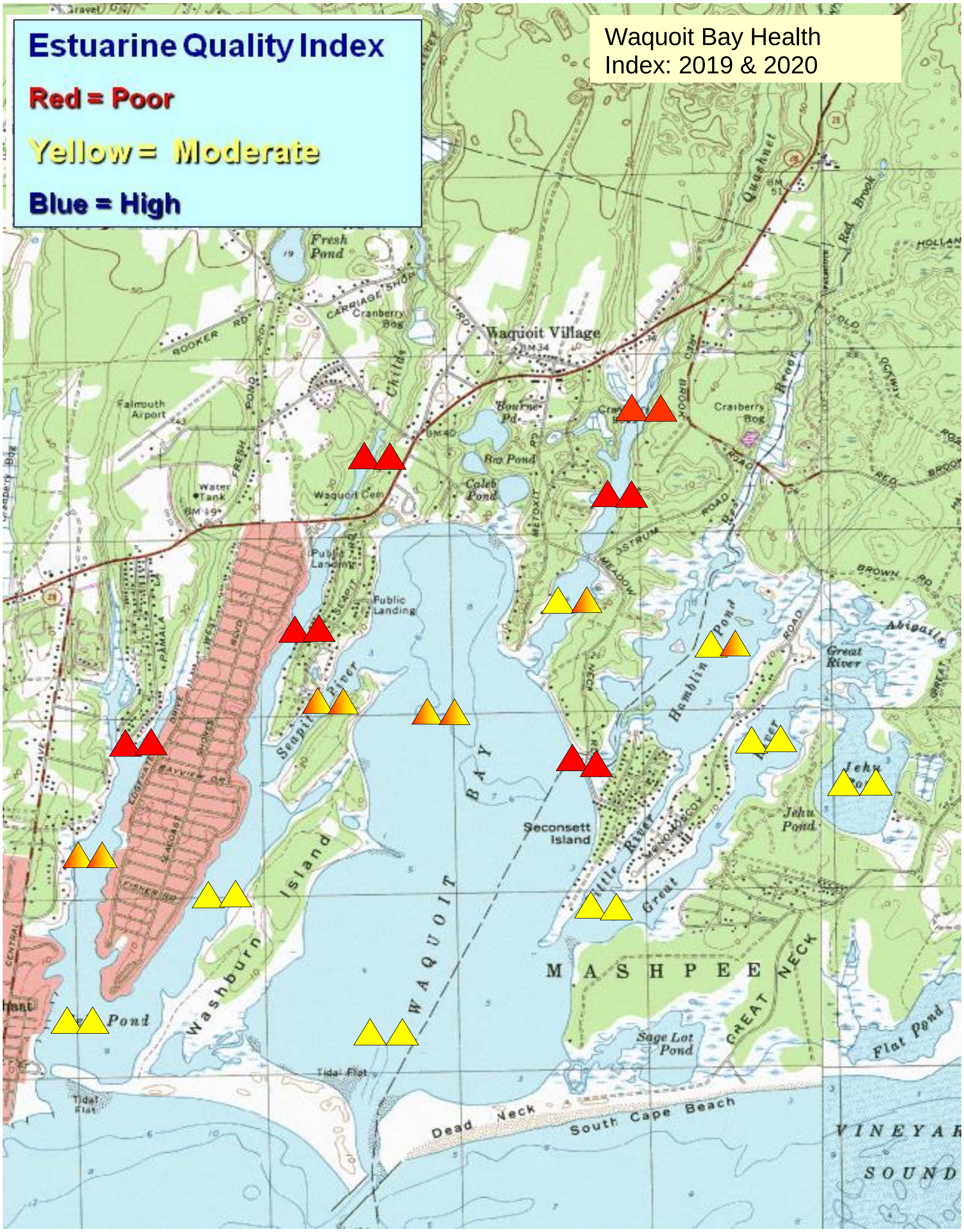

Figure 14a. 2019 (left symbol) and 2020 (right symbol) nutrient related water quality of the Waquoit Bay System, based upon monitoring data (Table 6) from stations in Figure 5. The Health Index was developed for Buzzards Bay open water embayments. Note the gradient in nitrogen related water quality with lowest quality within the inland tidal reaches and highest nearest the tidal inlets. No high quality sites remain in Bay.

