Massachusetts Estuaries Project

Benthic Monitoring Report:

West Falmouth Harbor 2019

Prepared for:
Massachusetts Department of Environmental Protection

June 2020

BENTHIC MONITORING REPORT:
WEST FALMOUTH HARBOR 2019

for

MassDEP Massachusetts Estuaries Project

Benthic Monitoring

Submitted to

Massachusetts Department of Environmental Protection
Massachusetts Estuaries Project
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Table of Contents

Page

List of Figures

List of Tables

Page

1 Introduction

The Massachusetts Estuaries Project (MEP) was established in 2001 to monitor and protect estuarine ecosystems in southeastern Massachusetts embayments. The technical reports produced from these embayment assessments documented embayment specific baseline water quality, habitat health, and identified the actions required to restore nutrient impaired waters for approximately 70 embayments. MEP provided technical guidance in support of policies on nitrogen loading to embayments, wastewater management decisions, and establishment of nitrogen Total Maximum Daily Loads (TMDLs) for over 30 estuaries. Many communities, including Falmouth, have begun the process of integrated water resources management planning or completed preparation of Comprehensive Water Resources Management Plans (CWRMPs) or Watershed Management Plans (WMPs). With implementation of the TMDLs and community measures, Massachusetts Department of Environmental Protection (MassDEP) identified a need to review and update the benthic monitoring procedures that were created in 2003 as part of the MEP Quality Assurance Project Plan (QAPP; Howes and Samimy 2003, Howes and Samimy 2005).

In 2017, MassDEP began the review process of the MEP Benthic Monitoring Program. Following a thorough review of MEP documents, relevant regional and federal benthic monitoring programs, and current scientific literature a tiered approach for previously assessed embayments and a baseline approach for unassessed embayments was recommended. New draft guidance documents for the collection of post-TMDL implementation and future baseline MEP benthic monitoring data were developed for the recommended approaches. The new guidance documents include a Marine Benthic Monitoring QAPP (Rutecki and Nestler 2019), Field Standard Operating Procedure (SOP; Sweeny and Rutecki 2019a), and Laboratory SOP (Sweeny and Rutecki 2019b) that describe the study objectives, field and laboratory techniques, data quality requirements and assessments, and data management for future MEP marine benthic monitoring. The goal of these documents is to develop guidelines and procedures that can be used by parties outside of MassDEP to collect benthic data that will be of sufficient quality to assess embayment conditions and be used in management decisions.

The MEP Marine Benthic Monitoring Pilot Field Study (Pilot Field Study) is being conducted to test the approaches and procedures described in the new draft guidance documents, and to obtain current benthic infaunal data for the embayments selected for the study. The development of a pilot field study is vital to verify the approaches and new documents will produce quality benthic data for MassDEP and coastal communities that 1) assess current embayment health, 2) are comparable between assessments and embayments, and 3) aid in future management decisions. MassDEP selected West Falmouth Harbor and the Pleasant Bay System, two previously assessed embayments with established TMDLs, and Wellfleet Harbor, a previously assessed largely unimpaired embayment, for the Pilot Field Study. West Falmouth Harbor was surveyed in 2019, the Pleasant Bay System and Wellfleet Harbor will be surveyed in 2020 and 2021 respectively. MassDEP selected West Falmouth Harbor for the Pilot Field Study because the embayment: (1) was previously assessed in the MEP in the fall of 2003 (Howes et al. 2006), (2) has established TMDLs, and (3) the Town of Falmouth implemented upgrades to the existing treatment plant to reduce nutrients and completed a Comprehensive Wastewater Management Plan, Final Environmental Impact Report, and Targeted Watershed Management Plan in 2013. The Targeted Watershed Management Plan seeks to implement a cost-effective wastewater and nutrient management plan spanning a 20-year period in conjunction with meeting nitrogen TMDLs for a number of town watersheds including West Falmouth Harbor (Sweeny and Rutecki 2019).

West Falmouth Harbor is located in the Town of Falmouth on Cape Cod, Massachusetts and receives tidal flow from Buzzards Bay. The Harbor extends a half mile inland where it divides and extends approximately three-quarters of a mile north and south (Figures 1 and 2; Howes et al. 2006, Cape Cod Commission 2017). West Falmouth Harbor supports a variety of recreational uses including boating, swimming, and shellfishing. West Falmouth Harbor is designated as a SA water under 314 CMR 4.00 Massachusetts Surface Water Quality Standards (Howes et al. 2006). The health of the harbor, like many embayments in the region, has declined in recent decades due to nutrient pollution entering the system from nearby development, as evidenced by increasing algal growth and loss of eelgrass beds. Tidal waters enter the estuarine system through one inlet to Buzzards Bay and freshwater enters from the watershed primarily through surface water discharges (e.g. Mashapaquit Creek upgradient of Chase Road) and direct groundwater discharges resulting in a range of salinities within the embayment (Howes et al. 2006). West Falmouth Harbor contains several benthic and shellfish habitat types including eelgrass (*Zostera marina*), softshell clam (*Mya arenaria*), quahog (*Mercenaria mercenaria*), bay scallop (*Argopecten irradians*), and eastern oyster (*Crassostrea virginica*; MassGIS 2020).

This report provides the results of the 2019 MEP Marine Benthic Monitoring Pilot Field Study conducted in West Falmouth Harbor. The report includes a comparison with the previous West Falmouth Harbor MEP assessment presented by Howes et al. (2006).

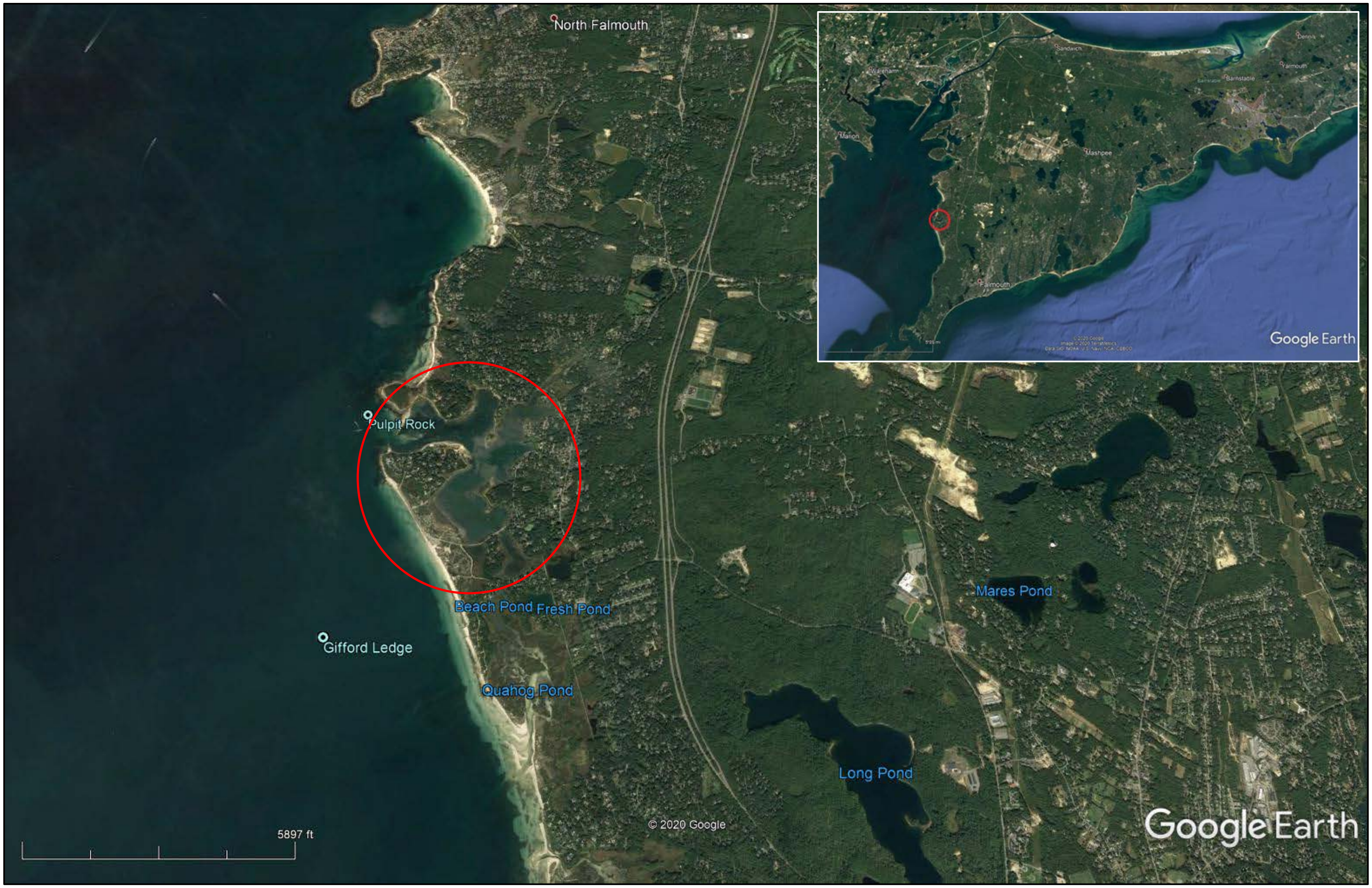

Figure 1. The location of West Falmouth Harbor, Massachusetts (indicated by red circles).

2 Methods

The Pilot Field Study conducted in West Falmouth Harbor followed the Previously Assessed Embayment Tier 2 approach and corresponding field methodologies selected during the planning phase and outlined in the Embayment-Specific Study Plan for West Falmouth Harbor (Sweeny and Rutecki 2019c). The survey was comprised of four components: water quality measurement profiles, digital images, benthic infauna, and sediment conditions (grain size and total organic carbon [TOC]). Benthic sampling stations used in the current assessment were consistent with the benthic infaunal sampling stations used in the previous 2003 assessment. The latitude and longitude coordinates of the 2003 benthic infaunal sampling stations used by Howes et al. (2006) were redefined through georeferencing techniques in ArcGIS[1] (Figure 2).

Detailed descriptions of the field and laboratory methods are contained in the draft MEP Benthic Monitoring QAPP (Rutecki and Nestler 2019), the draft MEP Marine Benthic Monitoring Field SOP (Sweeny and Rutecki 2019a), and the draft MEP Marine Benthic Monitoring Laboratory SOP (Sweeny and Rutecki 2019b). A brief overview of the methods, focused on information specific to this survey, is provided below in Section 2.1 to 2.3.

2.1 Field Methods

Sampling was conducted at 19 West Falmouth Harbor stations on August 28-29, 2019 and September 4, 2019. All stations except the 3 in Oyster Pond were assessed as planned. The Oyster Pond sub-embayment was not accessible by boat due to a culvert constructed during the extension of the Shining Sea Bikeway to North Falmouth in 2009, therefore samples were not collected in Oyster Pond. Water quality profiles, digital images, triplicate infaunal samples, and one sediment sample were collected at the 10 stations located in Snug Harbor and the South Basin (Figure 2). Bottom sediment for benthic infauna and sediment condition were collected using a 0.04-m^2 Ted Young-modified Van Veen grab sampler. At the Harbor Head, Outer- and Mid- Basins (Stations HH-1A, HH-1B, HH-1C Upper, 13A, 13B, 11A, 11B, 12A, and 12B) only water quality profiles and digital images were collected due to the presence of eelgrass (*Zostera marina;* Table 1). No grab samples were collected at these stations in accordance with Section B2.2.3 of the draft MEP Marine Benthic Monitoring QAPP (Rutecki and Nestler 2019).

A Garmin GPSMAP 78 with WAAS (Wide Area Augmentation System; accuracy +/-2 meter [m]) on a field computer running Nobeltec VNS (Visual Navigation System) was used to acquire coordinates at the location of each sample. Comparisons among sampling coordinates and target station locations confirm that all sampling was conducted within 30 m of the target locations.

Water quality measurement profiles were taken using an YSI 6820 V2 multi-parameter water quality sonde with data recorder and temperature, dissolved oxygen (DO), pH, and salinity/conductivity probes. Measurements were collected following the depths and protocol specified in the draft Marine Benthic Monitoring QAPP and draft Field SOP (Rutecki and Nestler 2019, Sweeny and Rutecki 2019a).

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[1] Latitude and longitude coordinates for the 2003 MEP benthic infaunal stations are unavailable. As a result station locations were re-identified by importing the image with MEP stations into ArcGIS. Control points for each station were selected from the image to the referenced map coordinate layer. The station locations were then digitized and the coordinates were exported.

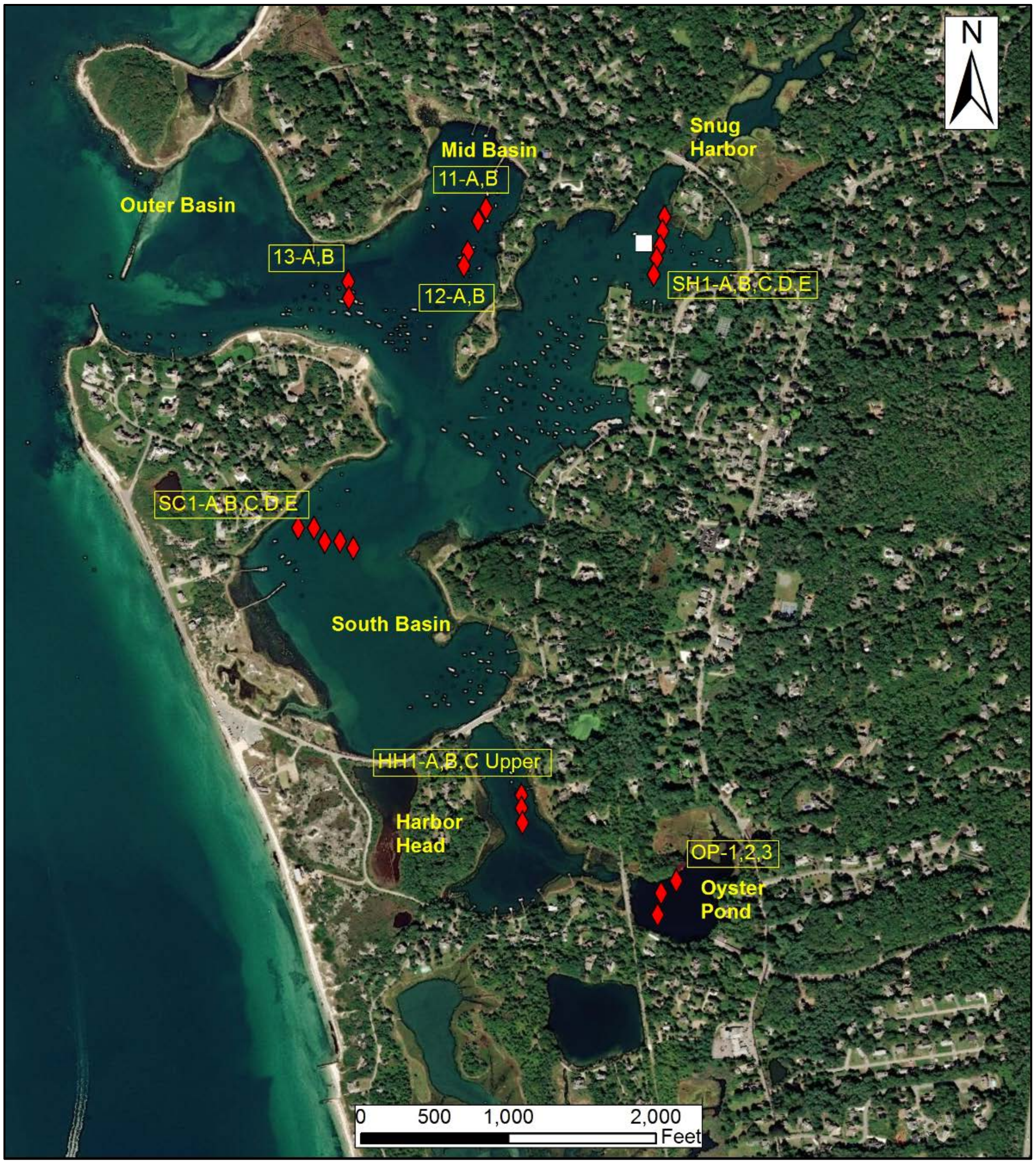


Figure 2. Map of benthic monitoring sampling locations in West Falmouth Harbor. The white square represents the sentinel station (PWF5) defined by Howes et al. (2006).

