University of Massachusetts Dartmouth
The School for Marine Science and Technology

Technical Memorandum
Updated Benthic Infauna Survey - Long Pond

To: Jeff Carlson, Town of Nantucket, Natural Resources Coordinator
Kaitlyn Shaw, Town of Nantucket, Water Resources Specialist

From: Brian Howes, Ph.D., CSP-SMAST, UMass-Dartmouth
Sara Sampieri, M.S., CSP-SMAST, UMass-Dartmouth
Roland Samimy, Ph.D., CSP-SMAST, UMass-Dartmouth

Re: Monitoring of Long Pond (inclusive of North Head) within the Town of Nantucket, Scope of Services for Assessment of Infaunal Health

Date:

Field Work Completed:	November 8, 2017
Raw Data Received from Ocean Taxonomics:	February 20, 2018
Technical Memorandum submitted:	April 18, 2018

The Massachusetts Estuaries Project (MEP) and follow-on TMDLs by MassDEP and USEPA focus on temporal changes in eelgrass coverage and benthic infaunal communities (animals that live in sediments of estuaries) as key indicators of environmental health and resource quality. Long Pond was determined by the MEP to have historically not been supportive of eelgrass habitat. The result was a focus on benthic animal habitat quality as the key health indicator, which clearly indicated that Long Pond was impaired by excess nitrogen. Surveys found benthic animal communities to be comprised of stress indicator species, with some areas with low productivity (low numbers of individuals) and low diversity consistent with its high levels of water column total nitrogen (TN). Restoration of this estuarine sub-basin requires a lowering of TN with resulting increased dissolved oxygen to improve benthic habitat quality, as evidenced by density of organisms, number of species and community diversity (Final MEP Threshold Report on Madaket Harbor - Long Pond Estuarine System November 2010).

In recent years, the Nantucket Estuarine Monitoring Program has observed an apparent decrease in nitrogen levels within Long Pond waters. Current TN levels (2013-2017) are approaching the regulatory TMDL for this basin, which targets benthic animal habitat quality as the major indicator of estuarine health. The lowering of TN levels was coincident with the Town of

Nantucket's activities at the landfill within the Long Pond watershed. This Technical Memorandum is focused on re-assessing benthic community habitat health for comparison to the water quality metrics (including TN) in order to determine the extent to which this key biological indicator may have improved within the context of the regulatory requirements under the Clean Water Act.

The recent benthic infaunal survey (November 2017) was undertaken in a manner consistent with the MEP QAPP. The methods used for the 2017 benthic survey of Long Pond are the same as for the previous SMAST MEP effort on the Madaket Harbor-Hither Creek-Long Pond system. In this manner, data collected in 2017 is directly cross comparable to infaunal data collected in 2003 under the MEP.

The infaunal survey is being considered to:

1) track restoration status and trajectory in Long Pond relative to the established MassDEP/USEPA TMDL[1] for that estuarine system,

2) document the link between Long Pond water quality and benthic infaunal habitat.

The context for the comparison between benthic communities in Long Pond as they existed in 2003 and 2017 is the water quality database that was developed in advance of the MEP nutrient threshold analysis (2003) and the results of the on-going Island-wide multi-year water quality monitoring effort which includes Long Pond (2010-2017). The 2017 benthic survey was undertaken to assess progress towards the regulatory TMDL targets and serves as compliance monitoring. The 2017 benthic survey was undertaken due to apparent declines in TN levels in Long Pond associated with management activities in the Long Pond watershed (landfill) to assess positive effects on benthic animal habitat in Long Pond.

The main objective of the 2017 infaunal monitoring effort was to track long-term changes in nitrogen related habitat health in this nitrogen impaired system. The 2017 infaunal monitoring program built upon and followed the specific protocols as used for the 2003 survey, as part of Massachusetts Estuaries Project which formed the basis of the MEP nitrogen threshold for the Madaket Harbor - Long Pond estuarine system.

The 2017 infaunal assessment was completed under the direction and management of Dr. Brian Howes, Director of the CSP and Technical Director of the MEP and Dr. Roland Samimy, Senior Research Manager of the CSP at SMAST-UMD. Ms. Jen Benson, M.S. and Sara Sampieri, M.S., the Coastal Systems Analytical Facility Managers (all members of the MEP Technical Team) were responsible for all field and analytical support. SMAST scientific staff worked directly with Ms. Kaitlyn Shaw, Town of Nantucket Water Resources Specialist within the Nantucket Natural Resources Department to organize and conduct the required field infaunal sample collection sample preparation.

