2023 Outfall Benthic Monitoring Results

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2023 Outfall Benthic Monitoring Results

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EXECUTIVE SUMMARY

Background. The Massachusetts Water Resources Authority (MWRA) operates the Deer Island Wastewater Treatment Plant, where sewage from more than 40 communities in Greater Boston undergoes primary and secondary treatment followed by disinfection. Following treatment, the effluent is discharged to Massachusetts Bay more than 5 miles (8 km) from the nearest shoreline. Massachusetts Bay has been the site of the effluent discharge since 2000, when MWRA moved the Deer Island discharge from Boston Harbor as part of the Boston Harbor Project to alleviate harbor pollution. MWRA has gathered environmental data in the bay since 1992 to evaluate the potential effects of the discharge.

MWRA is required to monitor the benthos (seafloor community) in Massachusetts Bay. The MWRA discharge permit requires benthic monitoring to detect any effects of the effluent on the ocean environment. The monitoring focuses on three main concerns: (1) eutrophication (excess organic material and nutrients) and related low levels of dissolved oxygen; (2) deposits of toxic contaminants; and (3) smothering of animals by sewage effluent solids, or other changes to benthic communities. MWRA measures levels of total organic carbon to assess whether effluent discharge has resulted in organic enrichment; tracks areas of possible contamination based on levels of a sewage indicator bacterium, *Clostridium perfringens*; and reports on benthic animal abundance and diversity. As animal communities vary naturally across different benthic habitats, monitoring is designed to detect changes in habitat that can be associated with sediment grain size. Within the context of natural variation, potential outfall impacts can then be assessed.

Benthic habitat quality has remained high near the outfall. The discharge is located in an area dominated by hydrodynamic and physical factors, including tidal and storm currents, turbulence, and sediment transport (Butman et al. 2008). These physical factors, combined with the high quality of the effluent discharged into the Bay (Taylor 2010, Werme et al. 2021), are the principal reasons that benthic habitat quality has remained high near the outfall. MWRA's discharge permit includes a Contingency Plan which sets out caution and warning threshold levels of key indicators including the diversity of benthic animals. There were no exceedances of these thresholds for any infaunal (soft-sediment) community in 2023. Data on these macrobenthic (larger than 0.3 mm) animals continue to suggest that the communities near the outfall remain healthy and diverse. Hard-bottom benthic communities near the outfall have not changed substantially during the post-diversion period. Some modest changes in hard-bottom communities (e.g., coralline algae, upright algae cover, sponge abundance, and barnacle settlement events) have been observed; nonetheless, factors driving these changes are unclear and may reflect natural cycles, interspecific competition, or other shifts in the environment. In addition, years of monitoring have shown that solids from the wastewater discharge do not reach levels that disturb or smother animals near the outfall.

The effluent discharge has not degraded sediment conditions. Sediment grain size and total organic carbon have remained generally consistent over time, with relatively small year-to-year changes. Results in 2023 were consistent with this historical pattern for these parameters (Nestler et al. 2024, Maciolek et al. 2008). Concentrations of the sewage tracer, *Clostridium perfringens*, decreased to levels comparable to other post-diversion years in all areas of the Bay in 2023, after sharp increases in 2022. *Clostridium perfringens* counts were highest at three stations located within two kilometers from the discharge. This spatial pattern has remained consistent since outfall relocation to the Bay in 2000 (e.g., Nestler and Madray 2023, Maciolek et al. 2007, 2008). These results provide evidence that effluent solids have settled at sites within about 2 km (1.25 miles) of the outfall, however there is no indication that the wastewater discharge has resulted in organic enrichment or changes to the sediment grain size composition near the outfall.

1 INTRODUCTION

Under its Ambient Monitoring Plan (MWRA 1991, 1997, 2001, 2004, 2010, 2021) the MWRA has collected extensive information over a nine-year “baseline” period (1992–2000) and a twenty-three-year “post-diversion” period (2001–2023) after the wastewater discharge was moved to Massachusetts Bay. Data are from surveys of sediments and soft-bottom communities using traditional grab sampling and sediment profile imaging (SPI; 1992–2019) as well as surveys of hard-bottom communities using a remotely operated vehicle (ROV). The SPI survey and the sediment contaminant evaluation in Massachusetts Bay were discontinued in 2020, as these studies had answered their monitoring questions fully. Data collected by this program provide a basis to explain any changes in benthic conditions and the question of whether MWRA’s discharge has contributed to any such changes.

Benthic monitoring during 2023 was conducted following the current Ambient Monitoring Plan (MWRA 2021), which is required under MWRA’s effluent discharge permit for the Deer Island Treatment Plant. Under this current plan, monitoring includes annual soft-bottom sampling for sediment conditions and infauna at 10 nearfield (NF) and 4 farfield (FF) stations, and hard-bottom surveys every three years at 23 stations. Nearfield stations are located within five kilometers (km) from the offshore outfall. The nearfield area is in close proximity to the wastewater discharge, where impacts to benthos could potentially be measured. Farfield stations are all more than 13 km from the outfall, with Stations FF01A and FF04 both over 20 km away. Stations located in the farfield area are presumably beyond the influence of the wastewater discharge. Changes detected in both nearfield and farfield areas are expected to represent large-scale, region-wide trends, unrelated to the wastewater discharge. The hard-bottom survey was conducted in 2023.

This report summarizes key findings from the 2023 benthic surveys, with a focus on the most noteworthy observations relevant to understanding the potential effects of the discharge on the offshore benthic environment.

2 METHODS

Methods used to collect, analyze, and evaluate all sample types remain largely consistent with those reported for previous monitoring years (Rutecki et al. 2022, Maciolek et al. 2008). Detailed descriptions of the methods are contained in the Quality Assurance Project Plan (QAPP) for Benthic Monitoring 2020–2023 (Rutecki et al. 2020). A brief overview of methods, focused on information that is not included in the QAPP, is provided in Sections 2.1 to 2.3.

2.1 FIELD METHODS

Sediment and infauna sampling was conducted at 14 stations on August 7, 2023 (Figure 2-1). To aid in analyses of potential spatial patterns reported herein, these stations are grouped, based on distance from the discharge, into four "monitoring areas" within Massachusetts Bay[1]:

- Nearfield stations NF13, NF14, NF17, and NF24 are located in close proximity (less than 2 km) to the offshore outfall.
- Nearfield stations NF04, NF10, NF12, NF20, NF21, and NF22 are located farther than 2 km and less than 5 km from the offshore outfall.
- Transition station FF12 is located between Boston Harbor and the offshore outfall (just under 8 km from the offshore outfall).
- Farfield reference stations FF01A, FF04, and FF09 are located in Massachusetts Bay but farther than 13 km from the offshore outfall.

Sampling effort at these stations has varied somewhat during the monitoring program. In particular, from 2004-2010 some stations were sampled only during even years (NF22, FF04 and FF09), Stations NF17 and NF12 were sampled each year, and the remaining stations were sampled only during odd years. Sampling at Station FF04 within the Stellwagen Bank National Marine Sanctuary was conducted in accordance with Research Permit SBNMS-2023-002.

Soft-bottom stations were sampled for grain size composition, total organic carbon (TOC), and the sewage tracer *Clostridium perfringens*. Infauna samples were also collected using a 0.04-m^2 Ted Young-modified van Veen grab; infauna samples were rinsed with filtered seawater through a 300-µm-mesh sieve.

The Benthic Hardbottom Survey was conducted on June 12, 2023, and June 14 through June 16, 2023, at 23 stations (waypoints) including one actively discharging diffuser head (T2-5) at the eastern end of the outfall and one inactive head (D#44; Figure 2-2). The diffuser stations were further divided into diffuser head and the rip rap (RR), since they represent very different habitats. Hardbottom stations along transects on either side of the outfall were surveyed using the same method as in previous years. A *SAAB SeaEye Falcon ROV* (remotely operated vehicle) equipped with an analog video camera was used to survey each station for 20 minutes of bottom time. The ROV was operated at slow speeds close to the

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[1] The current monitoring areas form a subset of stations that were sampled before 2011. For example, the transition area formerly included station FF12 and two others that are no longer sampled.

seafloor to optimize visual clarity of the images. An auxiliary *GoPro Hero 6* camera mounted on the ROV was used to obtain simultaneous high definition (HD) video throughout each transect. At least 18 usable minutes of both analog and HD video footage were obtained at all stations. The analog video was analyzed, and the HD video was reviewed and archived for potential future analysis.

2.2 LABORATORY METHODS

All bacteriological, physical, and chemical analyses were conducted by MWRA's Department of Laboratory Services Central Laboratory or its contractors following the procedures described in Constantino et al. (2014). All sample processing, including sorting, identification, and enumeration of infaunal organisms, was done following methods consistent with the QAPP (Rutecki et al. 2020).

2.3 DATA HANDLING, REDUCTION, AND ANALYSIS

All benthic data were extracted directly from the MWRA's database and imported into Excel. Data handling, reduction, graphical presentations, and statistical analyses were performed as described in the QAPP (Rutecki et al. 2020) or by Maciolek et al. (2008). Additional multivariate techniques were used to evaluate infaunal communities. Multivariate analyses were performed using PRIMER v7 (Plymouth Routines in Multivariate Ecological Research) software to examine spatial patterns in the overall similarity of benthic assemblages in the survey area (Clarke 1993, Warwick 1993, Clarke and Green 1988). These analyses included classification (cluster analysis) by hierarchical agglomerative clustering with group average linking and ordination by non-metric multidimensional scaling (nMDS). Bray-Curtis similarity was used as the basis for both classification and ordination. Prior to analyses, infaunal abundance data were fourth-root transformed to ensure that all taxa, not just the numerical dominants, would contribute to similarity measures (Clarke and Gorley 2015).