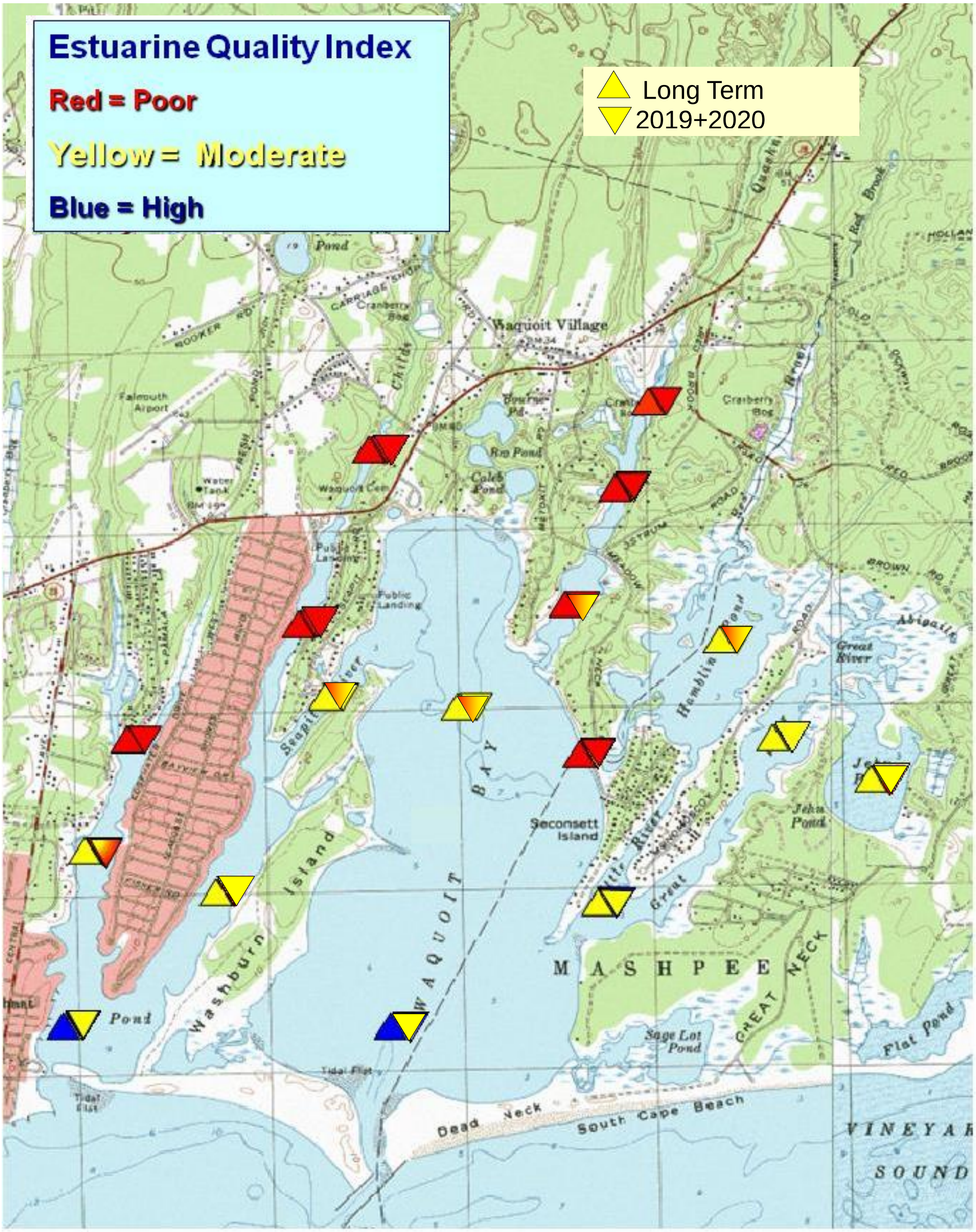

Figure 14b. Nutrient related water quality of the Waquoit Bay system, based upon monitoring data (Tables 6) from stations in Figure 4. The Health Index was developed for Buzzards Bay open water embayments. Note the gradient in nitrogen related water quality with lowest quality within the inland tidal reaches and highest nearest the tidal inlets. Conditions are tending to show declining water quality. The Index colors are red=poor, yellow=moderate decline, blue high quality. Triangles are average long-term index conditions and upside-down triangles are average 2019 & 2020 conditions.