[1] 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.

Coastal Systems Program scientific staff re-sampled sediments in Long Pond in November 2017 at five (5) previously established infaunal monitoring stations sampled under the MEP in 2003. Each station was sampled in duplicate for a total of 10 grab samples (Young modified Van Veen Grab). Four of the five stations were located in the main basin of Long Pond (LPN-4,5,7,8) and one station in the North Head of Long Pond (LPN-2). Station locations are shown in Figure 1 below. All 2017 surveying was completed using the same methods and protocols used for the previous MEP infaunal community sampling and characterization (under the SMAST's MEP QAPP) in December 2003 as part of the analysis of the Madaket Harbor - Long Pond Estuarine System. Both surveys were collected in fall to account for seasonal shifts in benthic communities, with duplicate samples collected from each location for QA/QC purposes.

Figure 1. Aerial photograph of the Long Pond system showing location of benthic infaunal sampling stations sampled by the MEP in 2003 and 2017 (yellow symbols).

Benthic animal indicators can be used to assess the level of habitat health from healthy (low organic matter loading, high D.O.) to highly stressed (high organic matter loading-low D.O.). The basic concept is that certain species or species assemblages reflect the quality of the habitat in which they live. Benthic animal species from sediment samples are identified and ranked as to their association with nutrient related stresses, such as organic matter loading, hypoxia/anoxia, and dissolved sulfide. The analysis is based upon life-history information and animal-sediment relationships (Rhoads and Germano 1986). Assemblages are classified as representative of healthy conditions, transitional, or stressed conditions. Both the distribution of species and the overall population density are taken into account, as well as the general diversity and evenness of the community. As was noted by the MEP, based on multiple years of eelgrass survey data (1951, 1995, 2001, 2006, MassDEP Eelgrass Mapping Program), documenting the absence of

eelgrass in Long Pond and the loss of established eelgrass beds in Hither Creek, that the Long Pond System was impaired by nitrogen enrichment at the time of the MEP analysis. The 2003 benthic infauna analysis within Long Pond further indicated nitrogen related impairment of benthic animal habitat. Therefore benthic habitat quality was the primary biological metric for determining the level of impairment (moderately impaired→significantly impaired→severely degraded) given the lack of seagrass for more than a half century.

Analysis of the evenness and diversity of the benthic animal communities and the natural history information was used to analyze the population density results relative to habitat quality. The evenness statistic can range from 0-1 (one being most even), while the diversity index does not have a theoretical upper limit. The highest quality habitat areas have the highest diversity (generally >3) and evenness (~0.7). The converse is also true, with poorest habitat quality found where diversity is <1 and evenness is <0.5.

Comparison of Benthic Animal Communities in Long Pond: 2003 to 2017

Long Pond and North Head of Long Pond are brackish water basins with significant wetland influence. As such, these basins are naturally nutrient and organic matter enriched, and assessment of infaunal habitat needs to consider their functional types. Overall, Long Pond and North Head of Long Pond supported productive benthic animal communities in 2003 as seen in the high density of organisms (total number per grab). However, the number of species represented was relatively low, with associated low diversity and Evenness (Table 1). Equally important, at some stations the community included stress indicator species (Tubificids, Capitellids), comprising 20% of the community within the main basin. However, at most stations, the species are common to wetland channels throughout southeastern Massachusetts and are dominated by a very common nutrient enrichment tolerant species, *Streblospio benedicti*, which is also common to pristine salt marsh creeks. However, the low numbers of total species and overall diversity indicate an impaired habitat consistent with the observed hypoxic conditions and elevated chlorophyll levels. The North Head of Long Pond is similar to Long Pond with lower numbers of individuals, and a community is dominated by amphipods rather than oligochaeta worms, indicative of a productive organic rich habitat and consistent with the observed oxygen levels in this basin.

It appears that benthic habitat has improved in Long Pond from 2003 to 2017, likely the result of the lower TN conditions[2]. Similarly the North Head of Long Pond has shifted from an amphipod dominated community to one dominated by mollusks and polychaetes, with no stress indicator organisms, but with lower productivity (possibly due to an on-going community shift).