Digital video images for each sampling location were recorded using a Sony HC3 HD camera in a Light-n-Motion waterproof housing attached to a stainless steel frame (15.5 inches by 15.5 inches) with scaling lights set 4 inches at 1 meter (m) apart. A GoPro Hero 3+ was also attached to the camera frame to provide digital still images and camera redundancy. Due to elevated turbidity at many of the stations, the camera used for the underwater images was positioned closer to the bottom than the 1 m outlined in the draft Marine Benthic Monitoring QAPP and draft Field SOP. The turbidity also prevented the use of additional lights on the camera frame as they produced backscatter and prevented a clear view of the bottom. Digital images at the Harbor Head stations (Stations HH-1A, HH-1B, HH-1C Upper) were collected in a transect to provide greater coverage of the eelgrass present in the area since these stations are located in very close proximity. Digital images were collected but only reviewed to provide documentation of eelgrass and a general visual description of the bottom at the sampling locations.

Table 1. Listing of benthic stations and eelgrass presence in West Falmouth Harbor 2019 Survey (WFH-2019).

SUB-EMBAYMEN	STAT_ID	STAT_ARRIV_LOCAL	BEG_LATITUDE	BEG_LONGITUDE	NAV_QUAL	DEPTH_TO_BOTTOM	DEPTH_UNIT_CODE	COMMENTS
Snug Harbor	SH1E	8/28/2019 12:40	41.36406	-70.38286	+/- 2m	0.5	m	
	SH1D	8/28/2019 13:25	41.36422	-70.38268	+/- 2m	0.5	m	
	SH1C	8/28/2019 14:10	41.36435	-70.38266	+/- 2m	0.7	m	
	SH1B	8/28/2019 15:10	41.36451	-70.38273	+/- 2m	0.9	m	
	SH1A	8/28/2019 16:03	41.36471	-70.38267	+/- 2m	1.0	m	
Outer Basin	13A	8/28/2019 17:14	41.36402	-70.38724	+/- 2m	1.5	m	Eelgrass
	13B	8/28/2019 17:31	41.36378	-70.38719	+/- 2m	2.6	m	Eelgrass
Mid Basin	11A	8/29/2019 10:02	41.36475	-70.38530	+/- 2m	2.1	m	Eelgrass
	11B	8/29/2019 10:22	41.36467	-70.38532	+/- 2m	1.5	m	Eelgrass
	12A	8/29/2019 10:42	41.36444	-70.38560	+/- 2m	1.1	m	Eelgrass
	12B	8/29/2019 10:42	41.36402	-70.38562	+/- 2m		m	Eelgrass
South Basin	SC1E	8/29/2019 11:54	41.36096	-70.38720	+/- 2m	0.5	m	
	SC1D	8/29/2019 12:54	41.36109	-70.38748	+/- 2m	0.9	m	
	SC1C	8/29/2019 13:39	41.36110	-70.38768	+/- 2m	0.9	m	
	SC1B	8/29/2019 14:19	41.36125	-70.38784	+/- 2m	0.8	m	
	SC1A	8/29/2019 14:54	41.36118	-70.38808	+/- 2m	0.8	m	
Harbor Head	HH1A	9/4/2019 10:57	41.35823	-70.38489	+/- 2m	1.3	m	Eelgrass
	HH1B	9/4/2019 11:01	41.35806	-70.38482	+/- 2m	1.2	m	Eelgrass
	HH1C Upper	9/4/2019 10:27	41.35789	-70.38481	+/- 2m	1.0	m	Eelgrass
Oyster Pond	OP1							Not Accessible
	OP2							Not Accessible
	OP3							Not Accessible

2.2 Laboratory Methods

Laboratory methods were consistent with the draft MEP Benthic Monitoring QAPP (Rutecki and Nestler 2019) and the draft MEP Marine Benthic Monitoring Laboratory SOP (Sweeny and Rutecki 2019b) with one exception (see sediment grain size below). Two infauna samples were randomly selected for processing, while the third was archived. A total of 10 benthic samples from Snug Harbor (Stations SH1A-E) and 11 from South Basin (SC1A-E) were sorted. An extra sample was sorted in the South Basin as part of quality control. Organisms were sorted and identified to the lowest possible taxonomic level using a dissecting microscope. Each distinct taxon was saved separately in a labeled vial with reagent alcohol and archived in a reference collection as directed under Section B4.1 of the draft MEP Benthic Monitoring QAPP. Counts were standardized to densities per square meter (m^2) of bottom.

Grain size samples were analyzed following Section III of the draft MEP Marine Benthic Monitoring Laboratory SOP (Sweeny and Rutecki 2019b). Samples were held longer than the 28 days outlined in the draft QAPP and were frozen to extend the hold time. Grain-size distributions were not altered due to the change in preservation method and no other parameters were analyzed from these samples. Sediment grain size analysis samples were subsampled at 50 mL of sediment as the total sample volume (500 mL) would not dry completely following laboratory procedures.

Grain size was classified following the Coastal and Marine Ecological Classification Standard (CMECS) mineral grain size descriptors adopted from Wentworth (1922; FGDC 2012) and reported as a percentage by weight in six categories as follows:

- Very coarse sand = sum of 2mm and 1mm sieve material
- coarse sand = 500µ to < 1mm
- medium sand = 250µ to < 500 µ
- fine sand = 125µ to < 250 µ
- very fine sand = 63µ to < 125 µ
- silt = <63 µ

Marine and estuarine sediments generally consist of a mixture of grain sizes. For example, silty sand is defined as the combination of the three smallest sediment size classifications: fine sand, very fine sand, and silt.

Sediment samples for TOC followed the draft MEP Benthic Monitoring QAPP for preservation and hold times. Analytical methods for TOC followed the Lloyd Kahn Method (Kahn 1988).

2.3 Data Analysis

Benthic infauna data were analyzed for the following community parameters: abundance, Shannon-Wiener diversity index (H'), Pielou's evenness (J'), Margalef's diversity index (D_{mg}), Simpson, and Average Taxonomic Distinctiveness (ATD), using the PRIMER v5 (Plymouth Routines in Multivariate Ecological Research) software program (Warwick and Clarke 1991, Clarke and Gorley 2001). Shannon-Weiner (H') was calculated using log base e-transformed data. ATD was calculated instead of the Total Taxonomic Distinctiveness (TTD) described in the draft QAPP based on communications with PRIMER-e.

Multivariate analyses were performed using PRIMER v5 software to examine spatial patterns in the overall similarity of benthic assemblages in West Falmouth Harbor (Clarke 1993, Clarke and Warwick 2001). These analyses included classification (cluster analysis) by hierarchical agglomerative clustering with group average linking and ordination by non-metric multidimensional scaling (MDS). Bray-Curtis similarity was used as the basis for both classification and ordination. Similarity measures compare counts within each taxon between all possible pairs of samples. Values range from 0, when two samples have no taxa in common, to 100 when two samples are identical in taxa and counts within taxa. MDS outputs a two-dimensional plot where spatial proximity illustrates relative similarity between samples and is interpreted by the closeness of the samples. Clarke (1993) suggested that a stress level less than 0.20 (shown in the upper right corner of the plot) indicates that a potentially useful two-dimensional representation has been achieved. The results are also presented with a hierarchical clustering tree diagram (a dendrogram), with the x-axis representing the full set of samples, and the y-axis defining a similarity level at which two samples or groups are considered to have fused (Clarke and Warwick 2001). For the purpose of reducing the influence of high-density outliers, densities were square-root transformed before calculating similarity. The square-root transformation decreases the influence of the most abundant species so that rare species factor in more heavily when calculating similarity.

US M-AMBI (multivariate AZTI Marine Biotic Index in United States coastal waters) was calculated following Pelletier et al. (2018) to determine West Falmouth Harbor sub-embayment and embayment soft bottom habitat health. Modifications to the existing M-AMBI taxonomic classification (Ecological Grouping [EG]) were made prior to using the program utilizing the taxonomic list and corresponding EGs established by Pelletier et al. (2018) to be specific for the northeast US region. Each taxon identified is classified as EG I, II, III, IV, or V, with I taxa being considered those found in healthy benthic habitats, and V taxa inhabiting low quality habitat. The available published EG taxonomic list is for European studies, and some classifications are not the same as those for other regions. The taxonomic EG list specific to the northeast US region was provide by M. Pelletier (personal communication 2019).

The data were prepared for US M-AMBI by first coding each station in West Falmouth Harbor as polyhaline (salinity range from 18 to <30 ppt) and then assigning each taxon with the Northeast United States EG codes (categories I-V). Some taxa in the West Falmouth Harbor samples were not included in the data set because no EG code was available for this region at this time (i.e. Oligochaetes, Nemertea, and mud crab *Dyspanopeus sayi*), or the specimens were not able to be identified to a low enough taxonomic level (i.e. Gastropoda and Bivalvia). The Biological Index (BI) was then calculated for each sample using the following formula:

$$BI = 0*\%EG(I) + 1.5*\%EG(II) + 3*\%EG(III) + 4.5*\%EG(IV) + 6*\%EG(V)$$

Species richness (S) and Shannon-Weiner diversity index (H') were calculated for all species (including Oligochaetes, Nemertea, etc.) using PRIMER. These four parameters (salinity code, BI, S, and H') were then run through the R script for the Northeast United States provided by M. Pelletier (personal communication 2019). The output number corresponding to benthic health condition falls within the following categories: bad (<0.20), poor (0.20 to 0.39), moderate (0.39 to 0.53), good (0.53 to 0.77), and high (>0.77).

3 Results and Discussion

3.1 Water Quality

Water quality in West Falmouth Harbor was characterized in 2019 by measuring four parameters at each of the nineteen sampling locations: water temperature, DO, pH, and salinity (Table 2). West Falmouth Harbor is designated as SA waters. SA waters are *designated as an excellent habitat for fish, other aquatic life and wildlife, including for their reproduction, migration, growth and other critical functions, and for primary and secondary contact recreation* (314 CMR 4.00). The criteria for SA waters states DO shall not be less than 6.0 mg/L, temperature shall not exceed 29.4°C (85°F) nor a maximum daily mean of 80°F (26.7°0C), and pH shall be between 6.5 and 8.5 standard units and not more than 0.2 standard units outside of the natural background range (314 CMR 4.00). The majority of the water quality readings recorded during this survey met the SA water quality criteria. Three DO readings fell below 6.0 mg/L, although all three of these DO readings were above 5.0 mg/L.

Table 2. Water quality measurements West Falmouth Harbor, August 29, 2019.

Sub-embayment	Station	Depth (m)	Temp (°C)	DO (mg/L)	pH	Salinity (ppt)
Outer Basin	13A	0.1	21.51	7.18	7.84	29.39
		0.5	21.51	7.22	7.84	29.39
		1.1	21.50	7.22	7.83	29.42
		1.5	21.50	7.23	7.83	29.42
	13**B**	0.1	21.40	6.97	7.82	29.57
		1.0	21.39	6.97	7.81	29.56
		2.0	21.39	6.96	7.81	29.53
		2.5	21.38	6.95	7.81	29.53
Mid Basin	11A	0.1	21.85	6.03	7.64	28.62
		0.5	21.85	5.96	7.65	28.70
		1.1	21.66	6.10	7.69	28.85
		1.2	21.66	6.12	7.69	28.86
	11B	0.1	21.83	6.15	7.69	28.94
		0.5	21.89	6.05	7.68	28.86
		0.8	21.91	5.92	7.67	28.85
	12A	0.1	22.17	6.05	7.64	28.20
		0.5	21.95	6.07	7.68	28.54
		0.7	21.71	6.26	7.71	28.75
	12B	0.1	22.15	6.52	7.70	28.09
		0.5	22.00	6.41	7.70	28.37
Snug Harbor	SH1A	0.1	22.25	8.41	7.83	27.69
		0.5	22.14	7.28	7.74	28.20
	SH1B	0.1	22.34	8.78	7.84	27.59
		0.5	22.17	8.03	7.76	28.14
	SH1C	0.1	22.49	8.60	7.88	27.74
		0.5	22.43	8.94	7.85	27.94
	SH1D	0.1	22.34	8.63	7.81	27.47
		0.5	22.31	8.76	7.85	28.50
	SH1E	0.1	22.30	7.50	7.68	26.99
		0.2	22.38	8.05	7.71	27.73
South Basin	SC1A	0.5	23.55	7.47	7.76	27.63
	SC1B	0.1	23.10	7.60	7.78	26.38
		0.5	23.03	7.66	7.78	26.65
	SC1C	0.1	23.04	6.75	7.70	27.01
		0.5	22.72	7.12	7.78	28.74
	SC1D	0.1	23.03	6.70	7.63	25.98
		0.5	22.56	6.65	7.69	27.93
	SC1E	0.1	22.47	6.33	7.60	25.39
Harbor Head	HH1A	0.1	22.83	6.30	7.64	27.43
		0.5	22.61	6.09	7.67	27.92

Sub-embayment	Station	Depth (m)	Temp (°C)	DO (mg/L)	pH	Salinity (ppt)
	HH1B	0.7	22.39	6.01	7.69	28.35
		0.2	22.61	6.68	7.65	27.77
		0.5	22.50	6.24	7.68	28.05
	HH1C Upper	0.7	22.47	6.15	7.69	28.20
		0.1	22.42	6.06	7.63	27.64
		0.5	22.32	5.94	7.65	27.96

3.2 Underwater Digital Images

Digital photographs and video were taken at each station in the Mid Basin, Outer Basin, Harbor Head, South Basin, and Snug Harbor. Dense beds of eelgrass with epiphytes were present along the Mid Basin (Figure 3a–d) and Outer Basin (Figure 4a-b). Along the Harbor Head transect, eelgrass patches were interspersed with macroalgae and soft silty bottom sediment (Figure 5a-c). The South Basin consisted of a soft silty sand bottom with some macroalgae clumps and shell debris (Figure 6a-e). The Snug Harbor transect was sampled from the north (SH1A) to the south (SH1E; Figures 7a-d). Bottom habitat along this transect was predominantly soft sediment with scattered macroalgae, shell pieces, and invertebrate tubes as observed at Stations SH1B, SH1C, and SH1E (Figures 7b and 7d). Station SH1A was the exception with a dense *Ulva* spp. bed that also contained other macroalgae (Figure 7a). The visibility was very poor at Station SH1D due to the high level of silt suspended in the water column (Figure 7c).