Cluster analysis produces a dendrogram that represents discrete groupings of samples along a scale of similarity. This representation is most useful when delineating among sites with distinct community structure. nMDS ordination produces a plot or "map" in which the distance between samples represents their rank ordered similarities, with closer proximity in the plot representing higher similarity. Ordination provides a more useful representation of patterns in community structure when assemblages vary along a steady gradation of differences among sites. Stress provides a measure of adequacy of the representation of similarities in the nMDS ordination plot (Clarke 1993). Stress levels less than 0.05 indicate an excellent representation of relative similarities among samples with little prospect of misinterpretation. Stress less than 0.1 corresponds to a good ordination with no real prospect of a misleading interpretation. Stress less than 0.2 still provides a potentially useful two-dimensional picture, while stress greater than 0.3 indicates that points on the plot are close to being arbitrarily placed. Together, cluster analysis and nMDS ordination provide a highly informative representation of patterns of community-level similarity among samples. The "similarity profile test" (SIMPROF) was used to provide statistical support for the identification of faunal assemblages (i.e., selection of cluster groups). The SIMPROF is a permutation test of the null hypothesis that the groups identified by cluster analysis (samples included under each node in the dendrogram) do not differ from each other in multivariate structure.

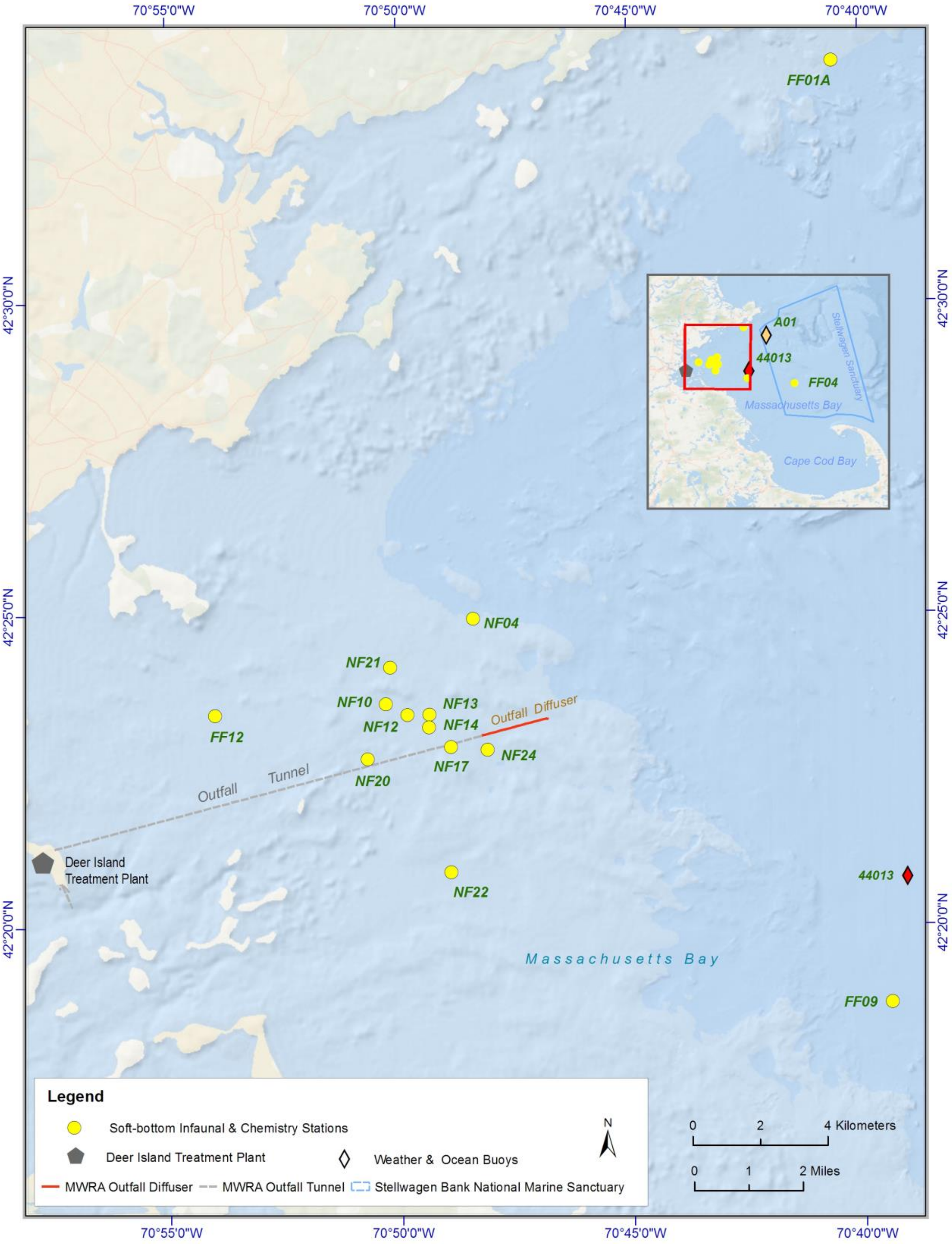

Figure 2-1. **Locations of soft-bottom sampling stations for 2023. Inset map shows farfield station FF04.**

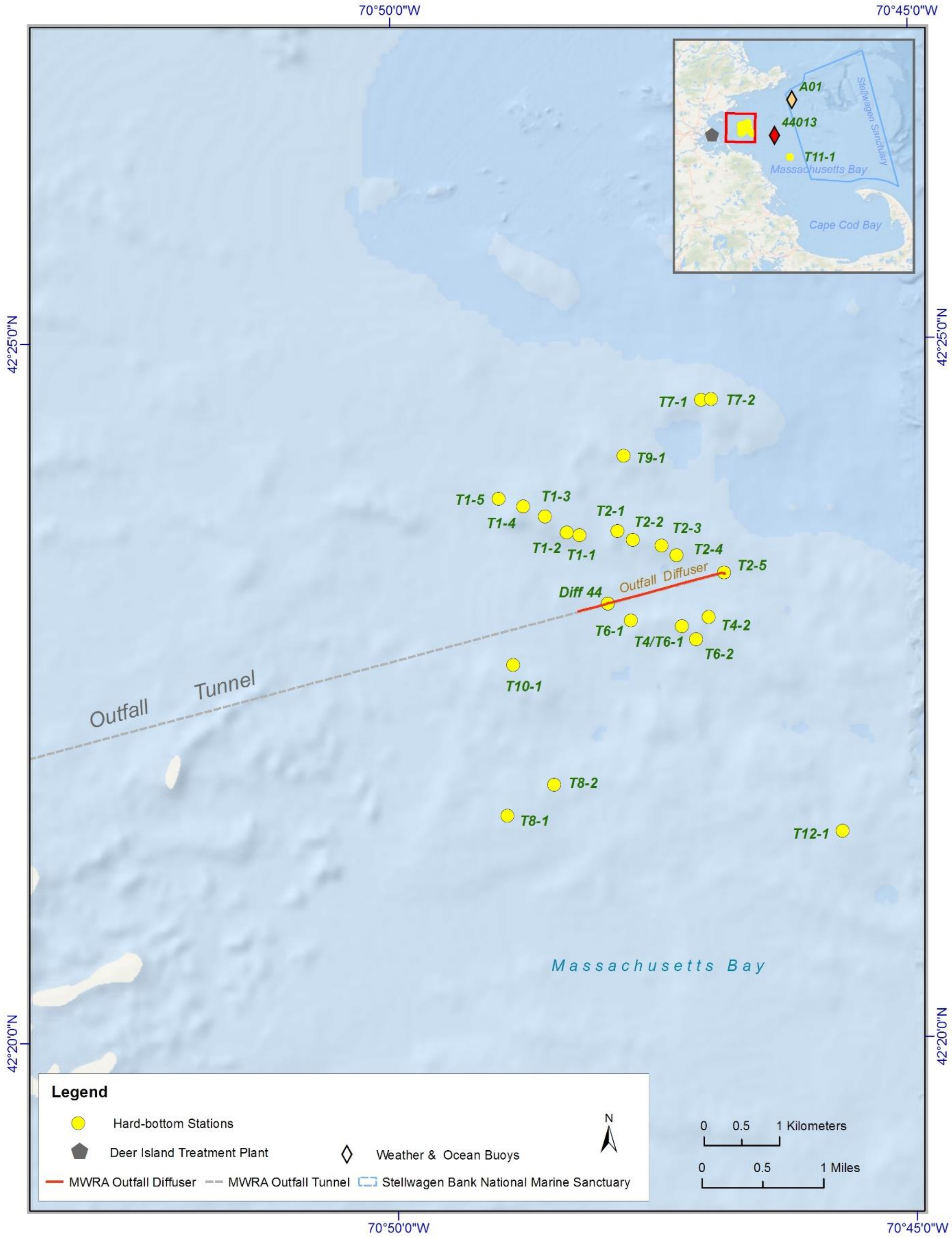

Figure 2-2. **Location of hard bottom video stations surveyed in 2023. Inset shows distant southern control site T11-1**

To help with assessment of spatial patterns, stations have been grouped into regions according to distance from the outfall. The monitoring areas include nearfield stations <2 km from the outfall, nearfield stations >2 km from the outfall, a transition station, and farfield stations (see Section 2.1). All Contingency Plan thresholds and comparisons to those thresholds to assess potential exceedances are based on the nearfield stations, including the transition station (FF12). The nearfield annual means and associated threshold limits reported herein are both based on the list of stations currently sampled (since the 2010 revision to the Ambient Monitoring Plan; MWRA 2010).

At each hardbottom station the video was reviewed to assess habitat relief, substrate size classes, relative amount of sediment drape (ranging from clean when the entire rock surface was visible to heavy when none of the rock surface was visible) and qualitative abundance of common taxa. Rare, large, and clearly identifiable organisms were enumerated. With the exception of Cunner, *Tautogolabrus adspersus* (which was frequently too abundant to accurately count), all fish were enumerated. Counts of abundant motile organisms (i.e., cunner), cryptic organisms (such as mussels), and all encrusting organisms were not attempted because of the large amount of time accurate counts would require and the general lack of resolution of the video footage. These organisms were assessed through a range of qualitative abundances (rare to abundant).

3 RESULTS AND DISCUSSION

3.1 SEDIMENT CONDITIONS

3.1.1 *Clostridium perfringens*, Grain Size, and Total Organic Carbon

Sediment conditions were characterized by three parameters measured during 2023 at each of the 14 sampling stations: (1) *Clostridium perfringens*, (2) grain size (categories from coarse to fine: gravel, sand, silt, and clay), and (3) total organic carbon (Table 3-1).

Table 3-1. Monitoring results for sediment condition parameters in 2023.