The main basin of Long Pond supports higher number of species 9 vs. 5 in 2017 vs. 2003, with lower density and higher diversity 1.8 vs. 1.2 and similar Evenness. Like the Head of Long Pond basin the major community shift is to species indicative of non-stress conditions with a near complete absence of Tubificids and Capitellids. However, consistent with its wetland and brackish nature, the community shows high numbers of individuals, but moderate to low

[2] No significant difference in salinity pre-MEP (average 12.3 ppt) and 2013-2017 (average 13.9 ppt) at long-term water quality stations LOPO 4 and LOPO 5.

numbers of species, with moderate diversity and Evenness (Table 1). *Streblospio benedicti*, and oligochaeta worms remain the dominate species, as in healthy wetland channels (Table 2).

Table 1. 2003 and 2017 Benthic infaunal community survey data for the Long Pond Sub-Embayment. Estimates of the number of species adjusted to the number of individuals and diversity (H') and Evenness (E) of the community allow comparison between locations (Samples represent surface area of 0.0625 m^2). Stations refer to map in Figure 1, S.E. is the standard error of the mean, N is the number of samples per site.

Basin	Total Actual Species	Total Actual Individuals	Weiner Diversity (H')	Evenness (E)	Stations LPN
Long Pond Sub-Estuary - Main Basin - 2003 MEP					
Mean =	5	947	1.19	0.60	LPN: 4,5,7,8
S.E. =	1	412	0.33	0.07	
N =	8				
Long Pond Sub-Estuary - Main Basin - 2017					
Mean =	9	332	1.78	0.58	LPN: 4,5,7,8
S.E. =	1	132	0.25	0.06	
N =	8				
Long Pond Sub-Estuary - Head of Long Pond - 2003 MEP					
Mean =	5	181	1.59	0.68	LPN: 2
S.E. =	0	93	0.28	0.12	
N =	2				
Long Pond Sub-Estuary - Head of Long Pond - 2017					
Mean =	6	29	1.73	0.71	LPN: 2
S.E. =	2	4	0.49	0.08	
N =	2				
Note - all values are the average of replicate samples					

Within the main basin of Long Pond the communities observed in 2017 were indicative of a higher quality habitat than observed in 2003, given the lack of dominance of stress indicator species and the almost double average number of species per site. The observed community shift is consistent with a reduction in organic matter loading and possibly improved oxygen conditions, which also lead to lower numbers of individuals. In both 2003 and 2017 there were slightly more species (representing $\geq$1% of population) throughout the main basin, 10 vs. 12 (Table 2). Both years the average population density was moderate although lower in 2017 (947 vs. 332 per grab), although with higher species diversity, H'. The greatest improvement was seen in station LPN8 which went from 0 species and a diversity 0.0 in 2003 to 13 species and a diversity of 2.57 in 2017. The smallest improvement was in the semi-isolated Head of Long Pond, which has improved its overall community, but is currently supporting low numbers of individuals per grab.

Table 2. Most prevalent species found in 2003 and 2017 benthic infaunal community surveys for the Main Basin of Long Pond. Only species representing ≥1% of the total population in the main basin are shown. Grab samples (surface area of 0.0625 m^2) were collected from stations 4,5,7,8 in Figure 1.

Main Basin Long Pond 2017			
Taxon	**Species**	**% Community**	**Common Name**
Polychaeta	Oligochaeta spp.	36%	Small Worms
Polychaeta	*Streblospio benedicti*	26%	Tube dwelling worm
Insecta	chirinomidae	14%	Non-biting midge
Polychaeta	Ampharete arctica	7%	Amphipod
Crustacea	*Leptocheirus plumulosus*	3%	Amphipod
Crustacea	*Tanais cavolini*	3%	Benthic peracarid
Polychaeta	*Eteone longa*	3%	Paddleworm
Polychaeta	*Capitella capitata*	2%	Stress Indicator
Polychaeta	*Leitoscoloplos fragilis*	2%	Polychaete worm
Mollusca	*Tellina agillus*	1%	Bivalve
Anthrozoa	anthozoa spp.	1%	Anenomae
Crustacea	*Edotea triloba*	1%	Isopod
	Total Species	**12**	
Main Basin Long Pond 2003			
Polychaeta	Streblospio benedicti	29%	Tube dwelling worm
Insecta	chirinomidae	19%	Non-biting midge
Polychaeta	Paranais littoralis	17%	Brackish worm
Polychaeta	Tubificoides sp. 1	17%	Stress Indicator
Crustacea	tanaidacea sp. 1	6%	Tanaids
Crustacea	Gammarus fasciatus	4%	Amphipod
Polychaeta	Capitella capitata	3%	Stress Indicator
Nemertea	nemertea spp.	2%	Ribbon Worm
Crustacea	Leptocheirus plumulos	1%	Amphipod
Ecniodermata	holothuroidea spp.	1%	Sea Cucumber
	Total Species	**10**	