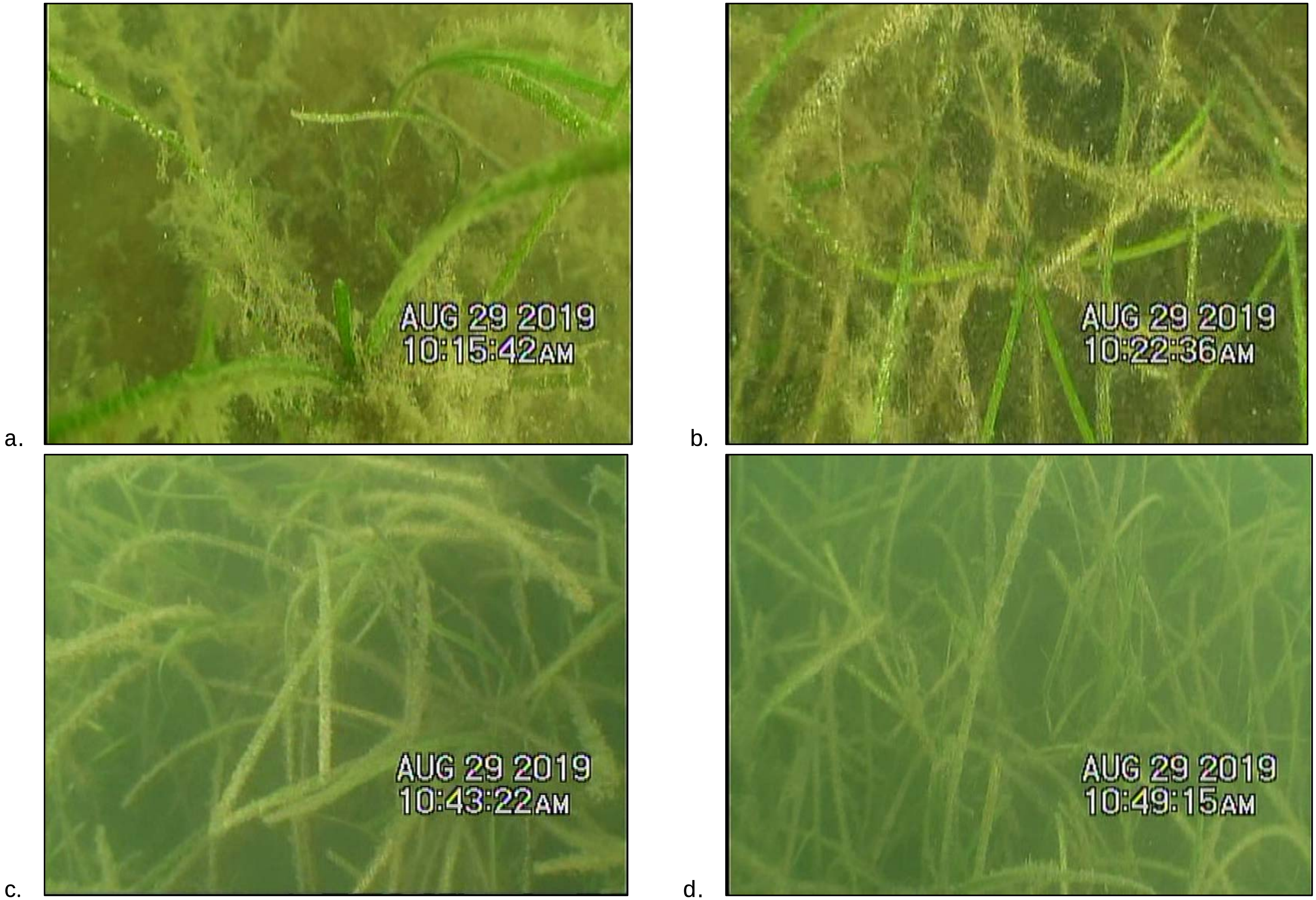
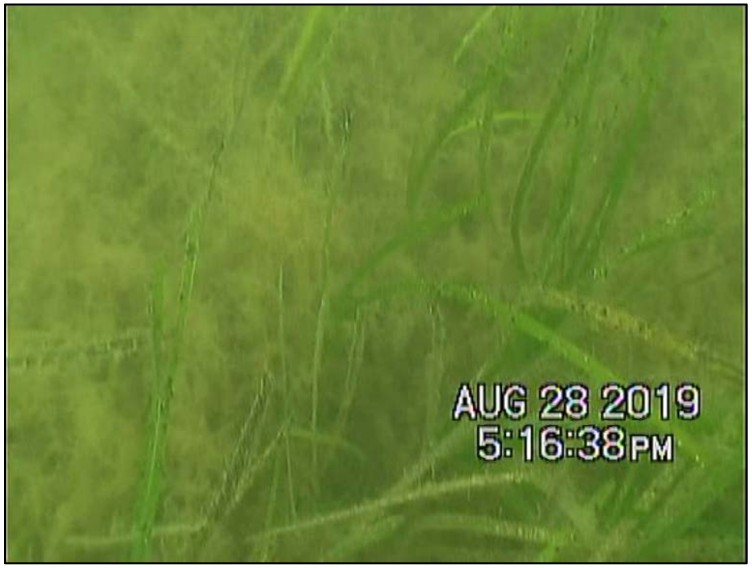


Figure 3. Images of eelgrass in Mid Basin taken on August 29, 2019 at stations: a) 11A, b) 11B, c) 12A, and d) 12B.

a. 

b. 

Figure 4. Images of eelgrass in the Outer Basin taken on August 28, 2019 at stations: a) 13A and b) 13B.

a.

b.

c.

Figure 5. Images of eelgrass in Harbor Head taken on September 4, 2019 at stations: a) Harbor Head 1A, b) Harbor Head 1B, and c) Harbor Head 1C.

a.

b.

c.

d.

Figure 6. Images of soft bottom habitat recorded on September 4, 2019 at stations: a) SC1A, b) SC1B, c) SC1C (GoPro camera), d) SC1D, and e) SC1E.

e. 

Figure 6 Continued.

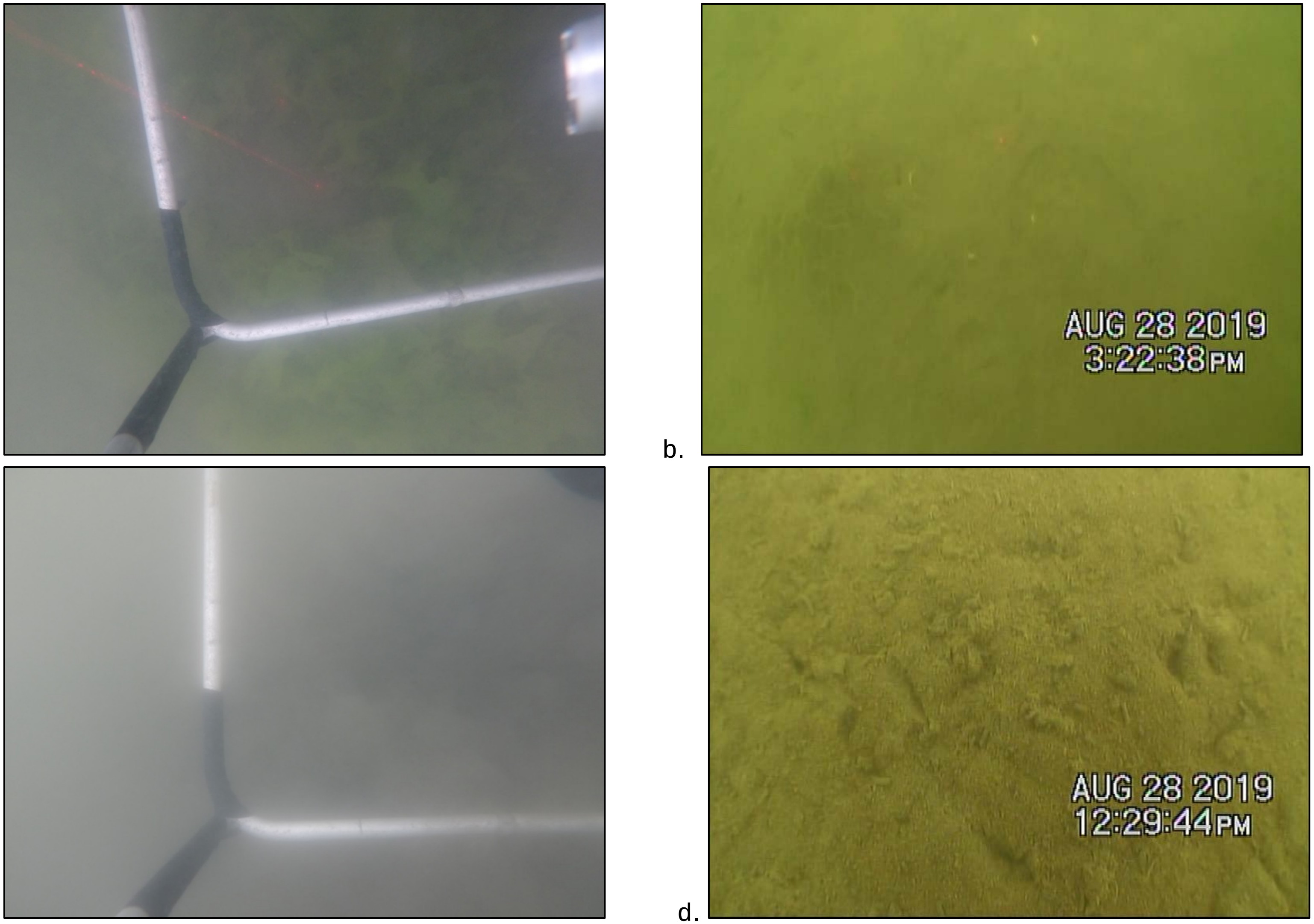


Figure 7. Images of bottom habitat recorded on August 28, 2019. a) *Ulva* spp. bed at Station SH1A (GoPro camera), b) macroalgae (on the left) and some shell pieces at Station SH1B, c) poor visibility caused by bottom sediments with high silt levels at Station SH1D (GoPro camera), and d) macroinfaunal tubes observed on soft bottom at Station SH1E.

3.3 Sediment Composition

Sediment conditions in West Falmouth Harbor were characterized in 2019 by measuring two parameters at each sampling location were grab samples could be collected: (1) grain size and (2) total organic carbon (Table 3).

Grain Size Analysis

Surface sediments collected at ten sampling locations in 2019 contained a range of sand and silt sediments summarized in Table 3 and Figure 8 below. Percentage of sediments in the West Falmouth Harbor samples varied within and among transects; overall sediments were less silty along the South Basin transect (Station locations SC1A-SC1E) compared to the Snug Harbor transect (station locations SH1A- SH1E; Table 3, Figure 8). Along transect SC1, the mean percent silt was 36.2% and ranged from 10.7% (SC1E) to 46.8% (SC1D). Along transect SH1, the mean percent silt was 52.9% and ranged from 13.1% (SH1A) to 86.4% (SH1E). The high percentage of silt at SH1D and SH1E is likely due to the location of these stations within the embayment. These samples were taken eastward of a spit of land with potentially less water circulation (Figure 2), causing a higher deposition rate compared to the three more northerly stations (SH1A-SH1C). Conversely, the samples with the highest percentage of sand, SC1E (76.3%) and SH1A (75.5%), appear to be exposed to higher tidal flushing.

In general, higher percentages of organic matter deposition (e.g. silt) to the sediments result in a relatively lower benthic habitat quality (Howes et al. 2006). Silty sediments are inhabited by low-diversity, shallow-dwelling organisms compared to high-diversity deep-burrowing organisms found in more sandy sediments (Howes et al. 2006).

Table 3. Results for West Falmouth Harbor sediment condition parameters in 2019.

Parameter	South Basin					Snug Harbor				
Grain Size	SC1A	SC1B	SC1C	SC1D	SC1E	SH1A	SH1B	SH1C	SH1D	SH1E
Very coarse sand (%)	1.8	25.4	9.0	10.1	34.9	8.1	4.4	21.6	1.2	0.3
Coarse sand (%)	10.5	6.7	12.6	12.4	15.6	30.4	22.4	4.8	2.3	1.3
Medium sand (%)	24.7	12.6	16.1	15.9	25.9	37.0	33.4	6.6	5.3	3.0
Fine sand (%)	12.3	9.0	11.3	7.9	10.2	8.5	11.5	4.4	2.3	4.4
Very fine sand (%)	8.0	7.0	9.6	7.0	2.8	2.9	4.2	5.4	5.2	4.6
Silt (%)	42.7	39.3	41.4	46.8	10.7	13.1	24.2	57.2	83.7	86.4
Total Organic Carbon (%)	2.08	3.18	2.68	2.80	1.16	1.26	1.95	3.65	4.20	4.26

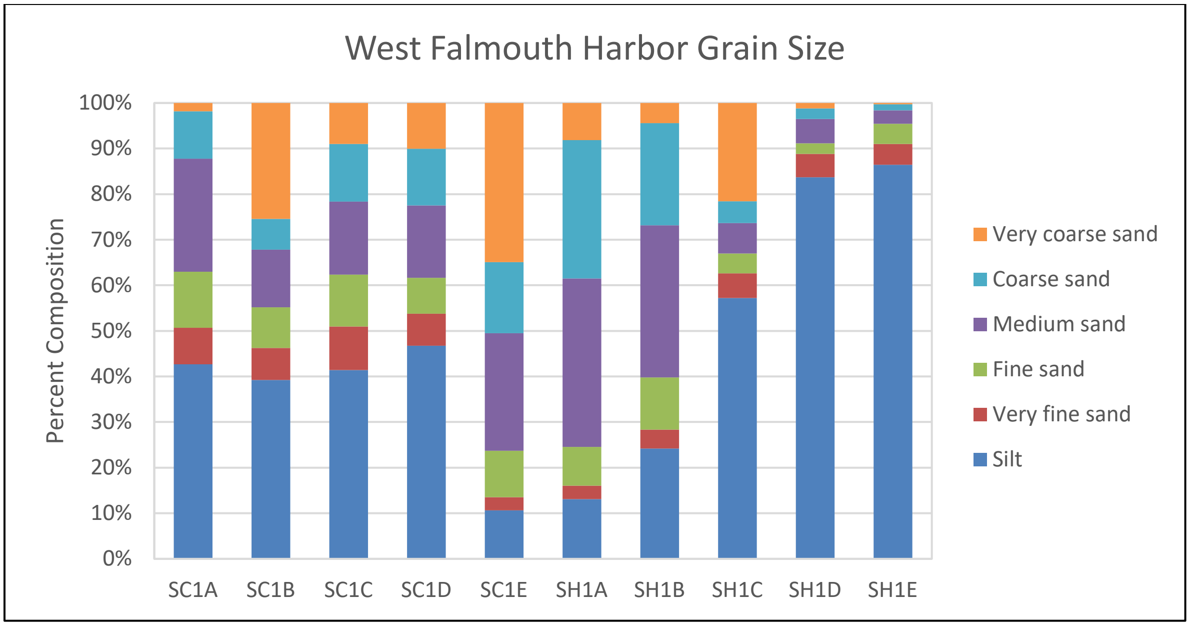


Figure 8. West Falmouth Harbor grain size analysis, June 2019.

Total Organic Carbon

Organic matter in sediments can form water-soluble and water-insoluble complexes with metal ions and hydrous oxides, interact with clay minerals and bind particles together, adsorb and desorb both natural and man-made organic compounds, and absorb and release nutrients (Schumacher 2002). Therefore, total organic carbon (TOC) is an important parameter in characterizing the health status of a site because the level of TOC can markedly influence how chemicals will react in the sediment (Schumacher 2002). Three basic forms of carbon may be present in sediments: elemental carbon (from charcoal, soot, graphite, and coal), inorganic carbon (from geologic or soil parent material sources), and organic carbon (derived from the decomposition of plants and animals). In addition to the naturally occurring organic carbon sources, anthropogenic activities can also increase the total carbon content to sediment. For example, spills or releases of contaminants into the environment increase the total carbon content in the sediment. In general, though, the total carbon contribution from contaminants to the total organic carbon content in sediment is relatively small to negligible unless a fresh spill has occurred (Schumacher 2002).

TOC in the two transects sampled in West Falmouth Harbor were variable ranging from 1.2% in the South Basin to 4.3% in Snug Harbor (Table 3). Higher TOC values were associated with a higher percent silt (Figure 9). The lowest TOC and percent silt were at Station SC1E (1.2%) in the South Basin and SH1A (1.3%) in Snug Harbor. The highest TOC and corresponding percent silt were both found in Snug Harbor at Stations SH1D (4.2%) and SH1E (4.3%), the two southernmost station locations. As described above, these stations appear to be in an area with decreased tidal flushing resulting in higher sedimentation rates than the other stations along the Snug Harbor transect. TOC data are not available from the previous assessment conducted in 2003 (Howes et al. 2006), therefore these TOC results could be used as a baseline for future surveys. Standard statistical tests (e.g. analysis of variance [ANOVA], correlation analyses, or regression analyses) can be used to analyze future sediment collected in West Falmouth Harbor with those taken in 2019.