Monitoring Area	Station	*Clostridium perfringens* (cfu/g dry/%fines)	Total Organic Carbon (%)[1]	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Percent Fines (Silt + Clay)
Nearfield (<2 km from outfall)	**NF13**	253.8	0.29	0.8	95.4	0.6	3.2	3.8
	NF14	97.4	0.51	2.5	71.7	10.7	15.0	25.8
	NF17	93.8	0.06	0.17	95.3	0.5	4.0	4.6
	NF24	65.7	0.62	1.0	63.4	20.5	15.1	35.6
Nearfield (>2 km and <5 km from outfall)	**NF04**	74.6	0.12	1.3	90.7	1.7	6.3	8.0
	NF10	32.2	0.58	0.4	52.4	26.7	20.5	47.3
	NF12	39.1	1.98	0.0	13.8	34.6	51.7	86.2
	NF20	74.5	0.53	3.7	82.5	6.7	7.2	13.8
	NF21	40. 6	0.35	0.1	32.6	41.0	26.3	67.3
	NF22	46.3	–	0.4	49.0	33.0	17.5	50.5
Transition (~ 8 km from outfall)	**FF12**	10.9	0.32	3.3	70.1	11.8	14.8	26.6
Farfield (>13 km from outfall)	**FF01A**	31.3	0.38	0.1	84.4	6.9	8.7	15.5
	FF04	17. 4	–	0.0	1.1	51.1	47.8	98.9
	FF09	61.9	1.06	1.9	84.3	3.8	10.0	13.8

[1] The TOC values at Stations NF22 and FF04 in 2023 were outliers compared to historical data at these sites and have been flagged as suspect. These data have been excluded from the TOC analyses.

3.1.1.1 Clostridium perfringens

Spores of the anaerobic bacterium *Clostridium perfringens* provide a sensitive tracer of effluent solids due to their presence in wastewater and the inability to remove them by conventional treatment practices. *Clostridium perfringens* abundances were reported as colony forming units per gram dry weight, normalized to percent fines (silt and clay; cfu/g dry/% fines). Abundances were normalized because the distribution of *C. perfringens* varies with the proportion of fine-grained material in the sediments, and normalization provides a more conservative means of evaluating the data for trends (Parmenter and Bothner 1993). A sharp increase in *C. perfringens* concentrations at sites within two kilometers from the diffuser occurred coincident with diversion of effluent to the offshore outfall (Figure 3-1). *C. perfringens* concentrations declined or remained comparable to the baseline at all other monitoring locations during the post-diversion period until 2022. Statistical analyses reported in Maciolek et al. (2007, 2008) confirmed that concentrations of *C. perfringens* were significantly higher at stations close to the outfall in 2006 and 2007 compared to pre-diversion concentrations and consistent with an impact of the outfall discharge. *C. perfringens* counts in samples collected during 2022 increased sharply at most stations, and in two areas of the Bay, were measured at the highest concentrations of the 1992 to 2023 time series, more than four times the historical averages for the areas (NF<2km and FF, Figure 3-1). *C. perfringens* counts for 2023 decreased just as sharply returning to levels comparable to other past post-diversion concentrations in all areas of the Bay (Figure 3-1). Normalized *C. perfringens* spore counts in samples collected in 2023 were highest at NF13, NF14, and NF17; three stations located within two kilometers from the discharge (Table 3-1, Figure 3-2).

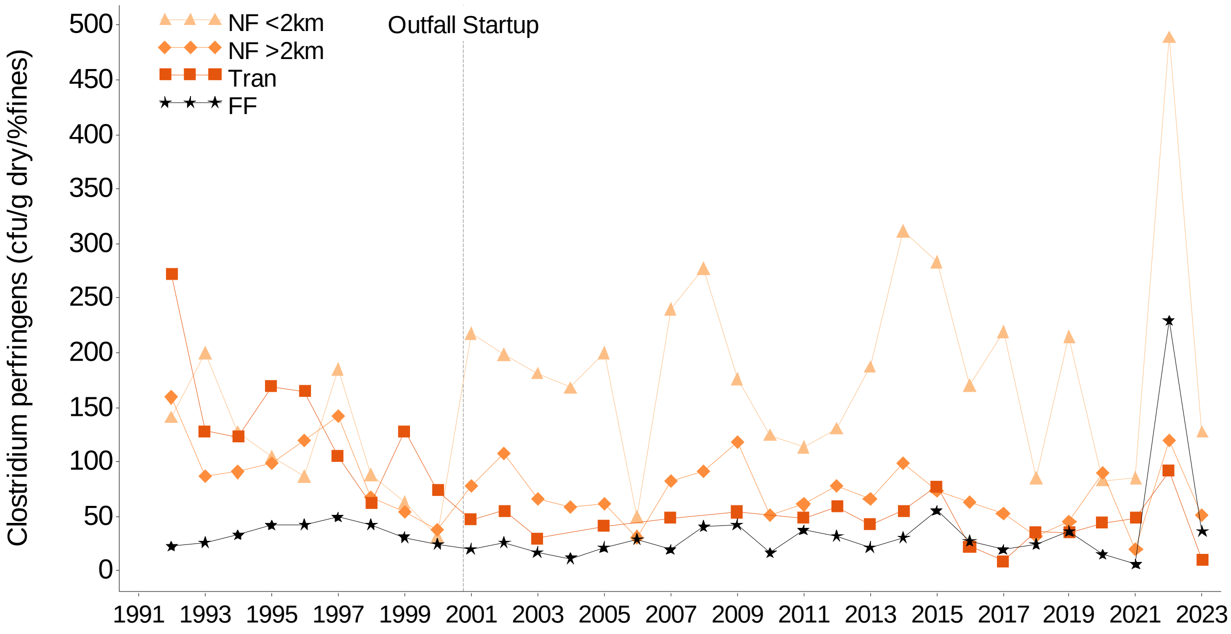

Figure 3-1. Mean concentrations of *Clostridium perfringens* in four areas of Massachusetts Bay, 1992 to 2023. Tran=Transition; NF<2km=nearfield, less than two kilometers from the outfall; NF>2km=nearfield, more than two kilometers from the outfall; FF=farfield.

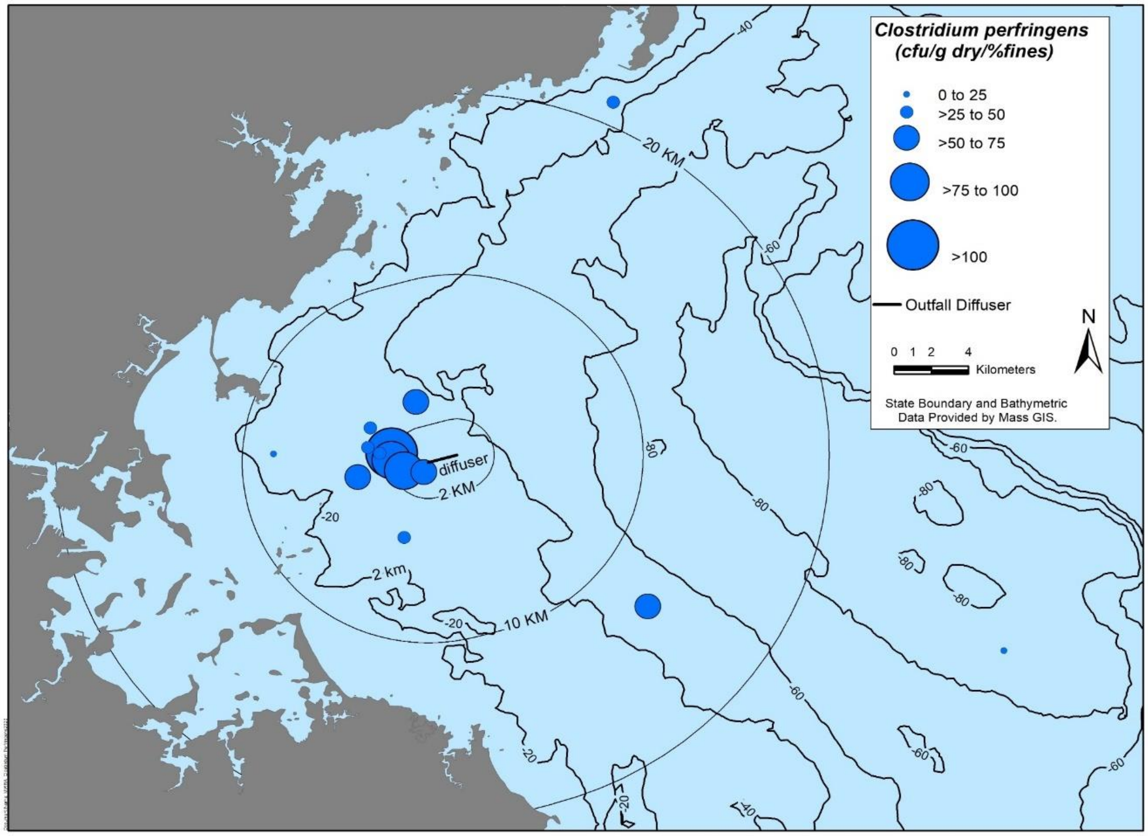

Figure 3-2. Monitoring results for *Clostridium perfringens* in 2023.

3.1.1.2 Sediment Grain Size

Sediment texture in 2023 varied considerably among the 14 stations, ranging from almost entirely sand (e.g., NF17 and NF13) to predominantly silt and clay (e.g., NF12 and FF04), with most stations having mixed sediments (Figure 3-3). Sediment texture has remained generally consistent over time, with relatively small year-to-year changes in the percent fine sediments at most stations (Figure 3-4). Annual variability in sediment texture at the Massachusetts Bay stations has typically been associated with strong storms. Sediment transport at water depths less than 50 meters near the outfall site in Massachusetts Bay occurs largely as a result of wave-driven currents during strong northeast storms (Bothner et al. 2002). Another source of year-to-year variability in sediment textures could be small-scale spatial variability of benthic habitat in the vicinity of a sampling location. Factors such as storm-driven sediment transport or habitat variability may explain the relatively high interannual variability at station NF12, where the percent fine sediments in 2022 were the highest reported, and in 2023 the third highest (Figure 3-4).