Overall, given the structure and brackish water environment of the main basin of Long Pond the benthic habitat has clearly improved from 2003 to 2017. This is based on the loss of most stress indicator species, increase in major species (from 10 to 12), increase in average number of species from 5 to 9, the increase in diversity from 1.19 to 1.78 and the re-colonization of the benthic habitat at station 8 from no species/organisms in 2013 to 13 species in 2017. For a wetland dominated brackish system the benthic animal habitat seems to be transitioning to a high quality, although diversity remains a bit low.

In contrast, the Head of Long Pond basin, while shifting to being colonized with species more indicative of higher quality habitat, the population is very low as seen in the low number of species and individuals in both years. However, it is the low number of individuals observed in 2017 which is the major metric. It is possible that this is part of a transition to more stable communities, but may also represent periodic hypoxia or low settlement. It is interesting to note that the improvement in benthic habitat was in the main basin which might be expected to be more affected by a reduction in landfill nitrogen loading compared to the semi-isolated basin of Head of Long Pond.

Comparison of Water Quality in 2003 vs. 2017

The underlying ultimate cause of the changes in the benthic infaunal community observed between surveys within Long Pond in 2003 and 2017 were investigated relative to changes in water quality conditions at the time of the MEP benthic survey (2003) versus more recent water quality conditions leading up to the November 2017 re-survey. It should be noted that the historic water quality monitoring and analysis followed the same field and laboratory procedures as the current Nantucket Island-wide Water Quality Monitoring Program (2010-2017). This allows for a direct comparison of historic data and the more recently collected water quality data. The 2003 / 2017 comparison is focused on total nitrogen values (mg/L TN) in the 3-5 years prior to the benthic surveys.

Historically, water quality monitoring in Long Pond was undertaken throughout the main basin and in the Head of Long Pond as was needed to support the MEP water quality modeling. Since completion of the MEP, water quality monitoring under the Island-wide Water Quality Monitoring Program has been focused on the two long-term Town Stations (5 and 6) which correspond to two historic stations (LOPO-2 and LOPO-4 respectively). Historic and current station locations are depicted in Figure 2.

Figure 2. Estuarine water quality monitoring station locations in the Madaket Harbor and Long Pond embayment system. Red station symbols (M-1,2,3,4,5,6,10,11 and LOPO-1,2,3,4,5,6) correspond to those used in the MEP baseline (2002-2004) water quality assessment. Blue station symbols (Stations 1,2,3,4 {Madaket Harbor} and Stations 5,6 {Long Pond}) correspond to long-term water quality monitoring stations being sampled by the Nantucket Island-wide Water Quality Monitoring Program (2010-2017).