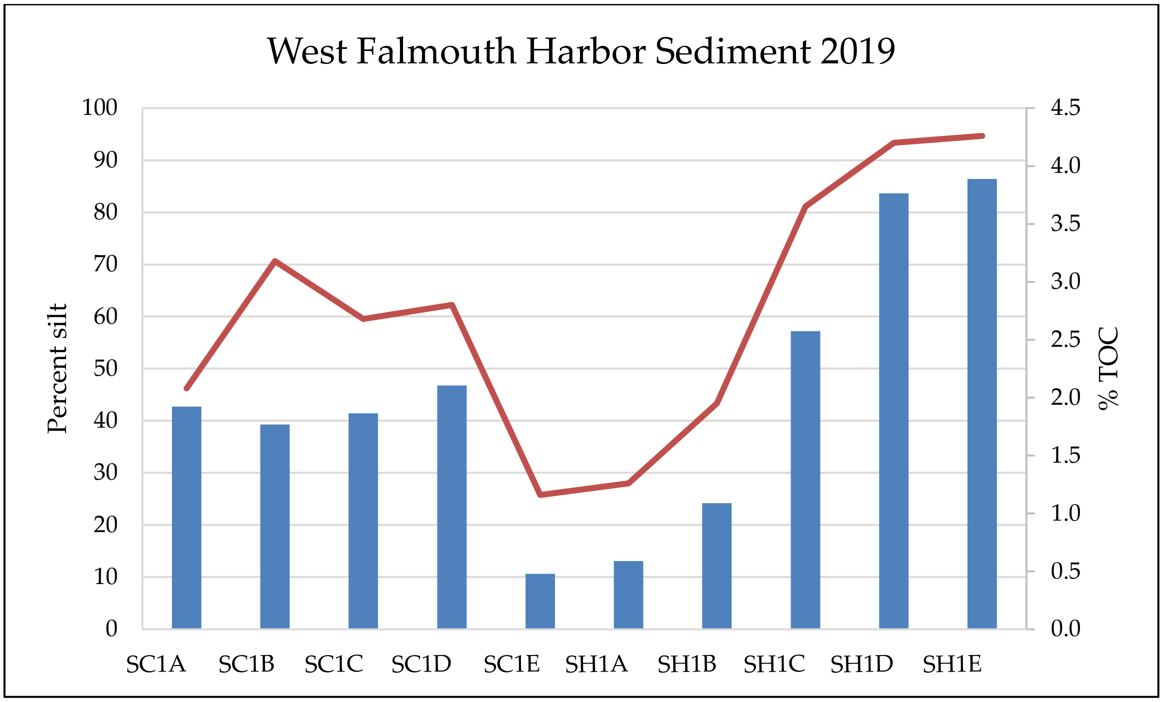
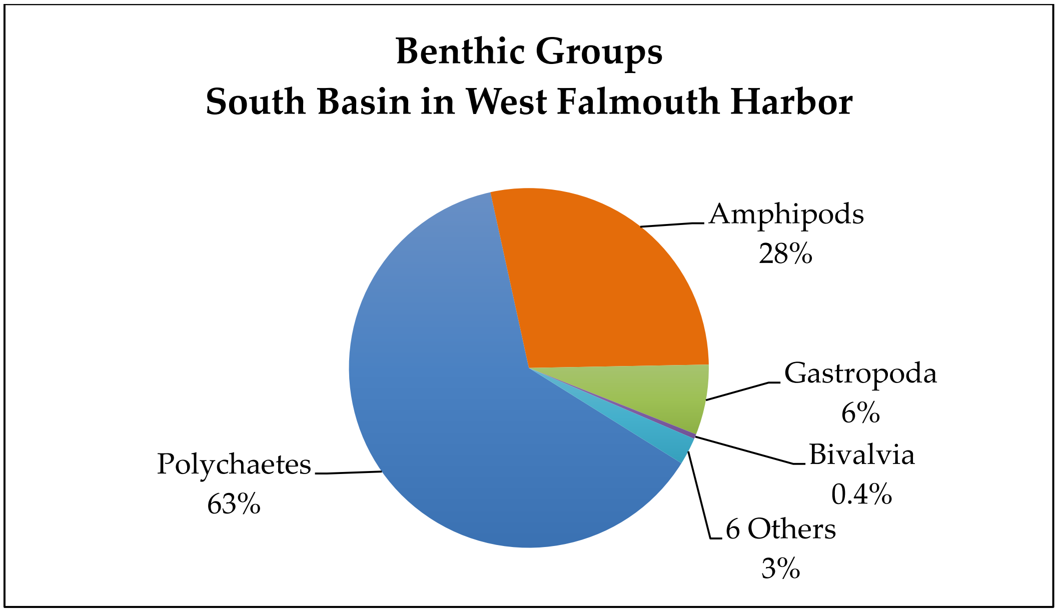


Figure 9. West Falmouth Harbor sediment, percent silt and TOC at the South Basin (SC) and Snug Harbor (SH) transects, 2019.

3.4 Benthic Infauna Community

The benthic community in the South Basin sub-embayment (Stations SC1A-E) and Snug Harbor sub-embayment (Stations SH1A-E) within West Falmouth Harbor were characterized based on the following macroinvertebrate metrics: number of species (S), abundance (N), species richness (Magalef, D_{mg}), diversity (Shannon-Weiner, H' and Simpson's index [1-λ]), and evenness (Pielou, J'). In addition, Average Taxonomic Distinctness (ATD), cluster and non-metric multidimensional scaling analyses, and US M-AMBI are presented to assess spatial and temporal trends in community composition within transects and between sub-embayments, and eventually between estuaries. Since US M-AMBI incorporates several of the above metrics (i.e. species number, Shannon-Weiner diversity H', salinity category, and BI score [see Methods section above]), US M-AMBI was used as an overall summary of the benthic habitat health status.

A total of 62 taxa were identified in the West Falmouth Harbor benthic samples (Table 4; Appendix A). These taxa represented four Phyla: Annelida (aquatic earth worms and bristle worms), Mollusca (bivalves and snails), Arthropoda (shrimp and crabs), and Nemertea (ribbon worms). Polychaetes were the dominant group at both the South Basin and Snug Harbor accounting for 63% and 72% of the total abundance respectively (Figure 10). Amphipods were the next highest group contributing 28% to the total abundance in the South Basin and 20% in Snug Harbor. Gastropods were the third highest group at the South Basin (6%) and Snug Harbor (5%). Bivalves and six other groups including tanaids and cumaceans (small crustaceans), crabs, shrimp, nemerteans, and barnacles each contributed <1% to the total abundance.



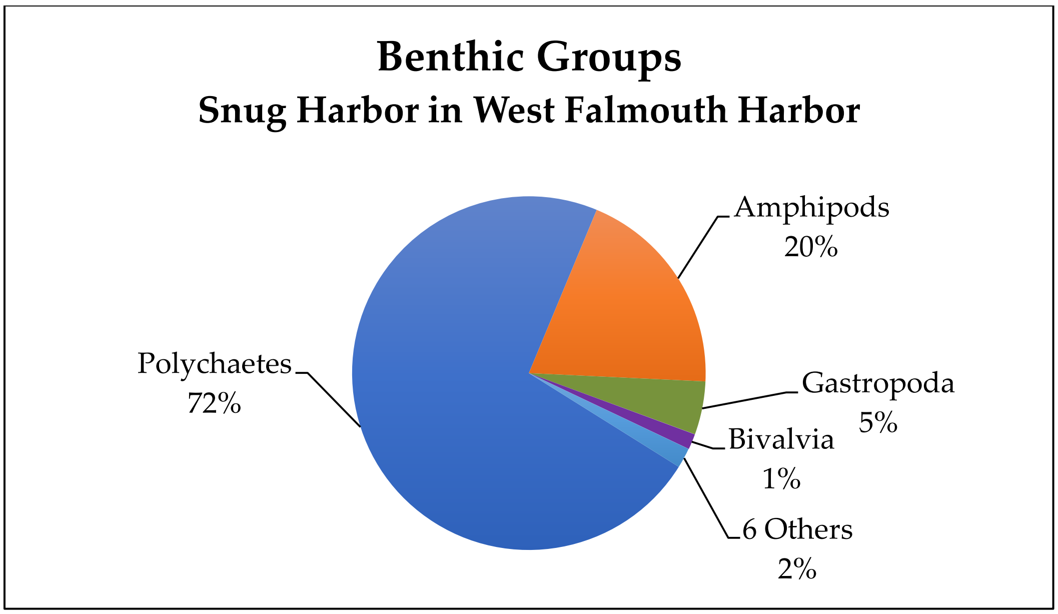


Figure 10. Percentage of benthic groups in the South Basin (top) and Snug Harbor (bottom) sub-embayments, West Falmouth Harbor, June 2019.

Table 4. Taxonomic list for West Falmouth Harbor benthos, June 2019.

Phylum	Subphylum/Class/Order	Taxa	Phylum	Subphylum/Class/Order	Taxa
Annelida	**Oligochaeta**		**Mollusca**	**Bivalvia**	*Anadara transversa*
	Polychaeta	*Alitta succinea*			*Gemma gemma*
		Capitella capitata			*Macoploma tenta*
		Chaetozone setosa			*Mercenaria mercinaria*
		Eumida sanguinea			*Mya arenaria*
		Exogone dispar			*Tellina* sp.
		Glycera dibranchiata			Tellinidae
		Glycera americana		**Gastropoda**	*Astyris lunata*
		Glycinde solitaria			*Credpidula plana*
		Heteromastus filiformis			*Crepidula fornicata*
		Hypereteone heteropoda			*Retusa obtusa*
		Microphthalmus sczelkowii			*Tritia obsoleta*
		Notomastus latericeus			*Boonea seminuda*
		Oxydromus obscurus	**Arthropoda**	**Cumacea**	*Leucon americanus*
		Parapionosyllis longicirrata		**Amphipoda**	*Ampelisca abdita*
		Pectinaria gouldii			*Cymadusa compta*
		Phyllodoce arenae			*Gammarus mucronatus*
		Pista elongata			*Grandidierella japonica*
		Polydora cornuta			*Jassa falcata*
		Prionospio sp.			*Microdeutopus gryllotalpa*
		Prionospio heterobranchia			*Monocorophium insidiosum*
		Salvatoria clavata			*Ptilohyale plumulosus*
		Scoletoma tenuis			*Lysianopsis alba*
		Scoloplos robustus		**Isopoda**	*Cyathura polita*
		Streblospio benedicti		**Tanaidacea**	Paratanaidae
		Syllidae			*Leptochelia rapax*
		Terebellidae		**Cirripedia**	Balanidae
				Decapoda	*Dyspanopeus sayi*
					Pagurus longicarpus
					Palaemon pugio
					Pinnixa sp.
			Nemertea		

The top five dominant species differed between transects (Figure 11). The South Basin dominants included two polychaetes (*Capitella capitata* and *Polydora cornuta*), two amphipods (*Ampelisca abdita* and *Grandidierella japonica*), and the gastropod *Credpidula fornicata*. The numerical dominants in Snug Harbor were all polychaetes (*Scoloplos robustus, Heteromastus filiformis, Streblospio benedicti*, *Scoletoma tenuis*, and Oligochaeta). Numerical dominants in both sub-embayments are organisms typically found in estuarine habitats in the northeast US (Gosner 1971). The top numerical dominant in the South Basin, *C. capitata* is a pollution-tolerant indicator species in polyhaline mud sediments (Pelletier et al. 2010). Gammarid amphipod *A. abdita* is a filter feeder found in fine sand to silty sand with low percentages of silt in low to moderate salinities (Gosner 1971, LeCroy 2002). In a study in the Mullica River- Great Bay Estuary in New Jersey, authors found that sediment composition, specifically the percent of silt-clay was a major factor in the distribution pattern of benthic macrofauna (Kennish et al. 2004). For example, *Lumbrineris (Scoletoma) tenuis*, one of the numerical dominants at Snug Harbor, was found only in sediments with more than 38% silt-clay in the Great Bay study (Kennish et al. 2004). The authors also indicated that other physicochemical factors (e.g., organic carbon content of the sediments, dissolved oxygen levels, bottom currents, and turbidity) might also influence the local distribution patterns of the fauna.

The difference in numerical dominance at the South Basin and Snug Harbor may be related to the relative level of silt in the sediment. The sediment at both sub-embayments is silty sand, but notes from the field crew, underwater video results, and grain size at least from Station SH1C, SH1D, and SH1E indicate that Snug Harbor habitat is siltier. The top five numerically dominant species at Snug Harbor are deposit feeders, eating organic material in the sediment, while those at the South Basin are a mixture of filter feeders (*C. fornicata, A. abdita*, and *G. japonica*) and deposit feeders (*C. capitata* and *P. cornuta*). Interestingly, in a study on community structure of macrobenthos inhabiting sand and mud flats in Barnstable Harbor (also on Cape Cod), Whitlatch (1977) found that while *S. benedicti* and *H. filiformis* were among the most ubiquitous and numerically important species found at all sediment types in Barnstable Harbor, they were always ranked as the first and second most dominant species at sandy mud and mud stations (as they were in Snug Harbor). Whitlatch (1977) also found that *S. robustus* was restricted to just one sediment type, only found in sandy-mud and mud. *S. robustus* was also found in the South Basin, ranked as the 7th most abundant organism. These results indicate that the benthic community dominated by deposit feeding polychaetes found at Snug Harbor is likely due to the relatively high level of silt and organic material.

In general, in terms of the number of species and abundance, the South Basin appears to have higher quality benthic habitat compared to Snug Harbor. The mean number of taxa was higher along the South Basin transect (mean of 16 taxa, ranging 8 to 25 taxa per sample) compared to the Snug Harbor transect (mean of 9 taxa, ranging from 1 to 20 taxa per sample; Table 5). In addition, the mean Margalef's species richness (D_{mg}) was also higher along the South Basin (1.7) compared to Snug Harbor (1.0; Table 6, Figure 12). Margalef's species richness is a measure of the number of species present, making some allowance for the number of individuals. The samples in the South Basin had approximately twice as many individuals per sample (mean of 6,334 individuals per m^2) compared to samples in Snug Harbor (mean of 3,222 individuals per m^2).