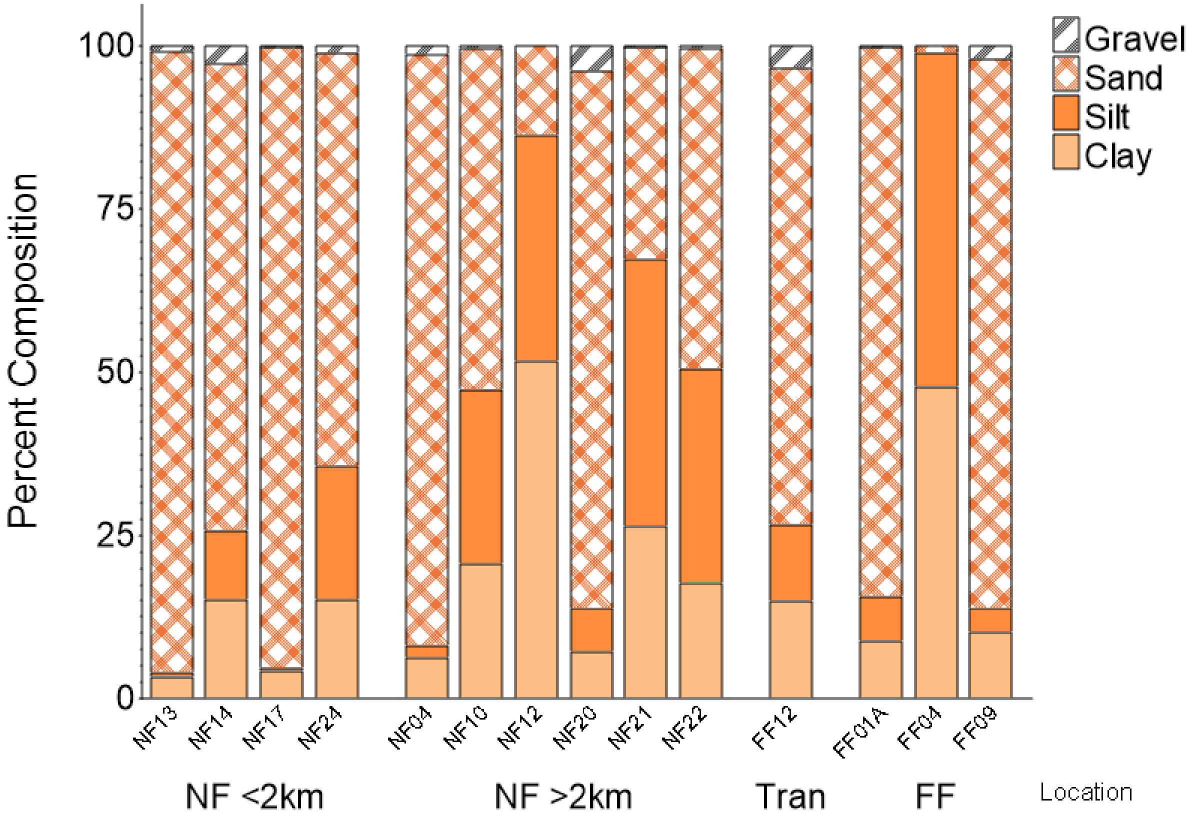

Figure 3-3. Monitoring results for sediment grain size in 2023.

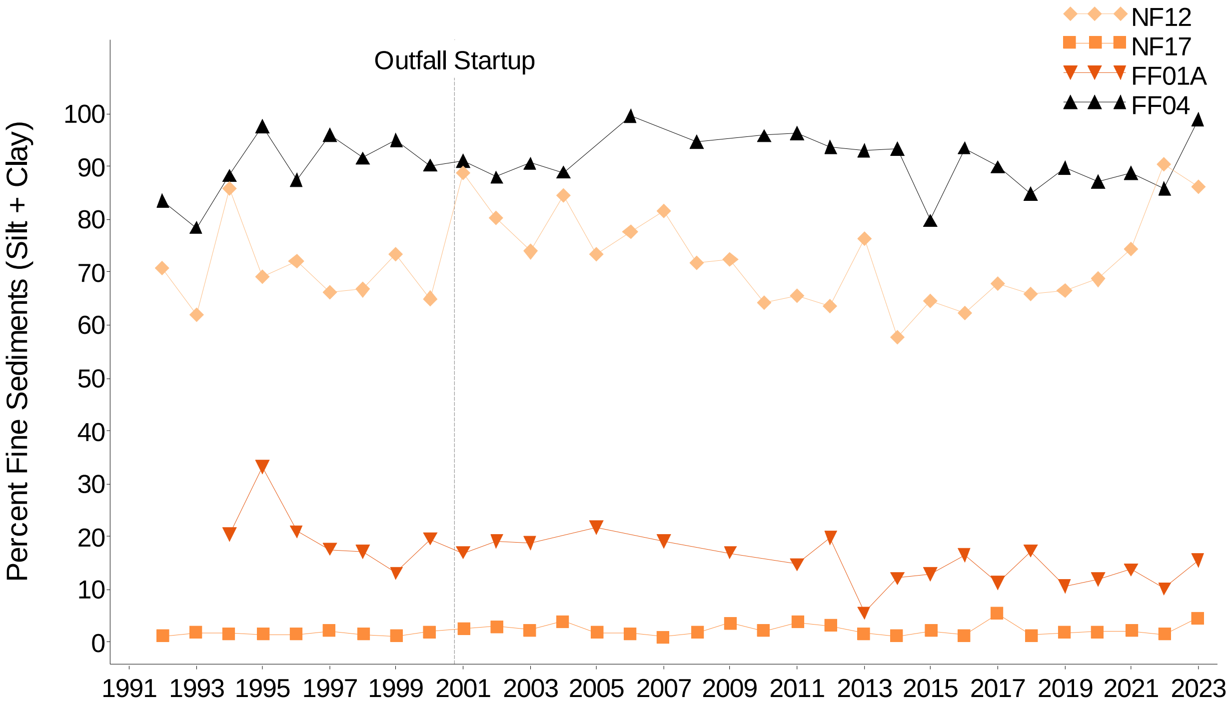

Figure 3-4. Mean percent fine sediments at FF01A, FF04, NF12 and NF17; 1992 to 2023.

3.1.1.3 Total Organic Carbon

Concentrations of TOC in 2023 were similar to the previous year at several nearfield stations (e.g., NF17 and FF01A), with more year-to-year variability at others further from the outfall (e.g., NF12; Figure 3-5). The 2023 TOC values for Stations FF04 (a depositional site in Stellwagen Basin) and NF22 (approximately 4 km from the outfall) were flagged as suspect and excluded from the TOC analysis. Supplemental information explaining the concerns with these data are presented in Appendix A. Despite year-to-year variability, TOC values were generally consistent with historically reported values at different locations within the Bay (Figure 3-5). Higher TOC values are generally associated with higher percent fines (compare Figures 3-4 and 3-5). To further assess spatial patterns in TOC concentrations while accounting for the association between TOC and percent fine sediments, TOC values were normalized to percent fines (Figure 3-6). To normalize the TOC values, the percentage of TOC was divided by the percentage of percent fine sediments (i.e., silt and clay).

While *C. perfringens* counts continue to provide evidence of effluent solids depositing near the outfall (Table 3.1), there is no indication that the wastewater discharge has resulted in changes to the sediment grain size composition and no indication of organic enrichment at the Massachusetts Bay sampling stations. Overall, TOC concentrations remain comparable to values reported during the baseline period, even at sites closest to the outfall (Figures 3-7 and 3-8).

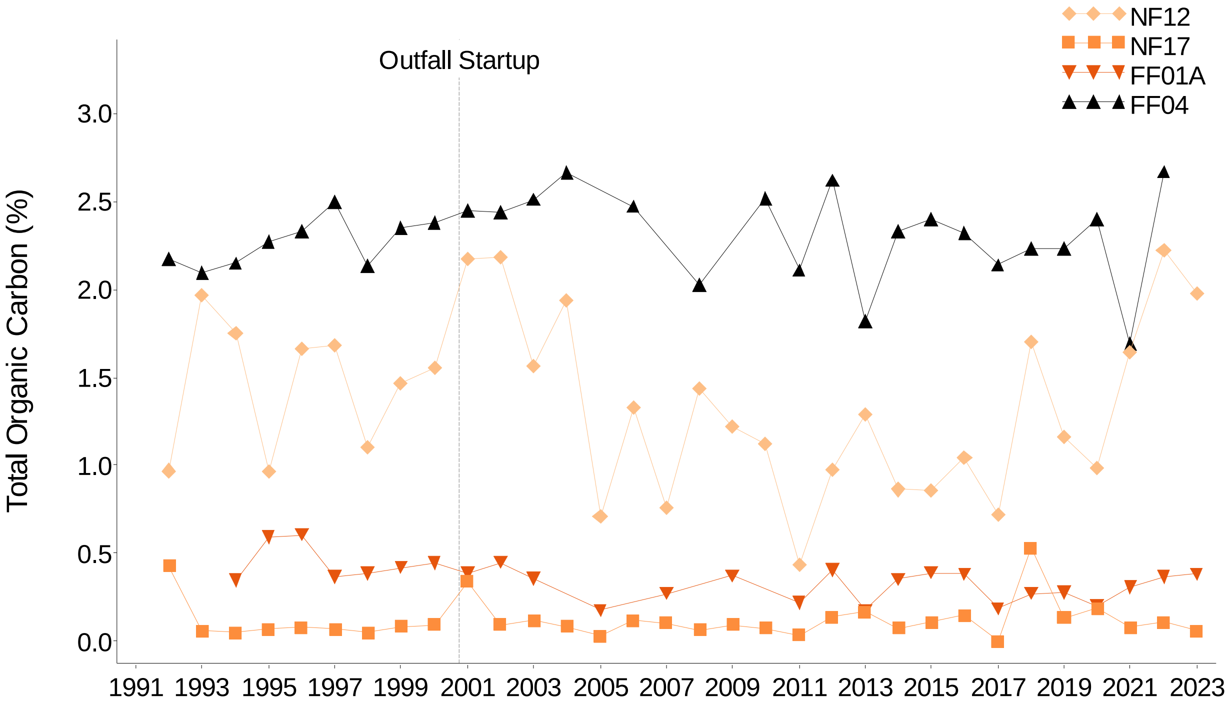

Figure 3-5. Mean concentrations of TOC at four stations in Massachusetts Bay, 1992 to 2023. Station FF04 2023 TOC mean concentration was flagged as suspect and excluded from analyses (see Appendix A).