Comparing the 2003 water quality data at LOPO-2 (aka Town Sta. 5) and LOPO-4 (aka Town Sta. 6) to the water quality in subsequent years (2012, 2013, 2014, 2015, 2016, 2017) shows that total nitrogen concentrations of nitrogen have generally decreased, particularly from 2015 onward. Although there has been inter-annual variations in the temporal decline in TN, the trend has generally been downward and periodic departures from the trend likely represent small inter-annual variations (Figure 3 and Table 4). TN concentration at LOPO-2 in 2002, 2003 (the year of the MEP benthic survey) and 2004 was 1.16 mg L^{-1}, 0.860 mg L^{-1} and 0.895 mg L^{-1} respectively, averaging 0.971 mg TN L^{-1}. In contrast, TN concentration at LOPO-2 in 2013, 2014,2015, 2016 and 2017 (most recent benthic survey) was 0.709 mg L^{-1}, 0.704 mg L^{-1}, 0.697 mg L^{-1}, 0.650 mg L^{-1} and 0.867 mg L^{-1} respectively, averaging 0.725 mg TN L^{-1}. This difference in historic TN concentrations compared to recent TN levels and the downward trend in concentrations post-MEP is mirrored at LOPO4 (Town Sta. 6). TN concentration at LOPO-4 in 2002, 2003 and 2004 was 0.939 mg L^{-1}, 0.889 mg L^{-1} and 0.821 mg L^{-1} respectively, averaging 0.883 mg TN L^{-1}, while the TN concentration at LOPO-4 (Town Sta. 6) in 2013, 2014, 2015, 2016 and 2017 (most recent benthic survey) was 0.880 mg L^{-1}, 0.718 mg L^{-1}, 0.656 mg L^{-1}, 0.630 mg L^{-1} and 0.712 mg L^{-1}, respectively, averaging 0.719 mg TN L^{-1} (Figure 3).

The multiple years (2013-2017) of reduced TN concentration is generally reflected in reduced chlorophyll-a concentrations compared to 2010-2012. It is clear that the 2003 benthic analysis was preceded by significantly higher TN and chlorophyll-a levels than in the years preceding the 2017 survey (Figure 4, Table 3). It should be noted that the TN average for LOPO2 (Town Sta. 5) in July was anomalously (impossibly) high in 2014 and did not show a corresponding increase in total pigment and has been excluded from the average. In contrast, in 2017 average TN concentrations at both LOPO2 and LOPO4 show a slight increase with a corresponding increase in total pigment (Figure 4), suggesting that Long Pond is quite sensitive to increases in total nitrogen.

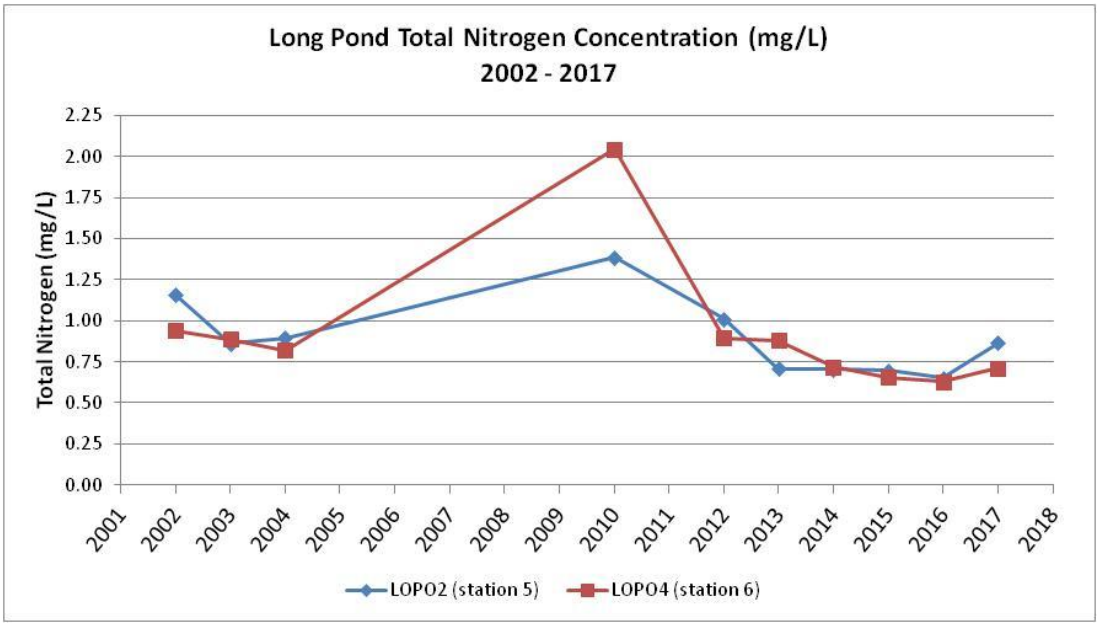

Figure 3. Annual average total nitrogen concentrations in Long Pond at stations LOPO2 (station 5) and LOPO4 (station 6).