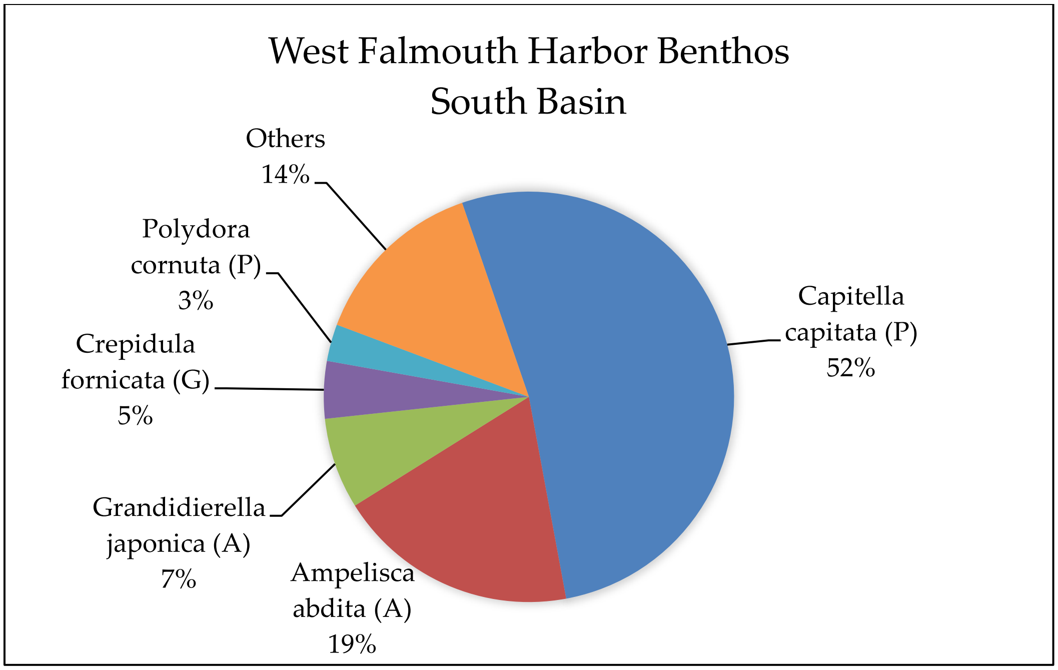
Overall, diversity indices for both sub-embayments were relatively low. The Shannon-Wiener diversity index is a function of the number of different taxa in a sample, the number of individuals per taxa, and the total number of individuals. H' increases with the number of species in the community and when a more even distribution of numbers among taxa is found. H' ranges from 0 when only one species is present to 5.0 when many taxa are found in equal numbers of individuals. Diversity indices in West Falmouth Harbor were variable, ranging from 0 (Station SH1E-1 along the Snug Harbor transect) to 2.1 (Station SC1C-1 along the South Basin transect; Figure 13). The 0 value at Station SH1E-1 was due to a depauperate sample with only three individuals of a single taxon, *Capitella capitata*. The mean diversity index for the South Basin transect was 1.4 and 1.2 for Snug Harbor (Table 6). These low values are due to the relatively high density of a few taxa. Along the South Basin transect two taxa contributed 71% (polychaete *Capitella capitata*, 52% and gammarid amphipod *Ampelisca abdita*, 19%) to the total abundance and similarly along the Snug Harbor transect two taxa contributed 69% (*Scoloplos robustus*, 46% and *Heteromastus filiformis*, 23%; both polychaetes) to the total abundance. Simpson's diversity results were similar, ranging from 0 to 0.73 and a mean of 0.54 in Snug Harbor and from 0.32 to 0.82 in the South Basin with a mean of 0.60 (Table 6, Figure 14).

Evenness is another expression of how individuals are distributed among different species or taxa. Pielou's evenness index (J') ranges from 0 to 1 and is essentially the reverse of dominance and therefore a sample with low evenness would be highly dominated by a small number of the taxa present. Evenness indices were also variable within sub-embayments ranging from 0 at SH1E-1 in Snug Harbor to 0.8 at SC1B-3 in the South Basin (Figure 15). With the exception of Station SH1E-1, evenness indices were relatively consistent within the Snug Harbor transect, ranging from 0.5 to 0.7. As expected, the mean evenness was relatively low along both transects: 0.5 along the South Basin transect and 0.6 along the Snug Harbor transect (Table 6).

3.5 Average Taxonomic Distinctness (ATD)

Taxonomic distinctness is a biodiversity calculation used to indicate the relatedness of organisms based on Linnaean classification system. Average Taxonomic Distinctness (ATD) is a relatedness measure that can not only be calculated from simple species lists (e.g. Phylum, Class, Order, Family, Genus, and Species) but also possesses a robustness to the varying number of species in the lists. More specifically, mean values are unchanged in different-sized sublists generated by random sampling from a larger list. This suggests that it is valid to compare Delta+ over historic time or biogeographic space scales, under conditions of variable sampling effort.

Average taxonomic distinctness (delta+) for West Falmouth Harbor benthos is represented in the funnel plot showing the 95% upper and lower limits of the expected range of diversity (Figure 16). Results indicate that while most samples are within the expected range, two samples from the South Basin (SC1A-2 and SC1D-1) and one from Snug Harbor (SH1E-1) were below the expected range of biodiversity. Station SC1A-1 had a relatively low number of species, n = 11 belonging to 8 families. Three species belonged to the Spionidae family of polychaetes and two species belonged to the Capitellidae family of polychaetes, thus reducing the taxonomic distinctness of the sample. Similarly, Station SC1D-1 had 15 species from 10 families (3 species belonged to Spionidae and 2 belonged to Capitellidae). As mentioned above, Station SH1E-1 only had a single species, *Capitella capitata*, which is represented on the funnel plot in the lower left corner with a taxonomic distinctness of 0.



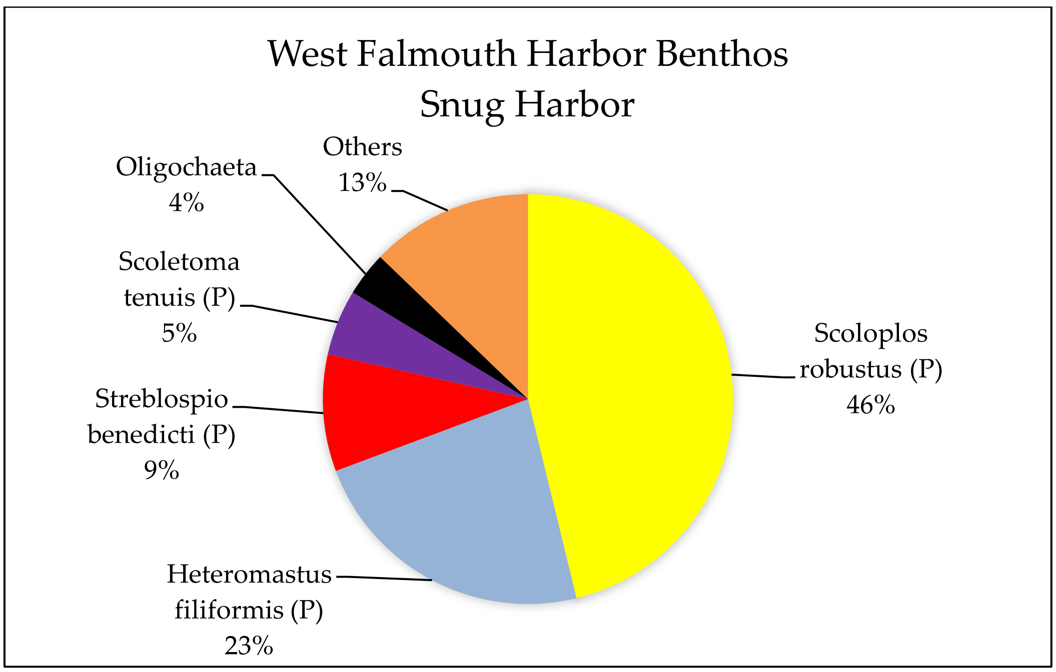


Figure 11. Five dominant species of benthos at the South Basin (top) and Snug Harbor (bottom) sub-embayments in West Falmouth Harbor, 2019. (P) = Polychaete, (G) = Gastropod, (A) = Amphipod.

Table 5. Number of species and individuals per sample along the South Basin (SC) and Snug Harbor (SH) transects in West Falmouth Harbor, 2019.

South Basin				Snug Harbor			
	S	N	d		S	N	d
Station-replicate	Species number	Number of individuals per m²	Margalef species richness	Station-replicate	Species number	Number of individuals	Margalef species richness
SC1A-3	21	8,475	2.211				
SC1A-2	11	7,525	1.120	SH1A-1	11	1,700	1.344
SC1B-2	11	3,350	1.232	SH1A-3	20	10,400	2.054
SC1B-3	8	1,150	0.993	SH1B-3	14	3,700	1.582
SC1C-1	25	11,325	2.571	SH1B-1	13	12,575	1.271
SC1C-2	13	7,275	1.349	SH1C-3	11	1,000	1.448
SC1D-2	15	3,475	1.717	SH1C-2	10	1,250	1.262
SC1D-1	15	10,725	1.509	SH1D-2	5	975	0.581
SC1D-3	17	5,950	1.841	SH1D-3	4	225	0.554
SC1E-1	20	5,875	2.189	SH1E-3	3	350	0.341
SC1E-2	17	4,550	1.900	SH1E-1	1	75	0.000

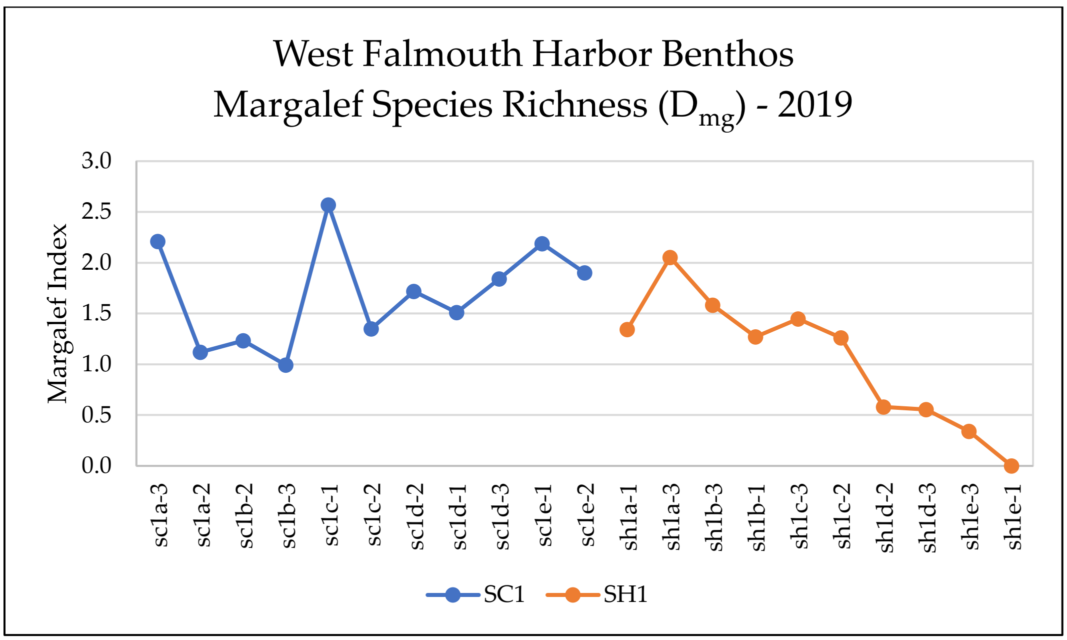


Figure 12. Magalef species richness for West Falmouth Harbor benthos, 2019.

Table 6. Summary of descriptive indices West Falmouth Harbor, 2019

Location	ID	Number of taxa	Total number of individuals (count)	Total density (number per m²)	Mean density (number per m²)	Mean Shannon-Weiner (H')	Mean Simpson diversity (1-λ)	Mean Pielou's evenness (J)	Mean species richness (D_{mg})
Snug Harbor	SH A,B,C,D,E	34	1,290	32,225	3,222	1.19	0.54	0.625	1.03
South Basin	SC A,B,C,D,E	46	2,787	69,675	6,334	1.44	0.60	0.531	1.69

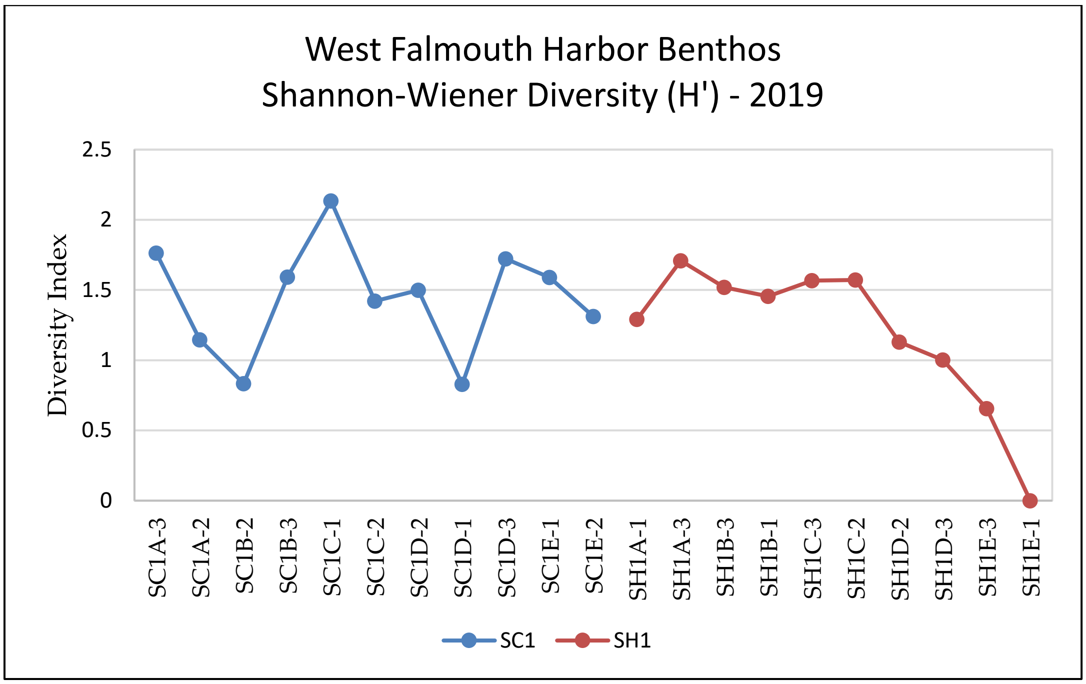


Figure 13. Shannon-Wiener diversity index (H') for West Falmouth Harbor benthos, 2019.

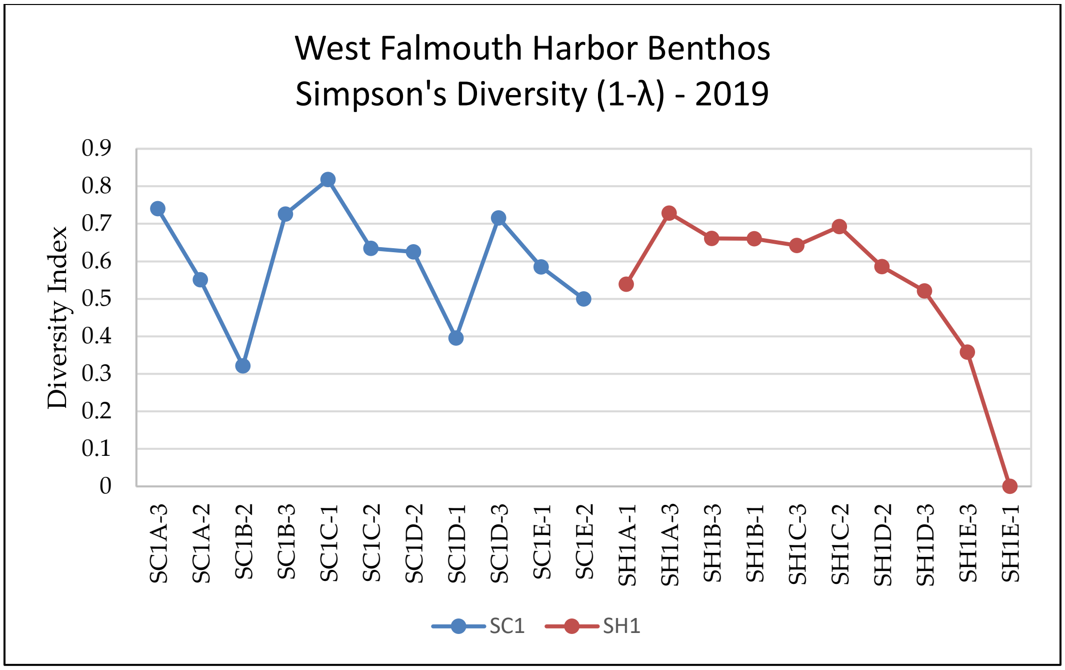


Figure 14. Simpson's diversity index for West Falmouth Harbor benthos, 2019.