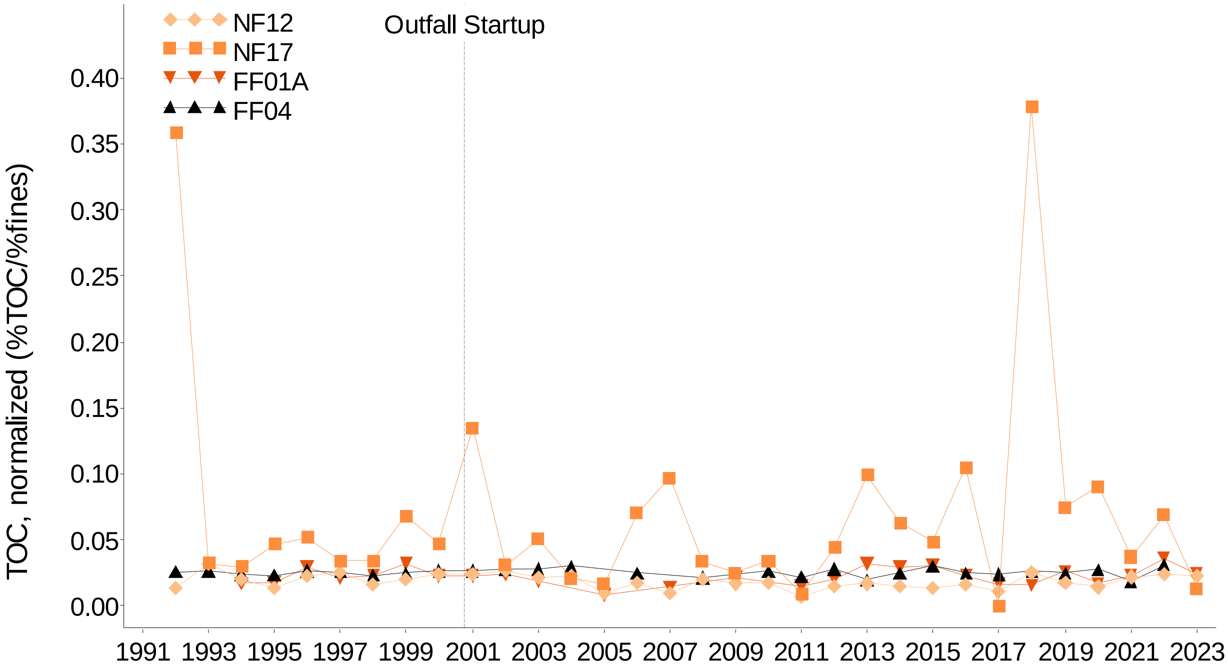

Figure 3-6. Normalized mean concentrations of TOC at four stations in Massachusetts Bay, 1992 to 2023. Station FF04 2023 TOC mean concentration was flagged as suspect and excluded from analyses (see Appendix A).

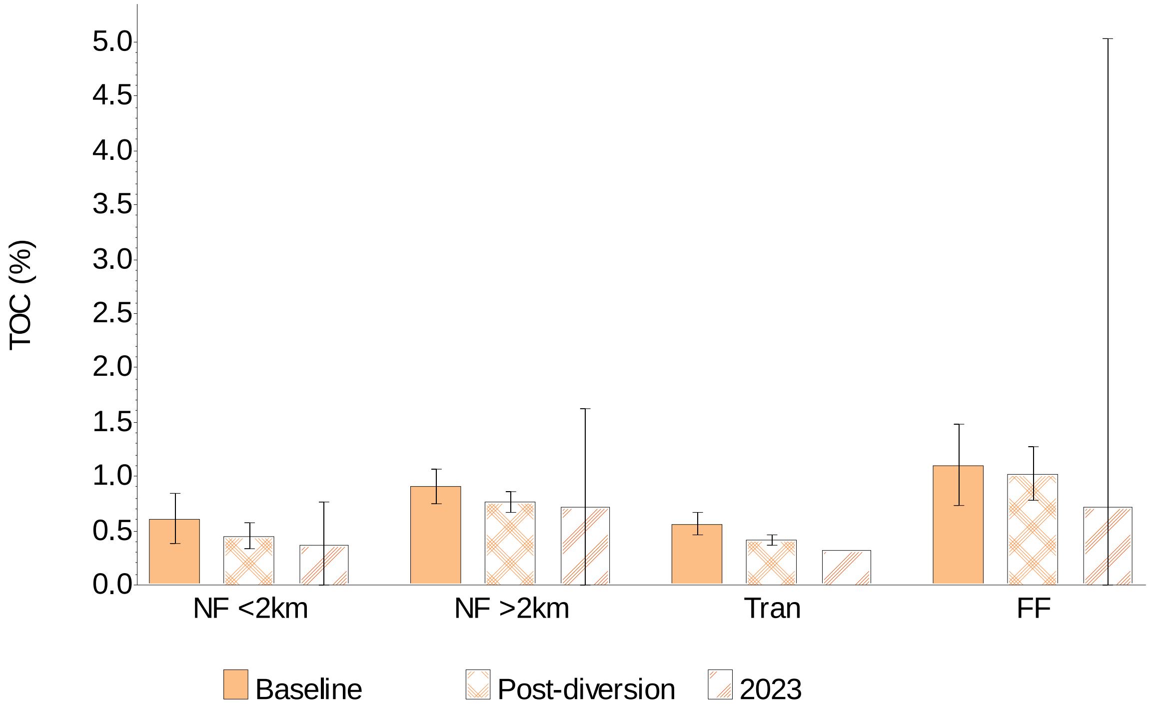

Figure 3-7. Mean (with 95% confidence intervals) concentrations of TOC at four areas in Massachusetts Bay during the baseline (1992-2000) and post-diversion (2001 to 2022) compared to 2023.

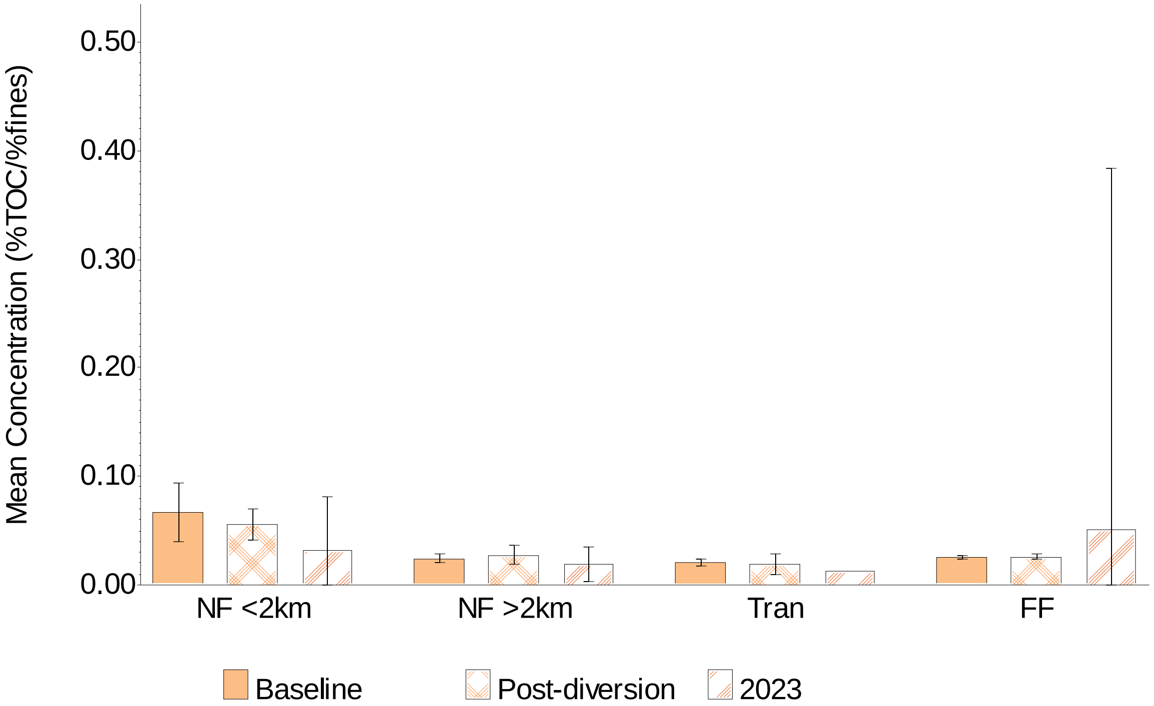

Figure 3-8. Normalized mean (with 95% confidence intervals) concentrations of TOC at four areas in Massachusetts Bay during the baseline (1992 to 2000) and post-diversion (2001 to 2022) periods compared to 2023. Tran=Transition; NF<2km=nearfield, less than two kilometers from the outfall; NF>2km=nearfield, more than two kilometers from the outfall; FF=farfield.

3.2 BENTHIC INFAUNA

3.2.1 Community Parameters

A total of 27,099 infaunal organisms were counted from the 14 samples (one sample per station) in 2023. Organisms were classified into 197 discrete taxa; 174 of those taxa were species-level identifications. The abundance values reported herein reflect the total counts from both species and higher taxonomic groups, while all diversity measures and multivariate analyses are based on the species-level identifications only (Table 3-2).

Table 3-2. Monitoring results for infaunal community parameters in 2023.

Monitoring Area	Station	Total Abundance (per grab)	Number of Species (per grab)	Log-series alpha	Shannon-Wiener Diversity (H′)	Pielou's Evenness (J')
Nearfield (<2 km from outfall)	**NF13**	1104	62	14.30	4.36	0.73
	NF14	2223	71	14.03	4.24	0.69
	NF17	757	48	11.45	3.06	0.55
	NF24	2393	61	11.41	3.65	0.62
Nearfield (>2 km and <5 km from outfall)	**NF04**	351	39	11.29	3.97	0.75
	NF10	2268	68	13.21	4.19	0.69
	NF12	1718	65	13.37	4.28	0.71
	NF20	2638	71	13.58	4.18	0.68
	NF21	2497	62	11.52	4.17	0.70
	NF22	3434	62	10.76	3.42	0.57
Transition (~ 8 km from outfall)	**FF12**	2482	60	11.10	3.79	0.64
Farfield (>13 km from outfall)	**FF01A**	3239	71	12.96	3.92	0.64
	FF04	768	38	8.42	3.73	0.71
	FF09	1227	85	21.59	4.66	0.73

Total abundance values in 2023 were higher than the 2022 values at all areas in Massachusetts Bay (Figure 3-9). The numbers of species per sample in 2023 were also higher than in 2022 at all locations except the nearfield sites >2km away from the outfall, with the sharpest increase at the Transition area (Figure 3-10). Shannon-Wiener Diversity (H') and Pielou's Evenness (J') values were both lower in 2023 compared to the previous year at the nearfield stations, but within the range of variability reported historically (Figures 3-11 and 3-12). The spionid polychaete *Prionospio steenstrupi* was the historical dominant from 1997 to 2005, when abundance of this species was considerably higher than all other dominant taxa. *Prionospio steenstrupi* was less abundant in 2023 than it had been from 2019 to 2022 and was comparable to values observed from 2016-2018 (Figure 3-13). Nonetheless, this species remained among the top dominant taxa, along with other historically dominant polychaetes such as *Aricidea catherinae* and *Mediomastus californiensis* (Figure 3-13).