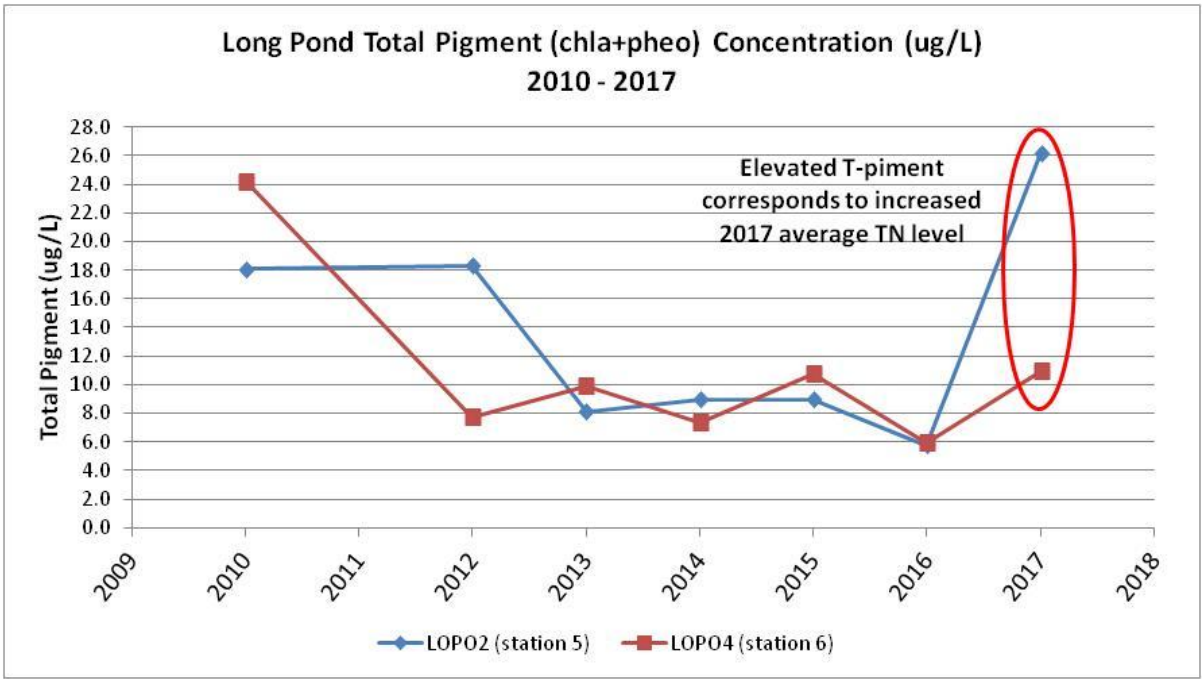

Figure 4. Average Total Pigment (Chlorophyll-a +Pheophytin) concentrations by station in the Long Pond portion of the Madaket Harbor system during the summer 2017 sampling season compared to 2010, 2012, 2013, 2014, 2015 and 2016.

Table 3. Average total pigment (chla + pheo-a) concentrations based on summer time conditions.

Year	T-Pig (ug/L)	
	Station 5 LOPO2	Station 6 LOPO4
2010	18.080	24.210
2012	18.300	7.700
2013	8.100	9.900
2014	8.988	7.342
2015	8.950	10.780
2016	5.740	5.900
2017	26.192	10.919

Table 4. Summary of Total Nitrogen (TN mg/L) concentrations (2002, 2003, 2004) in Long Pond as developed under the Massachusetts Estuaries Project as baseline for validation of the water quality model used to develop nitrogen thresholds for the Madaket Harbor - Long Pond embayment system

Sub-Embayment	Monitoring station	2002 mean	2003 mean	2004 mean	2010 mean	2012 mean	2013 mean	2014 mean	2015 mean	2016 mean	2017 mean	2002-2004 Mean	2010-2013 Mean	2014-2016 Mean
Long Pond	LOPO1	1.243	0.746	1.185	--	--	--	--	--	--	--	**1.058**	--	--
Long Pond	LOPO2	1.157	0.860	0.895	1.385	1.013	0.709	0.704	0.697	0.650	0.867	**0.971**	**1.036**	**0.942**
Long Pond	LOPO3	--	1.001	0.848	--	--	--	--	--	--	--	**0.924**	--	--
Long Pond	LOPO4	0.939	0.889	0.821	2.044	0.897	0.880	0.718	0.656	0.630	0.712	**0.894**	**1.270**	**0.668**
North Head Long Pond	LOPO5	1.029	0.929	0.781	--	--	--	--	--	--	--	**0.954**	--	--
Long Pond	Station 5 *	--	--	--	1.385	1.013	0.709	1.481	0.697	0.650	0.867	--	**1.036**	**0.942**
Long Pond	Station 6 **	--	--	--	2.044	0.897	0.880	0.718	0.656	0.630	0.712	--	**1.270**	**0.668**
NOTE:	* Station 5 corresponds to historic monitoring station LOPO2 and infaunal sampling location LPN7													
	** Station 6 corresponds to historic monitoring station LOPO4 and infaunal sampling location LPN4													