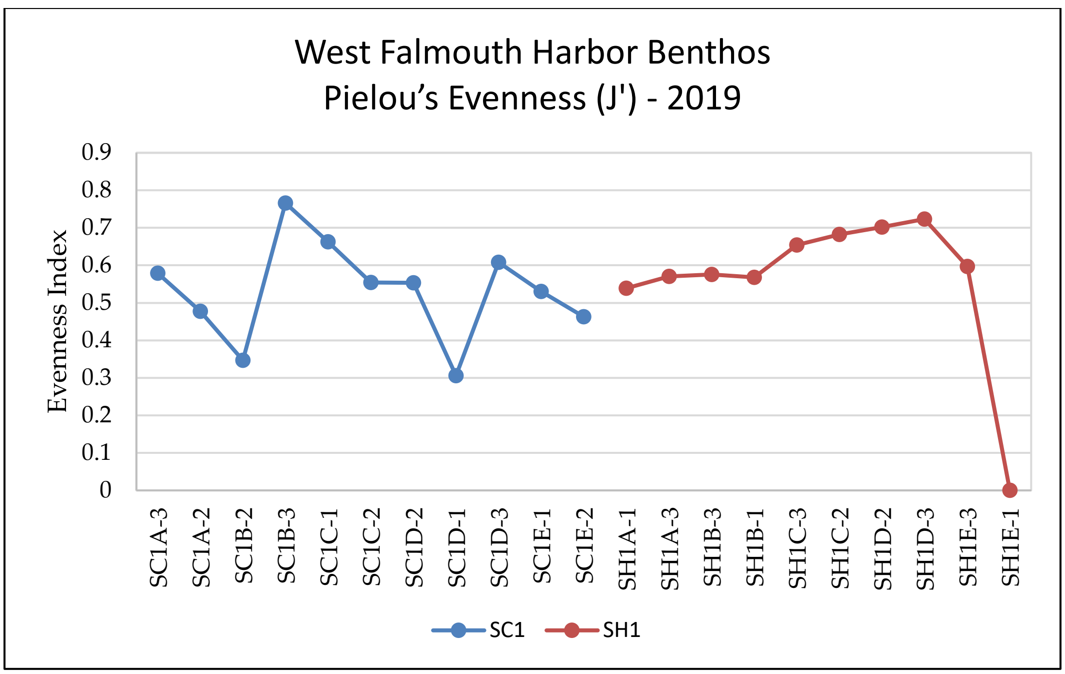


Figure 15. Pielou's evenness index (J') for West Falmouth Harbor benthos, 2019.

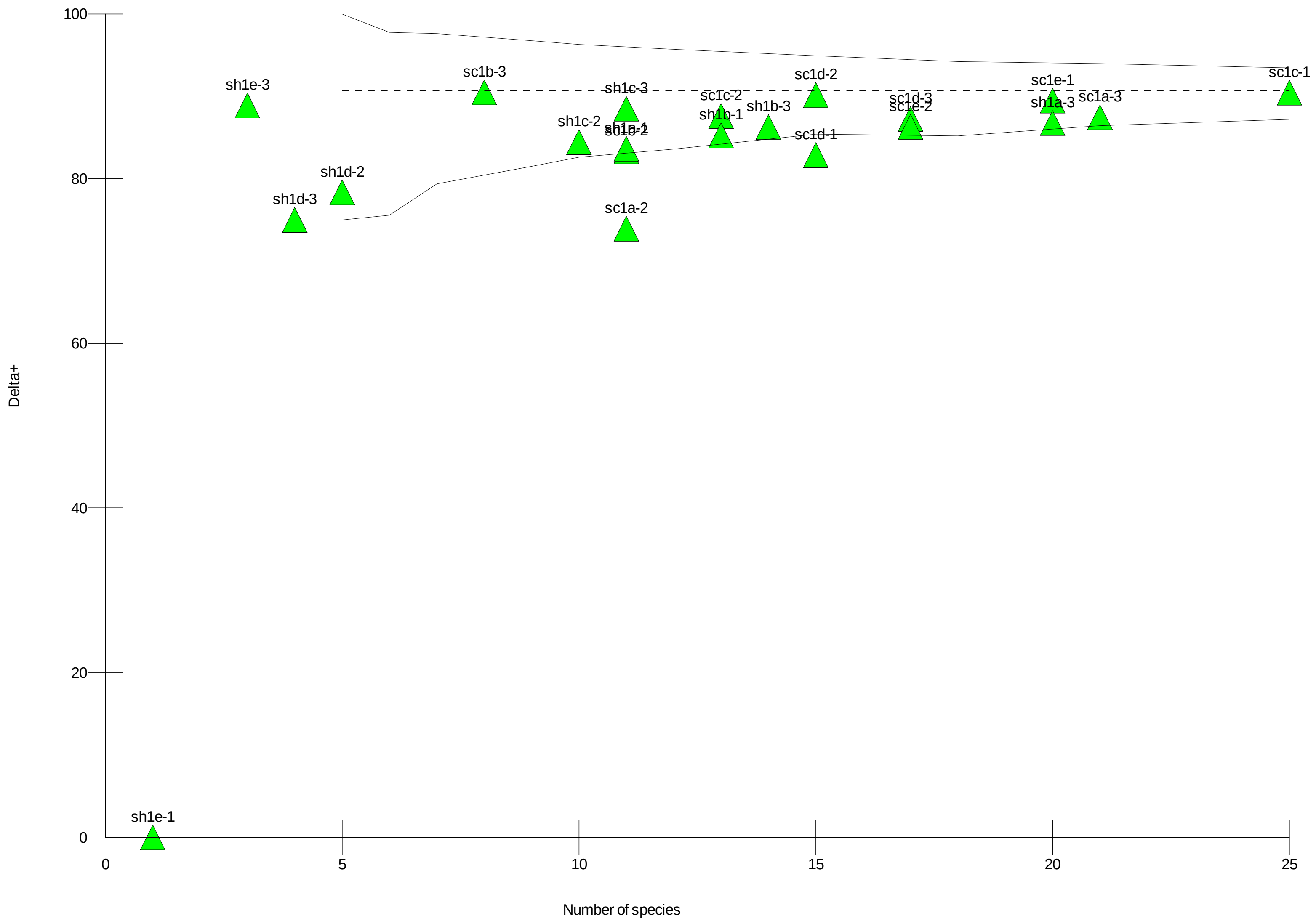


Figure 16 West Falmouth Harbor Average Taxonomic Distinctness (Delta+) for South Basin (SC) and Snug Harbor (SH).

3.6 Cluster and non-metric multidimensional scaling (MDS) analyses

MDS and cluster diagram plots both indicate that the benthic communities sampled were more similar within transect than basin wide. Interestingly, the South Basin samples were more similar to each other than the Snug Harbor samples. Figure 17 illustrates this as a tighter cluster for the South Basin samples (circles) compared to the Snug Harbor cluster (squares), with the sample most unlike any others unassociated with any other samples in the lower right corner. This observation is supported in the cluster diagram (Figure 18), with the South Basin samples clustering together with a similarity of 40% compared to the Snug Harbor samples, also clustering together (with the exception of sample SH1E-1), but with a similarity to each other of 28%.

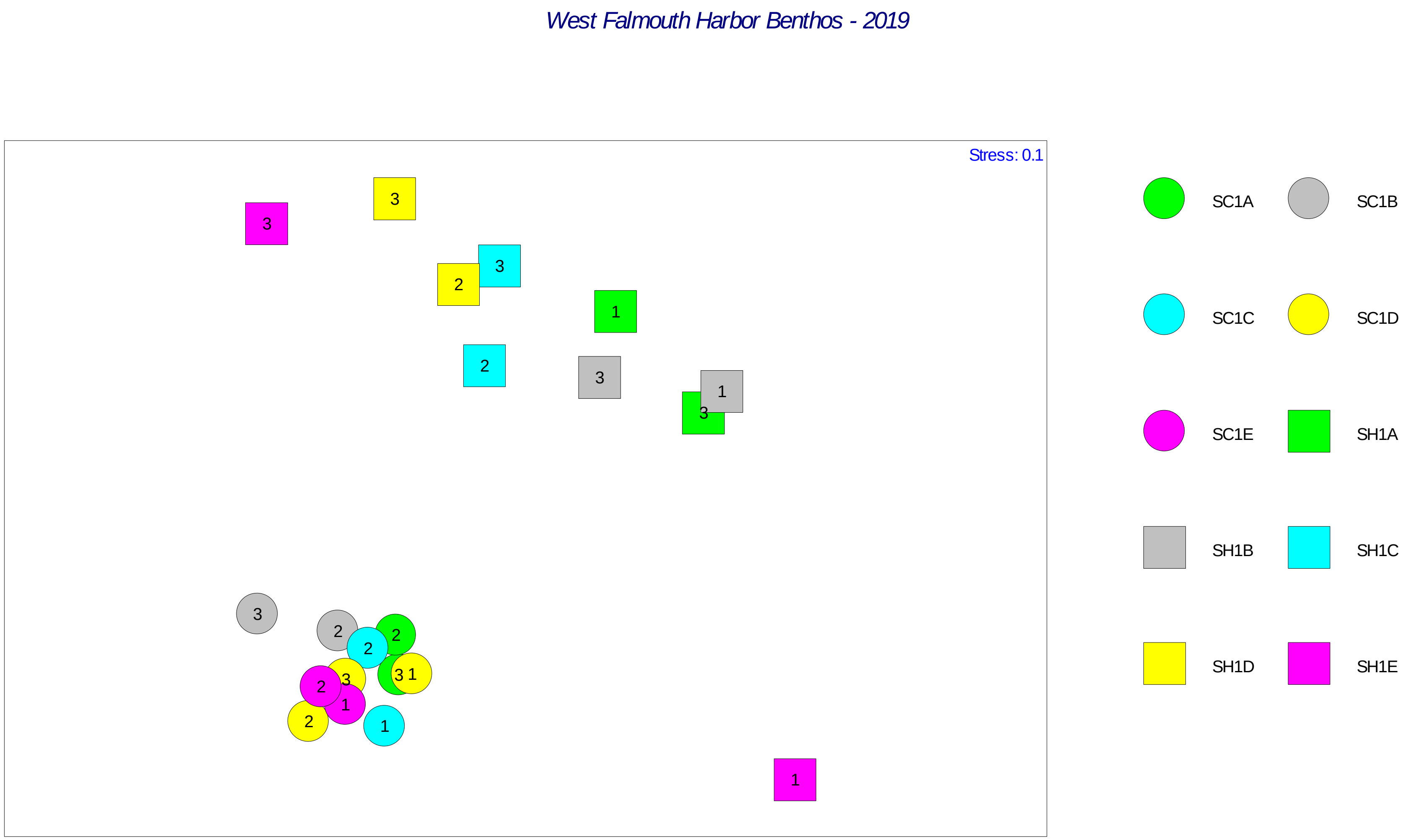


Figure 17. MDS plot of benthic samples from South Basin (circles, SC1A, B, C, D, E) and Snug Harbor (squares, SH1A, B, C, D, E) in the West Falmouth Harbor. The stations are color-coded from A to E along each transect (green, grey, blue, yellow, and pink) numbers within the circles and squares indicate replicate numbers for each sample.

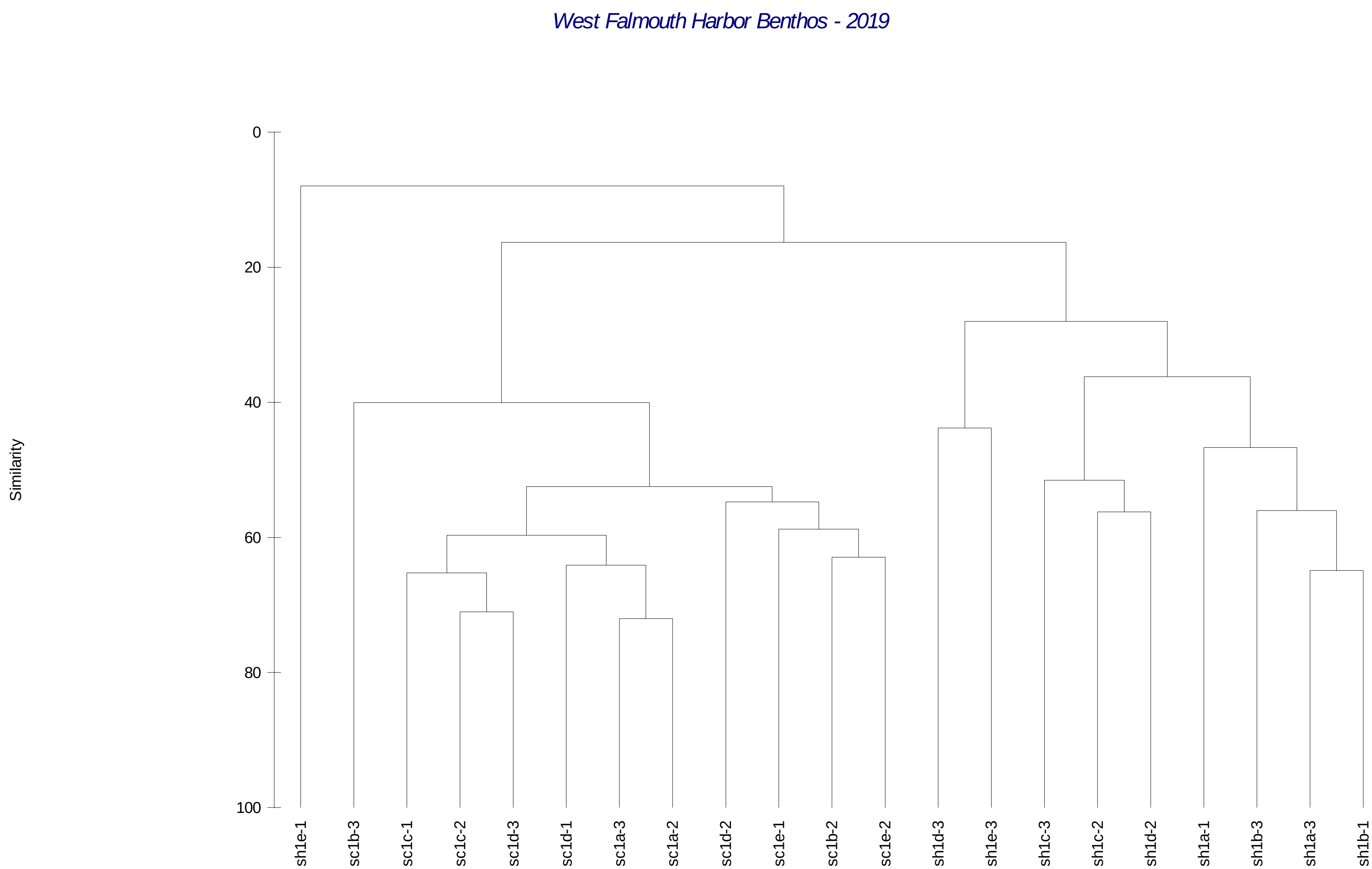


Figure 18. Cluster diagram of benthic samples from South Basin (SC1A, B, C, D, E) and Snug Harbor SH1A, B, C, D, E) in the West Falmouth Harbor.

3.7 US M-AMBI

US M-AMBI results indicate that the benthic community along the South Basin ranges from poor to good (Table 7 and Figure 19). Overall, the benthic habitat along the South Basin transect is Moderate, with a mean US M-AMBI score of 0.39. The US M-AMBI scores were variable, with no discernable pattern running from west to east (SC1A to SC1E). The benthic habitat along the Snug Harbor transect is rated Poor, with a mean score of 0.37. Interestingly, the relative health of the benthic habitat appears to decrease from north to south along the Snug Harbor transect (SH1A to SH1E), with the exception of replicate SH1A-1 which is ranked as Poor. The healthiest replicate of the transect (SH1A-3) is ranked as Good (although on the low end of Good), then as the transect progresses southward the habitat quality decreases from Moderate to Poor, and finally to Bad with the southern-most sample and replicate (SH1E-1). This sample is located to the east of a small spit of land within the harbor. According to the field crew this sample texture was distinctly different than the other samples in the transect, and consisted of very deep, soft, silty sediment. The field supervisor noted that this location, tucked in behind the spit of land appeared to have less access to the tidal flushing, or was perhaps in an eddy which may have increased the level of siltation.

The mean US M-AMBI score was correlated to the percent silt in West Falmouth Harbor ($r = -0.641$, $p = 0.046$). However, ten pairs are a very small sample size, and results should be considered with caution.