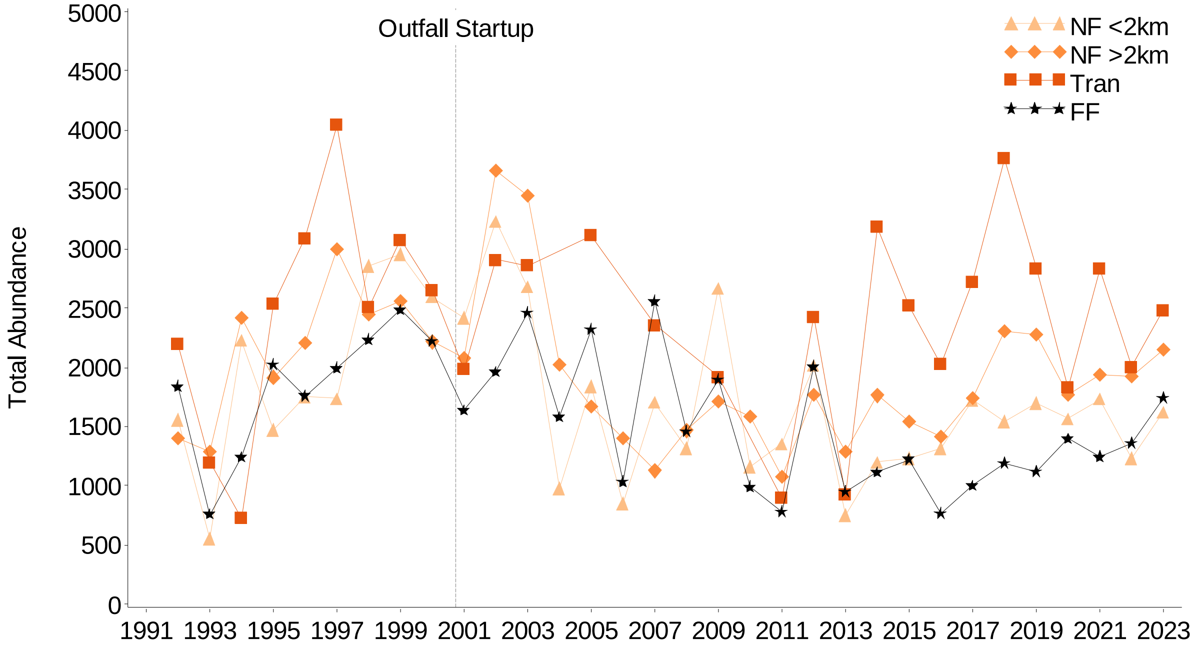

Figure 3-9. Mean infaunal abundance per sample at four areas of Massachusetts Bay, 1992 to 2023. Tran=Transition; NF<2km=nearfield, less than two kilometers from the outfall; NF>2km=nearfield, more than two kilometers from the outfall; FF=farfield.

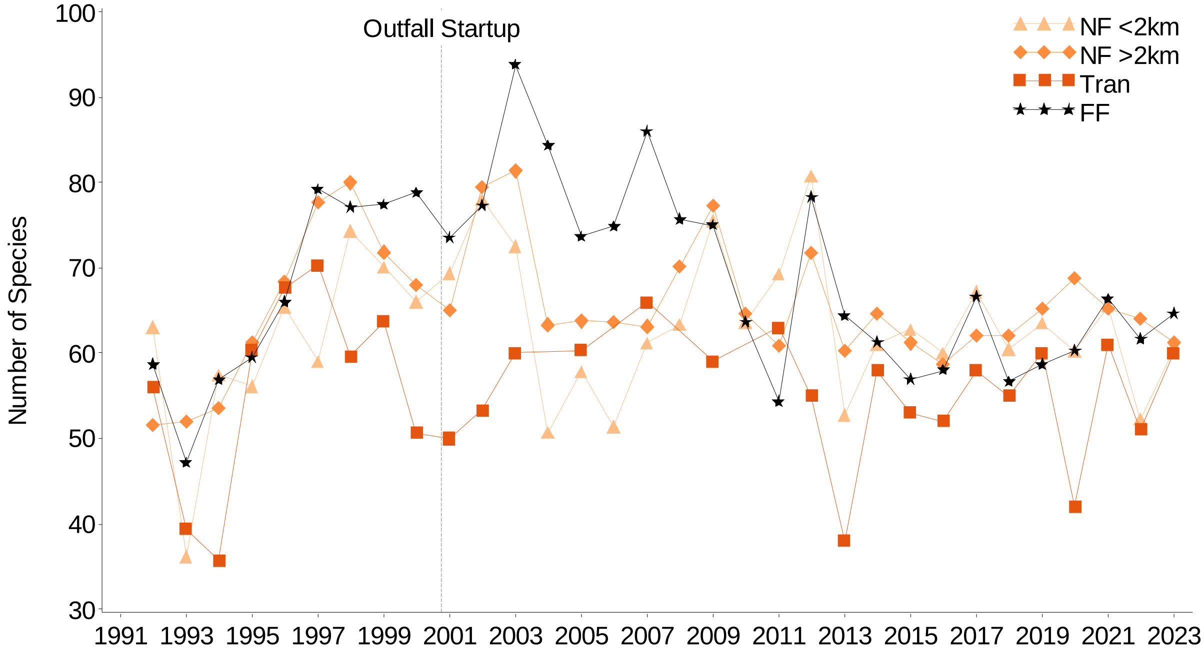

Figure 3-10. Mean number of species per sample at four areas of Massachusetts Bay, 1992 to 2023. Tran=Transition; NF<2km=nearfield, less than two kilometers from the outfall; NF>2km=nearfield, more than two kilometers from the outfall; FF=farfield.

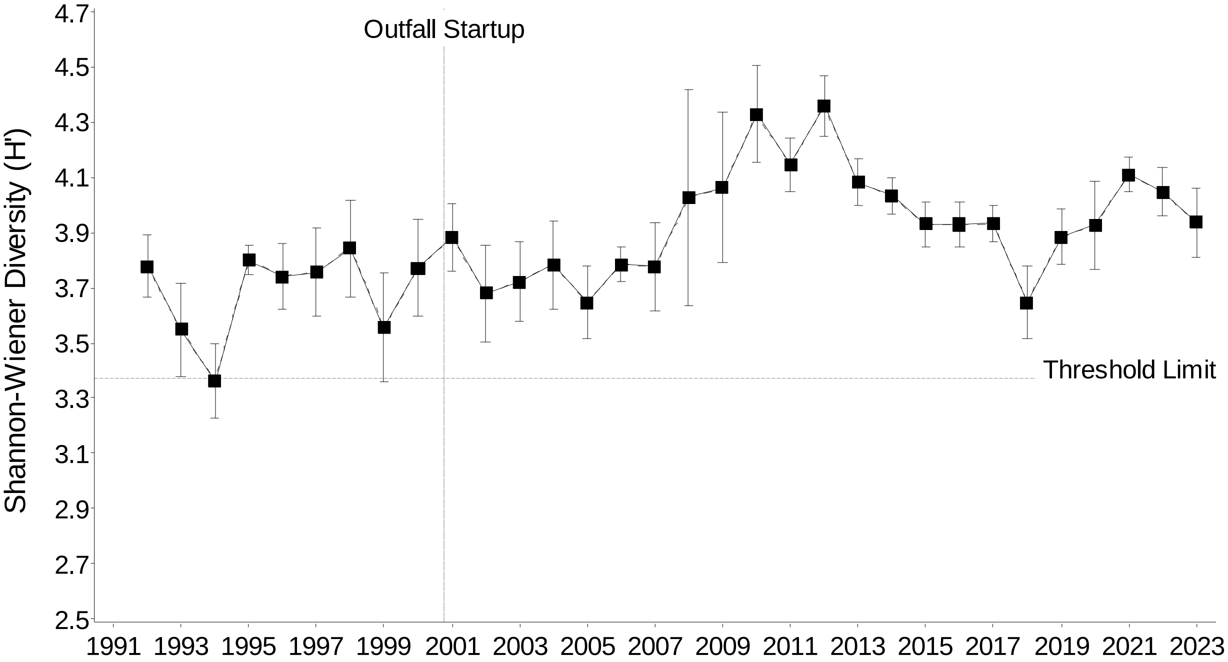

Figure 3-11. Mean (and 95% confidence intervals) Shannon-Wiener Diversity (H′) at nearfield stations in comparison to threshold limit, 1992 to 2023.