Conclusions and Recommendations

Comparison of the 2003 and 2017 benthic animal habitat surveys with the preceding 3-5 years of water quality (TN & chlorophyll a) data (all collected following the identical protocols) yielded some clear shifts in the habitat quality of the Long Pond Basin. In contrast, the semi-isolated Head of Long Pond showed less certain shifts in benthic habitat quality. Specifically,

- Nitrogen related water quality has significantly improved within the main basin of Long Pond in the 2002-2004 and 2013-2017 monitoring records. TN levels associated with the 2003 and 2017 benthic surveys declined from 0.883 mg TN L^{-1} to 0.719 mg TN L^{-1} at Town Station 6 (LOPO-4) and from 0.971 mg TN L-1 to 0.725 mg TN L-1 at Town Station 5 (LOPO-5).

- Given the structure and brackish water environment of the main basin of Long Pond the benthic habitat has clearly improved from 2003 to 2017, paralleling the water quality improvement. The assessment of improved benthic animal habitat is based on the loss of most stress indicator species, increase in major species (from 10 to 12), increase in average number of species from 5 to 9, the increase in diversity from 1.19 to 1.78 and the re-colonization of the benthic habitat at station 8 from no species/organisms in 2013 to 13 species in 2017. For a wetland dominated brackish system the benthic animal habitat seems to be transitioning to a high quality, although diversity remains a bit low.

- The Head of Long Pond basin, is still showing significantly impaired benthic habitat although it is now colonized with species more indicative of higher quality habitat. However, the population is very low as seen in the low number of species and individuals in 2017. The low number of individuals observed in 2017 is now the main metric of impairment. At present it is unclear if the present habitat is part of a transition to more stable communities or if it is in response to continuing stresses (e.g. periodic hypoxia) or low larval settlement.

- Overall, the improvement in benthic habitat seen in 2017 was in the main basin which may be due to its being more affected by a reduction in landfill nitrogen loading compared to the semi-isolated basin of Head of Long Pond.

- All of the data to date support the contention that the elevated TN levels in the Long Pond subsystem in 2003 were the ultimate cause of the impaired benthic habitat and that lowering the TN levels would result in improved benthic habitat which has been confirmed by the result of the ongoing water quality monitoring and the 2017 benthic survey.

- It appears that the benthic habitat within the main basin of Long Pond is approaching high quality habitat for this type of embayment as the TN levels approach the targets in the TMDL for this system.

Based upon these results several recommendations can be made, specifically:

- While TN appears to be the underlying cause of the habitat impairment in this sub-embayment and likely in Head of Long Pond as well, there is no on-going monitoring of the upper basin. Therefore, the cause of the current impairment of this uppermost basin cannot be determined with certainty.
    - It is recommended that ebbing water from the Head of Long Pond be included in future water quality monitoring efforts to determine the level of TN and Chlorophyll a for comparison to the 2017 and future benthic habitat survey results.
    - It is recommended that a time-series mooring be placed in Head of Long Pond in summer to determine if periodic hypoxia is the proximate cause of the present impairment in this summer or the next. This provides the key linkage between nitrogen levels and benthic animal communities and are also metrics in determining the level of habitat impairment and therefore level of progress towards TMDL compliance.
- Given the trajectory of improvement in the main basin of Long Pond and the need for water quality data from the Head of Long Pond, it appears that another benthic animal survey of this system should not be undertaken in less than 3 years. It is possible that this future survey will document either moderate impairment or healthy benthic animal habitat unless new nitrogen sources are added to the watershed or tidal flows are reduced.