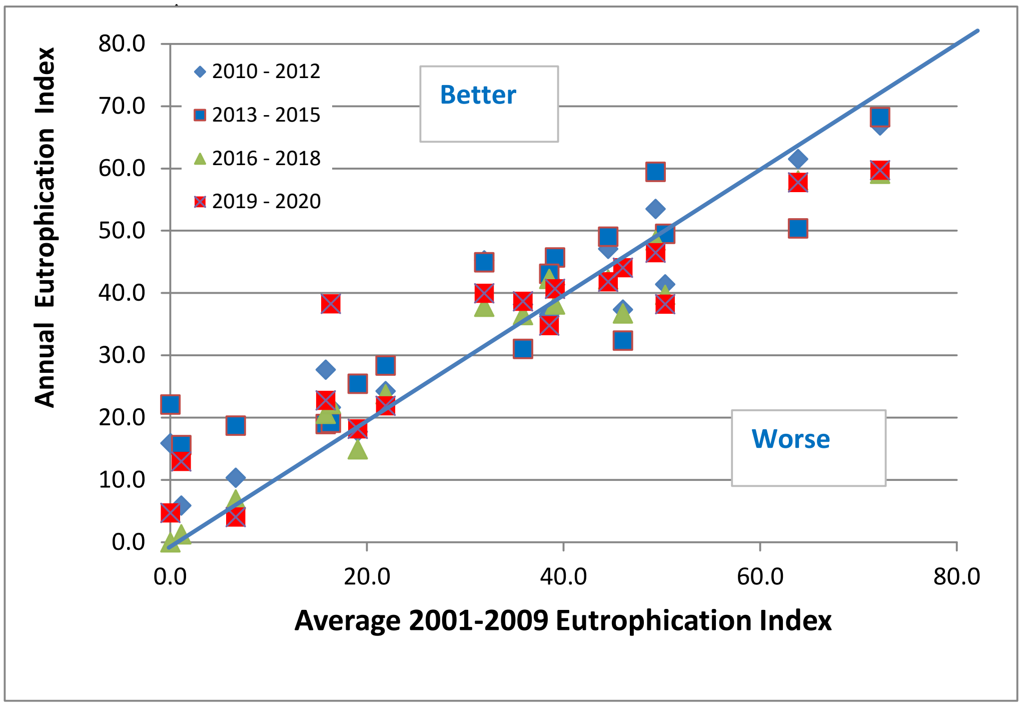

Figure 15. Eutrophication Index for each Waquoit Bay site averaged 2010-12, 2013-15, 2016-17 and 2019-2020 (Y axis) compared to the longer term average (2001-2009) for the same sites (X axis). Freshwater sites are not included. The 1:1 line represents "No Change", points above the line indicate improved conditions and points below the line indicate increased impairment. Severely degraded sites appear to be improving slightly, but moderate and high quality sites have declined