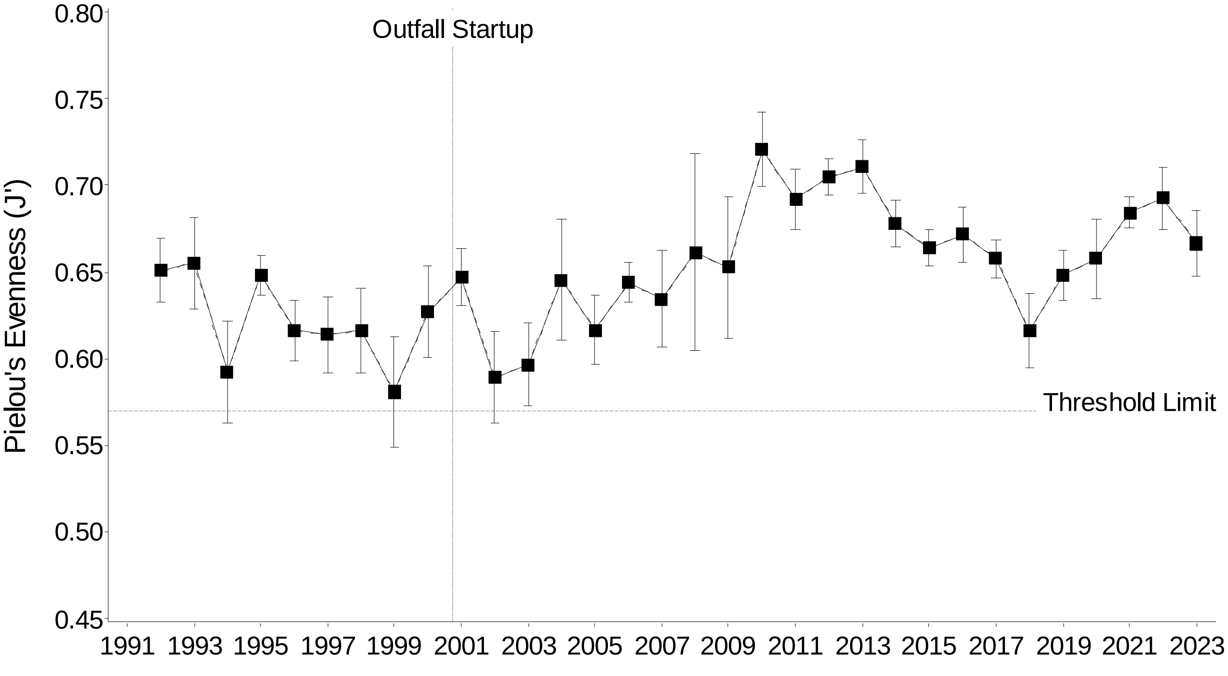

Figure 3-12. Mean (and 95% confidence intervals) Pielou’s Evenness (J′) at nearfield stations in comparison to threshold limit, 1992 to 2023.

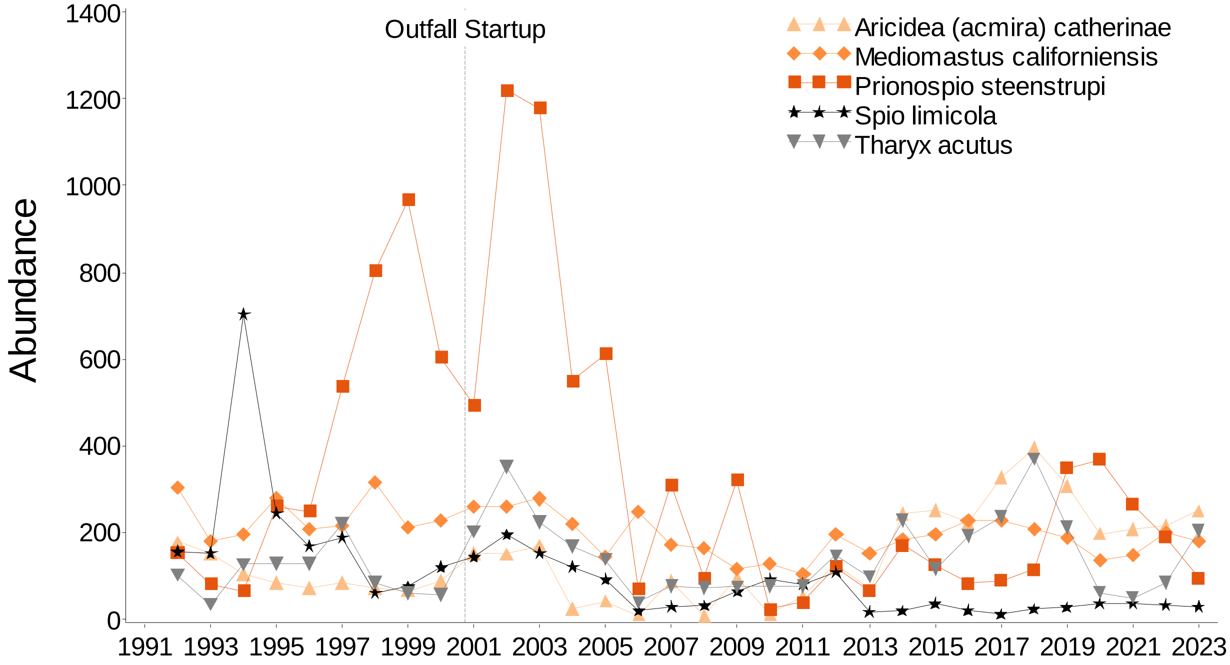

Figure 3-13. Mean abundance from 1992 to 2023, of the five numerically dominant taxa at nearfield stations in Massachusetts Bay.

There were no Contingency Plan threshold exceedances for any infaunal diversity measures in 2023 (Table 3-3). Spatial and temporal patterns of abundance, species richness, species diversity and evenness generally support the conclusion that there is no evidence of negative impacts caused by operation of the offshore outfall.

Table 3-3. Infaunal monitoring Contingency Plan threshold results, August 2023 samples.

Parameter	Thresholds*		Result	Exceedance?
	Value	Limit		
Total species	42.99	Low	60.82	No
Log-series Alpha	9.42	Low	12.36	No
Shannon-Weiner H′	3.37	Low	3.94	No
Pielou’s J'	0.57	Low	0.67	No
Percent opportunists	10% (Caution)	High	0.21%	No
Percent opportunists	25% (Warning)	High	0.21%	No

*Threshold exceedances occur when current year results are below threshold values for a “low” limit or above the values for a “high” limit for a given parameter.

3.2.2 Infaunal Assemblages

Multivariate analyses based on Bray-Curtis Similarity were used to assess spatial patterns in the faunal assemblages at the Massachusetts Bay sampling stations. Two main assemblages (Groups I and II) and an outlier assemblage (Group III) were identified in a cluster analysis of the 14 samples from 2023 (Figure 3-14). The groups were distinguished based on species composition and the relative abundances of each taxon in the samples. Clear differences in the mean abundances of dominant taxa were identified. Abundances at the stations included in Groups I and III were generally lower than Group II (compare Figure 3-14 with Table 3-2). The three assemblages were dominated by polychaetes, although the bivalves *Crenella decussata* and *Ennucula delphinodonta* were among the most abundant species in sub-assemblage IIA. Both main assemblages included stations within two kilometers of the discharge and stations more than two kilometers from the discharge (Figure 3-14). Some species were dominant only in Group I (e.g., *Aglaophamus circinata*, *Crassicorophium crassiorne*, and *Polygordius jouinae*), while others were more prevalent in Group II (e.g. *Rhodine loveni*, *Mediomastus californiensis, Prionospio steenstrupi*, and *Spio limicola*) or in Group III (e.g., *Chaetozone anasimus*, *Aricidea (strelzovia) quadrilobate, and Anobothrus gracilis*; Table 3-4).

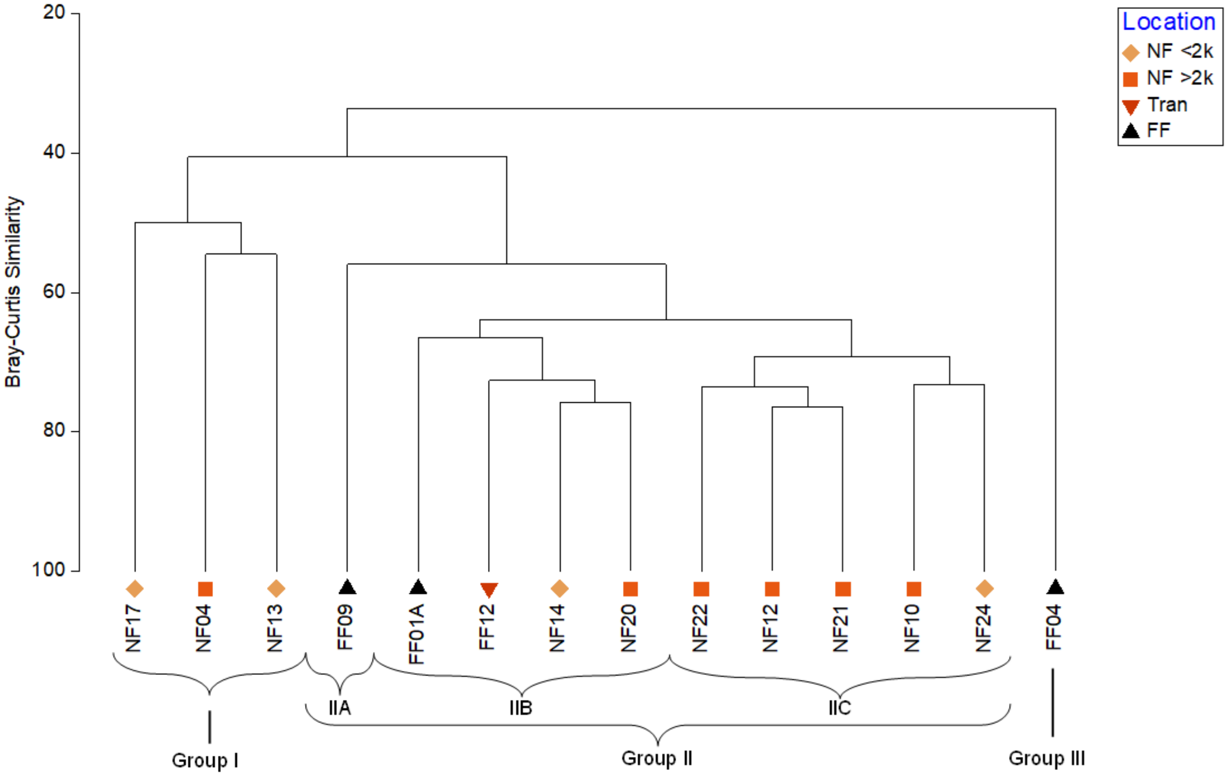

Figure 3-14. Results of cluster analysis of the 2023 infauna samples.

Table 3-4. Abundance (mean # per grab) of numerically dominant taxa (10 most abundant per group) composing infaunal assemblages identified by cluster analysis of the 2023 samples.