Table 7. US M-AMBI score and category for West Falmouth benthic samples.

Transect	Sample-replicate	BI	S	H1	US M-AMBI score	US M-AMBI category
South Basin	SC1A-3	4.15	21	1.764	0.499	Moderate
	SC1A-2	3.82	11	1.145	0.34	Poor
	SC1B-2	5.43	11	0.8322	0.233	Poor
	SC1B-3	4.37	8	1.593	0.354	Poor
	SC1C-1	3.84	25	2.134	0.597	Good
	SC1C-2	4.6	13	1.421	0.364	Poor
	SC1D-2	4.53	15	1.499	0.395	Moderate
	SC1D-1	5.22	15	0.8283	0.275	Poor
	SC1D-3	4.28	17	1.723	0.453	Moderate
	SC1E-1	4.45	20	1.59	0.454	Moderate
	SC1E-2	4.92	17	1.312	0.371	Poor
Snug Harbor	SH1A-1	3.55	11	1.292	0.372	Poor
	SH1A-3	2.5	20	1.709	0.549	Good
	SH1B-3	2.47	14	1.519	0.472	Moderate
	SH1B-1	2.34	13	1.456	0.46	Moderate
	SH1C-3	2.06	11	1.568	0.47	Moderate
	SH1C-2	2.43	10	1.571	0.447	Moderate
	SH1D-2	2.31	5	1.13	0.347	Poor
	SH1D-3	1.67	4	1.003	0.347	Poor
	SH1E-3	1.61	3	0.656	0.293	Poor
	SH1E-1	6	1	0	0.009	Bad

BI = Calculated Biological Index (see methods section), S = number of individuals, H1 = Shannon-Wiener diversity index

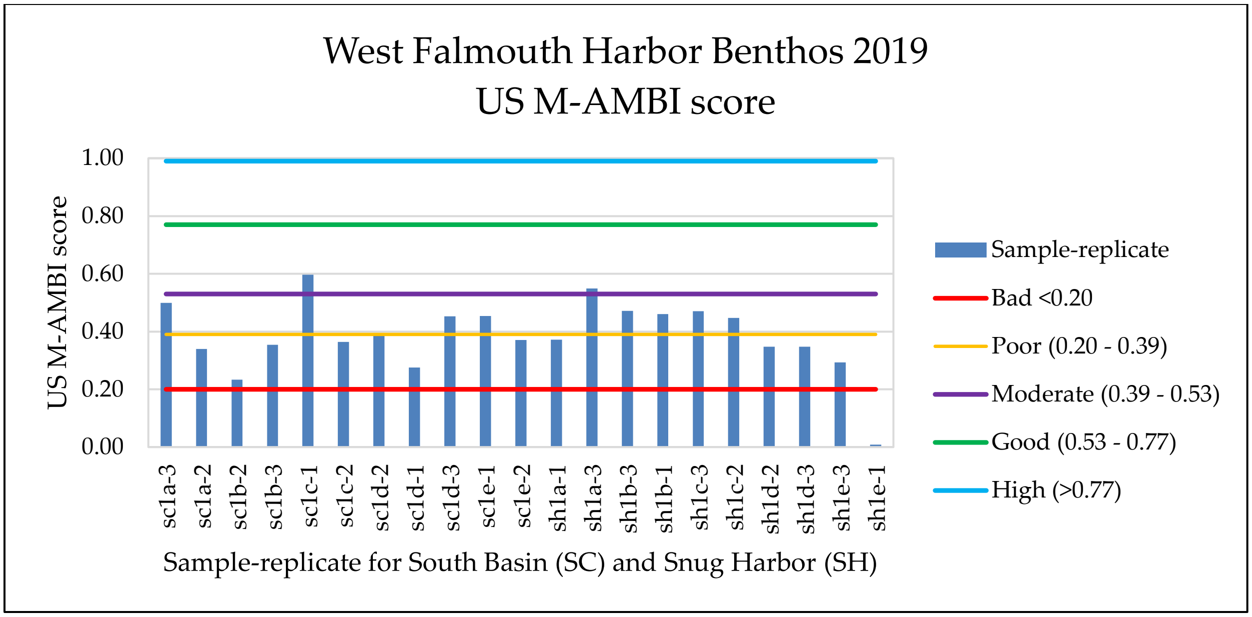


Figure 19. US M-AMBI scores for the South Basin and Snug Harbor transects in West Falmouth Harbor, 2019.

3.8 Comparison with Previous Assessment

Improvements in three of the six sub-embayments in West Falmouth Harbor were detected in 2019 (Table 8). In 2003, the Outer Basin and Station 12 in the Mid Basin were classified as "Healthy/Moderately Impaired". In 2019, these stations were classified as "Healthy", although no benthic samples were collected, based on the presence of eelgrass (Table 8). Similarly, Station 11 in the Mid-basin was previously classified as "Moderately/Severely Impaired" and in 2019 was classified as "Healthy" due to the presence of eelgrass. In 2003, the Harbor Head sub-embayment was classified as "Severely Impaired" and dominated by stress indicator species. The infaunal habitat in this sub-embayment appeared to be "significantly impaired" by organic matter enrichment stemming from nitrogen overloading (Howes et al. 2006). The 2019 assessment found eelgrass present in this sub-embayment. These three sub-embayments were classified as "Healthy" in 2019 because eelgrass beds have re-established. Eelgrass is considered a sentinel species for indicating nitrogen loading in coastal embayments. Changes in eelgrass distribution over time provide a strong basis for evaluating increases or decreases in water quality and nutrient enrichment (Dennison et al. 1993, Short et al. 1995, Howes et al. 2003). Eelgrass provides several ecological functions including shelter and food for a variety of commercial, recreational, and ecologically important organisms, and sediment stabilization (Laney 1997, Thayer et al. 1997). The presence of eelgrass in these areas indicates improvement of the benthic habitat.

Infaunal health classifications for the South Basin and Snug Harbor sub-embayments did not change, although the number of species and individuals increased substantially (Table 8). From 2003 to 2019 the number of species increased 4.2 times in the South Basin, and the number of individuals increased by a factor of 11.6. In Snug Harbor, the number of species increased by a factor of 2.6 and the number of individuals was 5 times higher in 2019 than in 2003.

The last sub-embayment, Oyster Pond, was classified as “Severely Impaired” in 2003. Oyster Pond, a drown kettle pond attached to the harbor only by a small channel with tidal flow, was found not to support benthic infaunal habitat throughout most of the basin. At all 3 sampling sites, less than 10 individuals per sample were collected (Howes et al. 2006). Oyster Pond could not be assessed in 2019 as result the current classification of this embayment cannot be determined.

Howes et al. (2006) designated a sentinel station for the West Falmouth Harbor system located along the Snug Harbor transect near Stations SH1C and SH1D (see white square in Figure 2). Sentinel stations are defined as those stations that once improved, would indicate similar improvement among the other sub-embayments within a system. According to the nitrogen loading model the sentinel station is an indicator for the status of the whole harbor system. In other words if the benthic habitat at the sentinel station is recovered (i.e. with eelgrass beds re-established), then the rest of the harbor would also be recovered. Although the overall 2019 infaunal health status in Snug Harbor was classified as poor, the infaunal habitat along the transect is patchy, with one of the ten samples classified as “bad”, four as “poor”, four as “moderate”, and one as “good”. Data are not available to know if the locations currently classified as moderate and good (SH1A, SH1B, and SH1C) were classified the same or as more impaired in 2003. However, these classifications can be used as the baseline for comparisons to future surveys.

Table 8. Comparison of West Falmouth benthic health indicators in 2003 and 2019.

		2003 Assessment (Howes et al. 2006)			2019 Assessment		
Sub-Embayment	Survey Station (replicates)	Total Number of Species	Total Number of Individuals	Infaunal Indicator	Total Number of Species	Total Number of Individuals	Infaunal Indicator
Outer Basin	13 (A,B)	10	951	H/MI	NS	NS	H[2]
Mid Basin	11 (A,B)	21	495	MI/SI[1]	NS	NS	H[2]
	12 (A,B)	14	1314	H/MI	NS	NS	H[2]
Snug Harbor	SH (A,B,C,D,E)	13	258	SI[1]	34	1290	SI/P[3]
South Basin	SC (A,B,C,D,E)	11	241	MI	46	2787	MI/M[4]
Harbor Head	HH (A,B,C)	11	405	SI[1]	NS	NS	H[2]
Oyster Pond	OP (1,2,3)	2	3	SI[1]	-	-	-

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 and values are averages of grab samples a-c).
H = Healthy habitat conditions; MI = Moderate Impairment; SI = Significant Impairment
NS = Not sampled in 2019 due to presence of eelgrass
[1]Capitellids or Spionids (stress indicators) dominant
[2]Healthy characterization based on presence of eelgrass
[3]SI/P SI =Severely Impaired using Howes et al. 2006 category, P = poor using US M-AMBI category
[4]MI/M MI = Moderately Impaired using Howes et al. 2006 category, M = Moderate using US M-AMBI category.

4 Recommendations

The MEP Marine Benthic Monitoring Pilot Field Study is being conducted to test the approaches and procedures described in the new draft guidance documents. Overall, the Pilot Field Study conducted in West Falmouth Harbor demonstrated that the new draft guidance documents will successfully provide guidance to parties outside of MassDEP and produce quality benthic data that

1) assess current embayment health, 2) are comparable between assessments, and 3) will aid in future management decisions. Recommendations for future sampling in West Falmouth Harbor are presented below, and minor recommended revisions to the draft guidance documents are presented in Appendix B.

Recommendations for future sampling in West Falmouth Harbor include:

1. A reduction in the number of sampling locations in Snug Harbor (Stations SH1A-SH1E) and South Basin (Stations SC1A- SC1E) to a maximum of three stations along each transect (e.g., beginning, middle and end). The locations identified for and sampled during the 2019 Pilot Field Study were based on the benthic infaunal sampling stations established by Howes et al. (2006). The stations in Snug Harbor and South Basin were conducted in transects in 2003, therefore there is considerable overlap of the 30 meter target location radius for each station. Due to their proximity, reducing the number of stations in these areas will maintain data quality while reducing sampling redundancy.
2. Future Oyster Pond reassessments should use an alternative method to a motorized boat to access this sub-embayment. The construction of the bike path prevents boat access from the harbor head due a culvert and there are no boat ramps in this small sub-embayment. The alternative access method most likely will prevent the use of a 0.04-m^2 Ted Young-modified Van Veen grab, as a result an alternative benthic sampler should also be considered if benthic samples are desired.
3. Lastly, program and assessment objectives change over time, the sampling locations in West Falmouth Harbor should be re-evaluated to ensure that they continue to meet program study design and objectives.

5 Summary

The presence of eelgrass at three of the six sub-embayments within West Falmouth Harbor indicates that the harbor has become more productive and biologically diverse (Homziak et al. 1982) over the past 16 years. No information is available regarding the current status of the Oyster Pond sub-embayment because the embayment cannot be accessed by boat due to the construction of a culvert since the sampling in 2003. The benthic habitats in the two sub-embayments in which benthic sampling occurred, have not substantially changed over the same time period. The benthic habitat in the South Basin remains moderately impaired and the Snug Harbor habitat currently classified as poor has not changed since 2003 when it was classified as “significantly impaired”. Although both of these sub-embayments have been classified as impaired, there are indications that at least some areas within each sub-embayment have improved over the past 16 years. The number of species in the South Basin was 4.2 times higher than in 2003 and the number of individuals increased by a factor of 11.6, and in Snug Harbor the number of species was 2.6 times higher and the number of individuals increased by a factor of 5 in 2019 compared to 2003. The Pilot Field Study conducted in West Falmouth Harbor demonstrated that the new draft MEP Marine Benthic Monitoring guidance documents will successfully provide guidance to parties outside of MassDEP and produce quality benthic data that 1) assess current embayment health, 2) are comparable between assessments, and 3) will assist in future management decisions.

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Appendix A. Benthic infaunal densities (organisms per m^2) in the South Basin and Snug Harbor sub-embayment in West Falmouth Harbor, 2019.

	South Basin										
	sc1a-3	sc1a-2	sc1b-2	sc1b-3	sc1c-1	sc1c-2	sc1d-2	sc1d-1	sc1d-3	sc1e-1	sc1e-2
Alitta succinea	50	25	25	0	200	125	75	0	25	325	25
Ampelisca abdita	2,325	4,675	175	225	1,500	1,300	75	1,975	875	125	0
Anadara transversa	0	0	0	0	25	0	25	0	25	50	0
Astyris lunata	75	0	0	0	25	0	0	0	0	50	25
Balanidae	0	0	0	25	0	0	0	0	0	0	0
Bivalvia	0	0	0	0	25	0	0	25	0	0	0
Boonea seminuda	125	0	0	0	475	0	0	0	125	250	50
Capitella capitata	3,425	1,825	2,750	525	4,025	4,075	1,975	8,100	2,875	3,725	3,175
Chaetozone setosa	0	0	0	0	0	0	0	0	0	0	0
Credpidula plana	0	0	0	0	25	0	0	0	0	25	0
Crepidula fornicata	25	0	50	100	1,225	75	750	0	300	225	400
Cyathura polita	25	0	0	0	0	0	0	0	0	0	0
Cymadusa compta	200	0	0	0	0	0	0	0	0	50	0
Dyspanopeus sayi	25	0	0	25	50	25	50	0	0	25	75
Eumida sanguinea	0	0	25	0	75	0	0	0	0	0	50
Exogone dispar	0	0	0	0	0	0	0	0	25	0	0
Gammaridae	0	0	0	0	0	0	0	0	0	0	0
Gastropoda	0	0	0	0	0	0	0	0	0	0	0
Gammarus mucronatus	0	0	0	0	0	0	0	0	0	0	0
Gemma gemma	0	0	0	0	0	0	0	0	0	0	0
Glycera dibranchiata	0	0	0	0	0	0	0	0	0	0	0
Glycera americana	25	0	0	0	25	0	0	50	0	0	0
Glycinde solitaria	0	0	0	0	0	0	0	0	0	0	0
Grandidierella japonica	1,025	225	125	0	1,400	950	100	200	875	50	50
Heteromastus filiformis	175	150	0	125	50	150	0	25	25	0	50
Hypereteone heteropoda	25	25	0	0	0	25	25	0	0	0	0
Jassa falcata	0	0	0	0	0	0	0	0	0	0	0
Leptochelia rapax	0	0	0	0	775	0	0	0	0	50	0
Leucon americanus	25	0	0	0	25	75	75	25	50	0	0
Lysianopsis alba	0	0	0	0	0	0	50	0	0	0	0
Macoploma tenta	75	0	0	0	0	0	0	0	0	0	0
Mercenaria mercinaria	0	0	0	0	0	0	0	0	0	0	0
Microdeutopus gryllotalpa	0	0	0	0	325	0	150	0	350	0	75
Microphthalmus sczelkowii	0	0	0	0	0	0	0	0	0	0	0
Monocorophium insidiosum	0	0	0	0	50	0	0	0	0	0	0
Mya arenaria	0	0	0	0	0	0	0	0	0	0	0
Nemertea (phylum)	0	0	0	0	50	0	0	0	0	0	0
Notomastus latericeus	0	0	0	0	0	0	0	0	0	0	0
Oligochaeta (subclass)	0	0	0	0	0	0	0	0	0	250	0
Oxydromus obscurus	0	0	0	0	0	0	0	0	0	0	75
Pagurus longicarpus	0	0	0	0	0	25	0	0	0	0	0
Palaemon pugio	50	0	0	0	0	0	0	0	0	75	0
Parapionosyllis longicirrata	0	0	0	0	0	0	0	0	0	0	0
Paratanaidae	0	0	0	0	0	0	25	0	0	0	0
Pectinaria gouldii	25	25	25	0	50	0	0	25	25	50	25
Phyllodoce arenae	0	0	0	0	0	0	25	25	0	25	0
Pinnixa sp.	0	0	0	0	0	0	0	0	25	0	25
Pista elongata	0	0	0	25	0	0	0	0	0	25	0
Polydora cornuta	175	150	50	100	650	75	50	75	125	350	225
Prionospio sp.	0	0	0	0	0	0	0	0	25	0	0
Prionospio heterobranchia	25	25	0	0	25	0	0	25	0	0	175
Ptilohyale plumulosus	0	0	25	0	0	0	0	0	25	25	25
Retusa obtusa	0	0	0	0	0	0	0	0	0	0	0
Salvatoria clavata	0	0	0	0	25	0	0	0	0	0	0
Scoletoma tenuis	0	0	0	0	0	0	0	25	0	0	0
Scoloplos robustus	25	25	25	0	200	325	0	100	175	125	25
Streblospio benedicti	550	375	75	0	0	0	0	25	0	0	0
Syllidae	0	0	0	0	0	0	0	25	0	0	0
Tellina sp.	0	0	0	0	0	50	0	0	0	0	0
Tellinidae	0	0	0	0	0	0	0	0	0	0	0
Terebellidae	0	0	0	0	25	0	25	0	0	0	0
Tritia obsoleta	0	0	0	0	0	0	0	0	0	0	0

Appendix A. Continued.