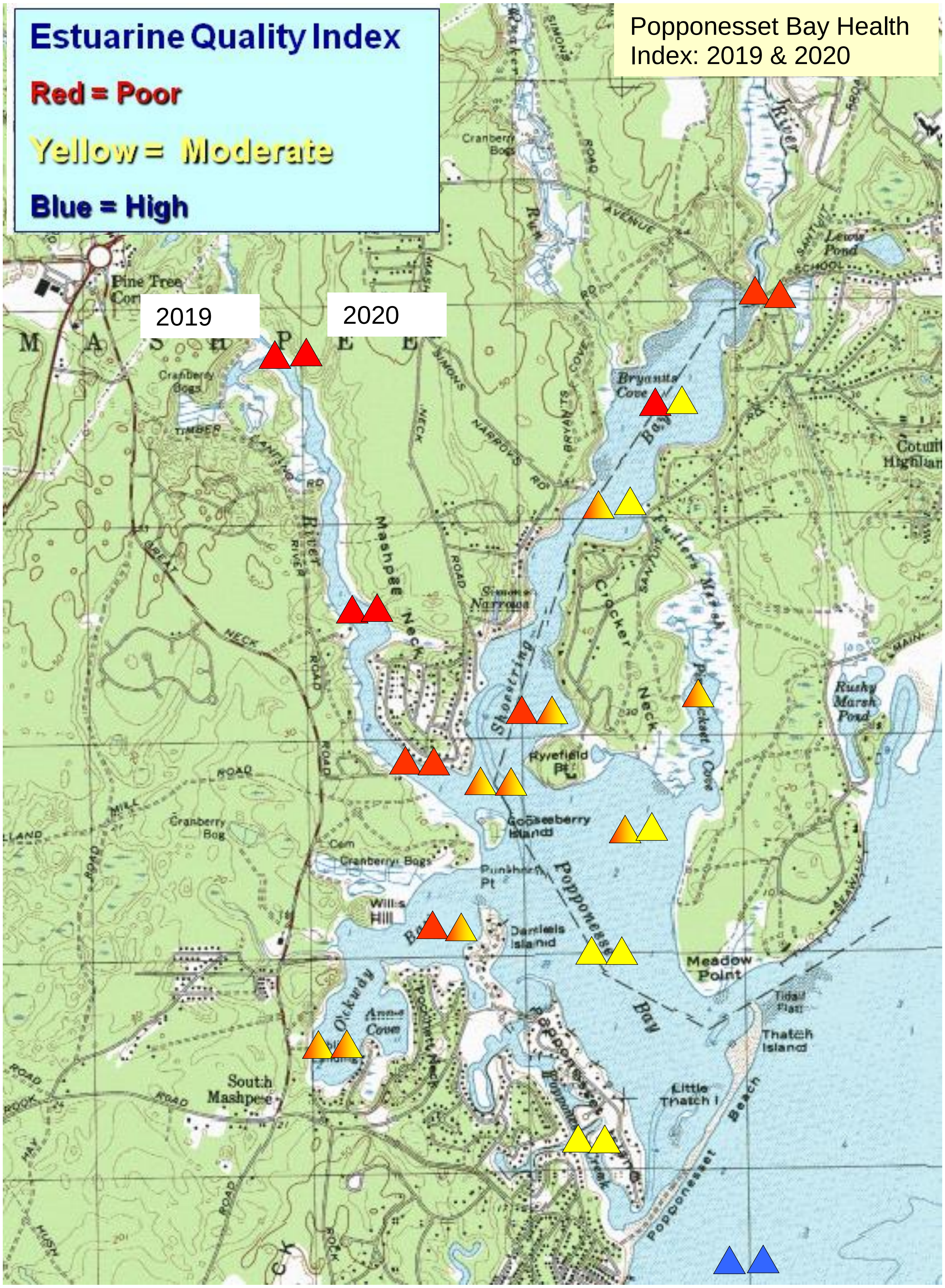

Figure 16. 2019 (left symbol) and 2020 (right symbol) nutrient related water quality of the Popponesset Bay system, based upon monitoring data (Table 7) from stations in Figure 5. The Health Index was developed for Buzzards Bay open water embayments. Note the gradient in nitrogen related water quality with lowest quality within the inland tidal reaches and highest nearest the tidal inlets.

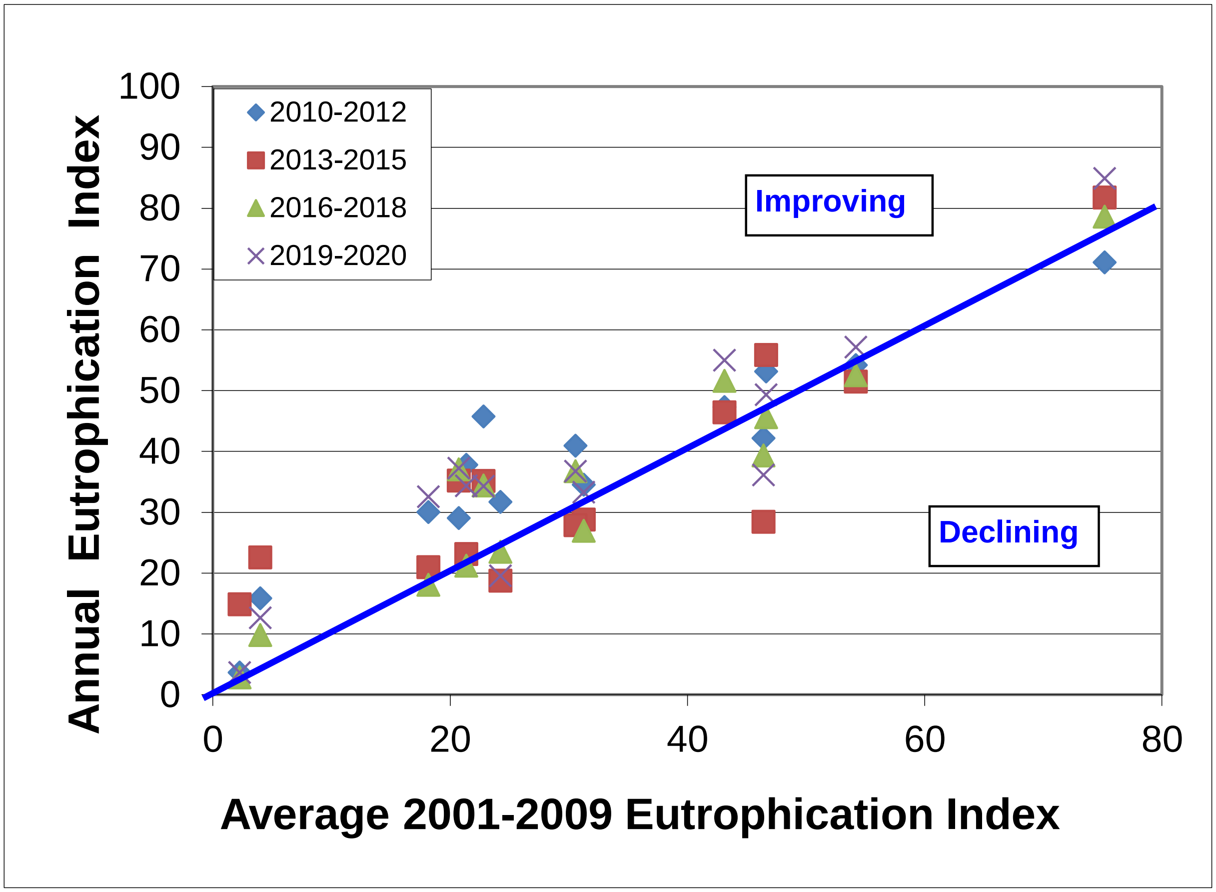

Figure 17. Eutrophication Index for each Popponesset Bay site averaged 2010-12, 2013-15 and 2016-17 and 2019-2020 (Y axis) compared to the longer term average (2001-2009) for the same sites (X axis). Freshwater sites are not included. The 1:1 line represents “No Change”, points above the line indicate improved conditions and points below the line indicate increased impairment. Scores less than 31 indicate a high level of impairment. The highest water quality area (>70) is the offshore reference station.