	Snug Harbor									
	sh1a-1	sh1a-3	sh1b-3	sh1b-1	sh1c-3	sh1c-2	sh1d-2	sh1d-3	sh1e-3	sh1e-1
Alitta succinea	0	0	25	0	25	25	25	0	0	0
Ampelisca abdita	0	50	50	0	0	50	0	0	0	0
Anadara transversa	0	0	0	0	0	0	0	0	0	0
Astyris lunata	0	0	0	0	0	0	0	0	0	0
Balanidae	0	0	0	0	25	0	0	0	0	0
Bivalvia	25	75	0	75	0	0	0	0	0	0
Boonea seminuda	0	0	0	0	0	0	0	0	0	0
Capitella capitata	25	50	50	50	0	50	50	0	0	75
Chaetozone setosa	0	25	0	0	0	0	0	0	0	0
Credpidula plana	0	0	0	0	0	0	0	0	0	0
Crepidula fornicata	0	0	0	0	25	0	0	0	0	0
Cyathura polita	0	0	0	0	0	0	0	0	0	0
Cymadusa compta	0	0	0	0	0	0	0	0	0	0
Dyspanopeus sayi	0	25	0	0	0	0	0	0	0	0
Eumida sanguinea	0	25	0	0	0	0	0	0	0	0
Exogone dispar	0	0	0	0	0	0	0	0	0	0
Gammaridae	0	25	0	0	0	25	0	0	0	0
Gastropoda	0	0	0	25	0	0	0	0	0	0
Gammarus mucronatus	25	0	0	0	0	0	0	0	0	0
Gemma gemma	0	625	50	125	0	0	0	0	25	0
Glycera dibranchiata	25	0	0	0	0	0	0	0	0	0
Glycera americana	0	0	0	0	0	0	0	0	0	0
Glycinde solitaria	0	0	25	0	0	0	0	0	0	0
Grandidierella japonica	0	0	0	0	0	0	0	0	0	0
Heteromastus filiformis	1,125	3,700	400	2,100	50	75	0	0	0	0
Hypereteone heteropoda	0	25	0	0	0	0	0	0	0	0
Jassa falcata	0	25	0	0	0	0	0	0	0	0
Leptochelia rapax	0	0	0	0	0	0	0	0	0	0
Leucon americanus	0	0	0	0	0	0	0	0	0	0
Lysianopsis alba	0	0	0	0	0	0	0	0	0	0
Macoploma tenta	0	0	50	0	0	0	0	0	0	0
Mercenaria mercinaria	0	0	0	25	25	0	0	0	0	0
Microdeutopus gryllotalpa	0	0	0	0	0	0	0	0	0	0
Microphthalmus sczelkowii	25	425	25	0	0	0	0	0	0	0
Monocorophium insidiosum	0	0	0	0	0	0	0	0	0	0
Mya arenaria	0	0	0	25	0	0	0	0	0	0
Nemertea (phylum)	0	0	0	0	0	0	100	0	0	0
Notomastus latericeus	0	0	0	0	25	0	0	0	0	0
Oligochaeta (subclass)	75	550	25	425	0	25	0	25	0	0
Oxydromus obscurus	0	0	0	0	0	0	0	0	0	0
Pagurus longicarpus	0	0	0	0	0	0	0	0	0	0
Palaemon pugio	0	25	0	0	0	0	0	0	0	0
Parapionosyllis longicirrata	0	525	0	125	0	0	0	0	0	0
Paratanaidae	0	0	0	0	0	0	0	0	0	0
Pectinaria gouldii	0	0	0	0	0	0	0	0	0	0
Phyllodoce arenae	0	0	0	0	0	0	0	0	0	0
Pinnixa sp.	0	0	0	0	0	0	0	0	0	0
Pista elongata	0	0	0	0	0	0	0	0	0	0
Polydora cornuta	0	0	0	0	0	25	0	0	50	0
Prionospio sp.	0	0	0	0	0	0	0	0	0	0
Prionospio heterobranchia	0	25	25	125	0	0	0	0	0	0
Ptilohyale plumulosus	0	0	0	0	0	0	0	0	0	0
Retusa obtusa	0	0	0	0	25	0	0	0	0	0
Salvatoria clavata	0	0	0	0	0	0	0	0	0	0
Scoletoma tenuis	75	75	275	1,150	75	0	0	25	0	0
Scoloplos robustus	225	3,800	1,975	6,725	575	600	575	150	275	0
Streblospio benedicti	50	200	700	1,600	125	50	225	25	0	0
Syllidae	0	0	0	0	0	0	0	0	0	0
Tellina sp.	0	0	0	0	0	0	0	0	0	0
Tellinidae	0	0	0	0	25	0	0	0	0	0
Terebellidae	0	0	0	0	0	0	0	0	0	0
Tritia obsoleta	25	125	25	0	0	325	0	0	0	0

Appendix B. Recommended revisions to the draft guidance documents.

The MEP Marine Benthic Monitoring Pilot Field Study is being conducted to test the approaches and procedures described in the new draft guidance documents. Overall, the Pilot Field Study conducted in West Falmouth Harbor demonstrated that the new draft guidance documents will successfully provide guidance to parties outside of MassDEP and produce quality benthic data that 1) assess current embayment health, 2) are comparable between assessments, and 3) will assist in future management decisions. Below are several recommended revisions to the draft guidance documents to provide greater direction to the field crew and laboratory technicians, clarify procedures, and improve data quality.

The following revisions to survey planning and field procedures are recommended for the draft MEP Marine Benthic Monitoring Quality Assurance Project Plan (QAPP) and Field Standard Operating Procedure (SOP):

1. The addition of an access review for previously assessed embayments as part of the survey preparation to identify changes in access to small or narrow sub-embayments, and a site evaluation for unassessed embayments to ensure sampling locations and alternative locations meet the target population identified in the selected GRTS (Generalized Random Tessellated [grid] Stratified) survey design. In the Pilot Field Study, the Oyster Pond sub-embayment was no longer accessible from the harbor head due to the extension of the Shining Sea Bikeway to North Falmouth in 2009 which prevented the sampling of three stations within this area. An access review would provide an opportunity to identify any problems with access before sampling and allow for discussion with MassDEP, the Town, or teaming partner to determine the importance of the stations in the area and possible alternative locations. The addition of a site evaluation for unassessed embayments would provide initial verification of site suitability and further align the MEP benthic monitoring protocols with the National Coastal Condition Assessment and Massachusetts Coastal Condition Assessment programs. It is recommended that both the access review and the site evaluation be conducted through a desktop evaluation to help minimize costs.
2. The draft Field SOP and QAPP should be revised to state that the chief scientist must notify the project manager and MassDEP, Town or teaming partner before any unanticipated changes to the survey sampling occur. In the Pilot Field Study, the chief scientist conducted the underwater image collections at the three Harbor Head stations in a single transect due to the presence of eelgrass, the close proximity of the stations (overlap of the 30 m target location radius), and the desire to provide more widespread imaging of the eelgrass bed. As a result, stations with soft bottom and eelgrass beds were imaged differently reducing the comparability of the video recordings, the latitude and longitude coordinates of the video and still imaging at two of the stations were not recorded in the field datasheets, and the images contained no identification that multiple stations were recorded. The addition of a notification requirement will reinforce that the survey should be conducted as stated in the Survey Plan and the selected procedures from the Field SOP unless there is a compelling reason for modification. The notification will also facilitate a brief discussion between the chief scientist, project manager, and MassDEP, the Town, or teaming partner which will help ensure that possible consequences in data collection and data quality are considered.

3. Field datasheets should be revised and consolidated to help prevent unnecessary data duplication, missing data, and incomplete forms. In the Pilot Field Study, individual datasheets were developed for the different types of samples collected to demonstrate and evaluate the use of the individual sampling procedures. As the survey was comprised of multiple procedures this produced a cumbersome number of datasheets for each station, unnecessary and inconsistent data duplication, and incomplete datasheets at some stations. It is recommended that sectional templates be developed for general survey information and each procedure in the Field SOP. Each template should contain the necessary data cells for that procedure. The templates for the protocols selected for a specific study would then be copied and pasted into a final survey datasheet/s that would be presented in the Embayment Specific Survey Plan. The use of pre-developed sectional templates would create consistent datasheets between assessments and users while allowing field datasheets to be tailored to an individual study.
4. Section IV Field Standard Operating Procedures for Underwater Still Images and/or Video in the draft Field SOP and the corresponding Sections B2.2.2 and B2.2.5 in the draft QAPP should be revised to include text that states in-field video or still image review should occur in a shaded or darkened area to help improve screen visibility and reduce glare from sunlight. Additional text recommending the optional use of a computer monitor or large screen should also be included.
5. Section IV Field Standard Operating Procedures for Underwater Still Images and/or Video in the draft Field SOP and the corresponding Sections B2.2.2 and B2.2.5 in the draft QAPP should be revised to include text that states camera lenses should be checked for debris and water droplets and carefully cleaned using a soft absorbent cloth after each time the water proof case is opened to replace batteries or download images.
6. The draft Field SOP should be revised to update the text in Section III Field Standard Operating Procedures for Soft-Bottom Infaunal and Sediment Sampling, subsection 2.0 Gear Deployment, the beginning of the second paragraph to read: *Once the survey vessel is on station and coordinates have been verified, the water quality and underwater video surveys will be performed (see Sections II and IV). Once these surveys have been completed, the sediment grab will be deployed*. The beginning of second paragraph of Section B2.2.3 in the draft QAPP should also be revised to reflect this change.

The following revisions to laboratory analysis and data management procedures are recommended for the draft MEP Marine Benthic Monitoring QAPP and Laboratory SOP:

1. The draft QAPP and Laboratory SOP should be revised to include 50 mL subsamples of the sediment collected for grain size analysis. In the Pilot Field Study, a sediment grain size sample was analyzed using the complete sediment sample (500 mL) as described in the draft guidance documents. The sample failed to dry completely in the drying oven following the procedure described in draft Laboratory SOP. The remaining sediment samples were subsampled at 50 mL and dried completely following the draft procedures.
2. The draft Laboratory SOP should be revised to update the text in Section II: Laboratory Standard Operating Procedures for Benthic Macrofauna Samples, subsection 4.0 Sample Preparation – Sorting, step 2 to read: *Carefully decant the reagent alcohol from the sample container by pouring the fluid through a 0.5 mm or 1.0 mm sieve (selected based on the sample type, benthic infaunal or hard-bottom/riprap destructive, being sorted) into a*

separate container. Gently rinse the sample with tap water using the spray nozzle being careful to use a low-volume spray so the organisms will not be damaged. Rinse sample until residual water coming through the sieve is clean. Using the spray, carefully direct the sample contents into a beaker being sure that all organisms have been removed from the sieve.

3. The draft Laboratory SOP should be revised to update the text to include a new step in Section II: Laboratory Standard Operating Procedures for Benthic Macrofauna Samples, subsection 5.0 Taxonomic Identification between steps 7 and 8. The new step should read: *Save one specimen from each taxa in a labeled vial with 70% reagent alcohol for the reference collection. The label should include: lowest possible taxonomic level of the organism, embayment collected from, station collected from, and date of collection.*

4. The use of Average Taxonomic Distinctness (ATD, delta +) versus Total Taxonomic Distinctness (TTD) should be reconsidered and the draft QAPP and Laboratory SOP documents updated to reflect the final selection. ATD is the average 'distance apart' of any two species or individuals chosen at random from the sample. TTD is the average taxonomic distance from species *i* to every other species, summed over all species in the sample. ATD was calculated for the 2019 West Falmouth Harbor study after communications with PRIMER-e which indicated that it was the preferred measure. The two measures are similar but provide slightly different information and have different advantages and limitations. These differences should be re-evaluated along with the prevalence of measure use by other researchers.

5. The draft QAPP and Laboratory SOP should be revised to include a statement that it is recommended prior to the calculation of US M-AMBI that the laboratory or researcher contact the first author of Pelletier et al. (2018), Marguerite C. Pelletier, Ph.D. at US EPA, Atlantic Coastal Environmental Sciences Division (ACESD) Laboratory, Narragansett, RI.

6. The data codes in Tables 25, 26, 27, 28, 29, 30, 31, 32, and 33 of the draft QAPP and the corresponding tables in the draft Laboratory SOP should be revised to include EVENT_ID. EVENT_ID identifies individual surveys in a database that contains data for multiple survey years and embayments.

7. The data codes in Tables 26, 27, 28, and 29 of the draft QAPP and the corresponding tables in the draft Laboratory SOP should be revised to replace SAMPLE_NUMBER that has a numeric format to SAMPLE_ID that has a character format to allow the use of alphanumeric sample identifiers. This will accommodate the use of existing alphanumeric MEP sampling locations (e.g., SH1E) as part of individual sample identifiers. For example, in the Pilot Field Study a sediment sample for grain size analysis (GS) was identified as a combination of the sampling location, the grab number, and the sediment analysis (e.g., SAMPLE_ID = SH1E-4-GS).

8. The draft QAPP and Laboratory SOP should be revised to include sediment grain size data codes. Recommended data codes are presented below:

Sediment grain size result data codes.

Field	Format	Description
YEAR	Numeric	Survey year
EVENT_ID	Character	Identifier of sampling event (survey)
SITE_ID	Character	Site identification code as used on sample label

Field	Format	Description
SAMPLE_ID	Character	Sample identifier as used on chain of custody form (on sample label)
PCT_GRAVEL	Numeric	Percentage of gravel
PCT_VC_SAND	Numeric	Percentage of very coarse sand
PCT_C_SAND	Numeric	Percentage of coarse sand
PCT_M_SAND	Numeric	Percentage of medium sand
PCT_F_SAND	Numeric	Percentage of fine sand
PCT_VF_SAND	Numeric	Percentage of very fine sand
PCT_SILT	Numeric	Percentage of silt

9. The draft QAPP and Laboratory SOP should be revised to include benthic community parameter data codes. Recommended data codes are presented below:

Benthic community parameter data codes.

Field	Format	Description
EVENT_ID	Character	Identifier of sampling event (survey)
SITE_ID	Character	Site identification code as used on sample label
SAMPLE_ID	Character	Sample identifier as used on chain of custody form (on sample label)
SPECIES_ COUNT	Numeric	The number of species in a sample
NUMBER_IND_M2	Numeric	Total number of individuals per square meter of bottom
D_RICHNESS	Numeric	Margalef's diversity index value
H'_DIVERSITY	Numeric	Shannon-Wiener diversity index value
J'_EVENNESS	Numeric	Pielou's evenness value
1-λ_SIMPSON	Numeric	Simpson diversity value
DELTA+	Numeric	Average taxonomic distinctness value
BI	Numeric	Biological index
US_M_AMBI	Numeric	Multivariate AZTI Marine Biotic Index in US coastal waters
CATEGORY	Character	US M-AMBI health condition category