Family	Species	Group I	Group II			Group III
		IA	IIA	IIB	IIC	FF04
Annelida (Polychaeta)						
Ampharetidae	*Anobothrus gracilis*	0.3	15.0	13.8	0.8	76.0
Apistobranchidae	*Apistobranchus typicus*	-	1.0	0.8	3.6	25.0
Capitellidae	*Mediomastus californiensis*	5.0	28.0	194.0	256.6	21.0
Cirratulidae	*Chaetozone anasimus*	6.3	-	-	-	158.0
	Kirkegaardia baptisteae	29.3	-	171.0	178.0	-
	Kirkegaardia hampsoni	0.7	2.0	101.8	69.4	-
	Tharyx acutus	20.7	56.0	172.8	311.6	-
Cossuridae	*Cossura longocirrata*	0.3	2.0	0.5	21.6	64.0
Lumbrineridae	*Ninoe nigripes*	0.3	37.0	44.5	80.0	25.0
Maldanidae	*Rhodine loveni*	-	175.0	0.3	13.8	-
Nephtyidae	*Aglaophamus circinata*	17.7	1.0	7.3	1.4	-
Oweniidae	*Owenia artifex*	1.0	3.0	117.8	61.4	-
Paraonidae	*Aricidea (acmira) catherinae*	37.7	12.0	423.3	234.6	-
	Aricidea (strelzovia) quadrilobata	-	21.0	11.0	18.2	81.0
	Levinsenia gracilis	3.0	163.0	153.0	407.8	123.0
Polygordiidae	*Polygordius jouinae*	90.0	8.0	53.8	1.0	-
Sabellidae	*Euchone incolor*	2.0	28.0	111.3	117.6	67.0
Scalibregmatidae	*Scalibregma inflatum*	19.3	24.0	27.3	17.0	-
Spionidae	*Prionospio steenstrupi*	4.0	53.0	143.3	100.8	5.0
	Spio limicola	-	31.0	0.8	41.0	2.0
	Spiophanes bombyx	178.7	3.0	332.8	131.6	-
Syllidae	*Parexogone hebes*	74.3	5.0	91.3	7.0	-
Arthropoda (Amphipoda)						
Corophiidae	*Crassicorophium crassicorne*	17.3	-	-	-	-
Mollusca (Bivalvia)						
Cardiidae	*Parvicardium pinnulatum*	28.7	11.0	29.8	1.8	-
Mytilidae	*Solamen glandula*	2.0	77.0	5.3	-	-
Nuculidae	*Ennucula delphinodonta*	16.3	75.0	95.3	28.8	5.0
Thyasiridae	*Thyasira gouldii*	-	45.0	2.0	1.0	4.0
Nemertea						
Tubulanidae	*Tubulanus* sp. 1	-	-	4.5	6.2	18.0

Group I consisted of three nearfield stations (NF04, NF17, and NF13). The Group II assemblage included three subgroups (Group IIA: Station FF09; Group IIB: Stations FF01A, FF12, NF20, and NF14; and Group IIC: Stations NF12, NF24, NF22, NF10, and NF21) that could be differentiated by species composition and total abundance. The relatively deep Station FF04 was characterized by low abundances and species richness. The outlier assemblage that was found at this station was labeled as Group III. Dominant species at Station FF04 (e.g., *Chaetozone anasimus* and *Levinsenia gracilis*; Table 3-4) are characteristic of the soft sediment community observed throughout Stellwagen Basin (e.g., Maciolek et al. 2008).

Groups I and II occurred at one or more of the four stations within two kilometers of the discharge as well as at stations more than two kilometers from the discharge (Figure 3-15). Thus, stations closest to the discharge were not characterized by a unique faunal assemblage reflecting potential effluent impacts. Comparisons of faunal distribution to habitat conditions indicated that patterns in the distribution of faunal assemblages are associated with habitat and sediment types at the sampling stations (Figure 3-16), and with station depth (not shown).

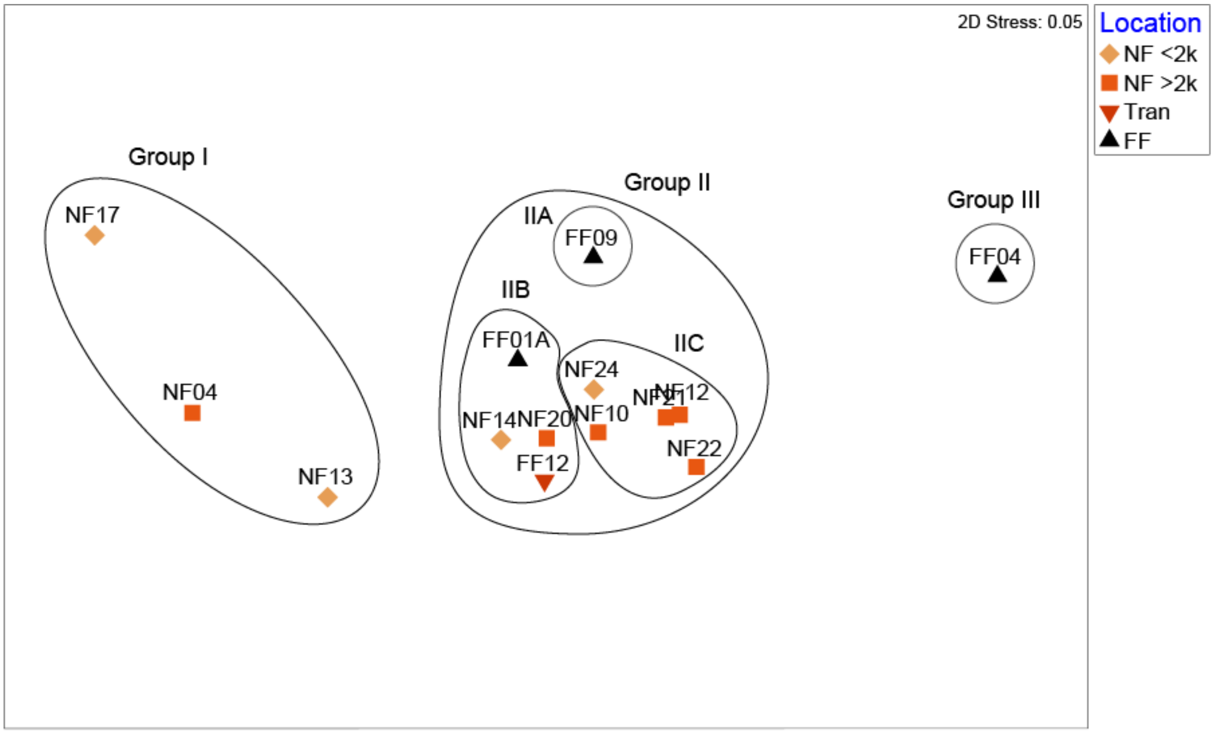

Figure 3-15. Results of a nMDS ordination of the 2023 infauna samples from Massachusetts Bay showing distance from the outfall.

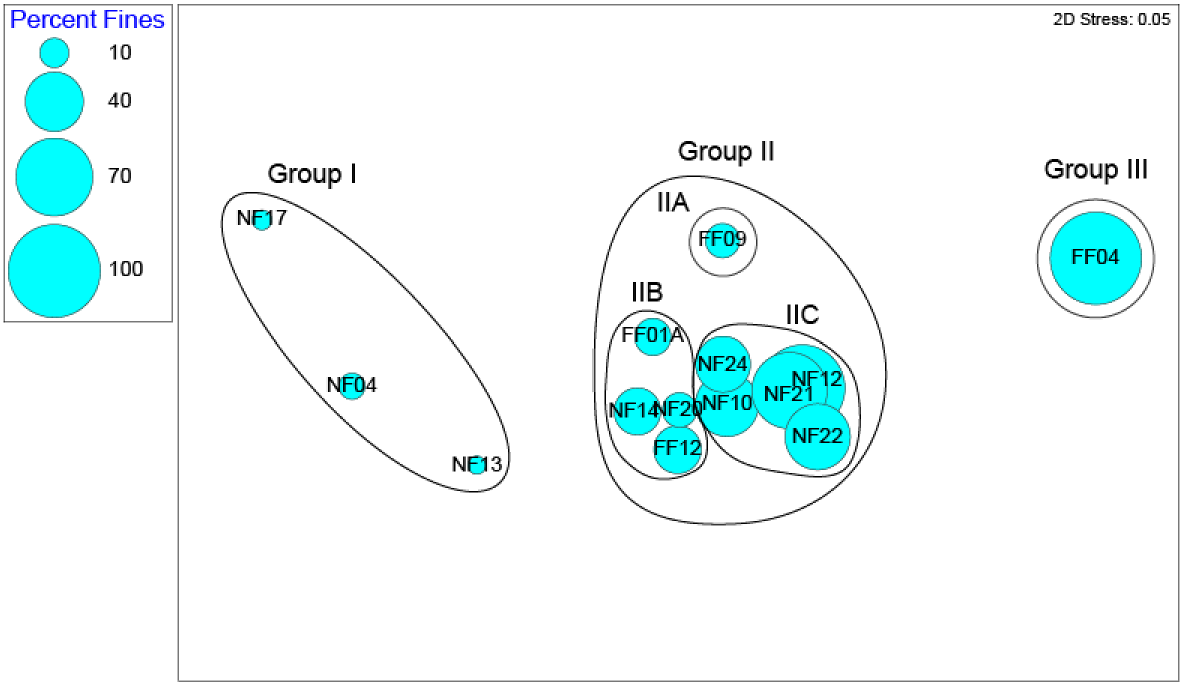

Figure 3-16. Percent fine sediments superimposed on the nMDS ordination plot of the 2023 infauna samples. Each point on the plot represents one of the 14 samples; similarity of species composition is indicated by proximity of points on the plot. Faunal assemblages (Groups I-II, and sub-groups) identified by cluster analysis are circled on the plot. The ordination and cluster analysis are both based on Bray-Curtis Similarity.

Patterns identified in these analyses were highly consistent with previous years. No evidence of impacts from the offshore outfall on infaunal communities in Massachusetts Bay was found. The outfall is located in an area dominated by hydrodynamic and physical factors (e.g., tidal and storm currents, turbulence, and sediment transport; Butman et al. 2008). These factors combined with the high quality of the effluent discharged into the Bay (Taylor 2010, Werme et al. 2021), are the principal reasons that benthic habitat quality has remained high in the nearfield area. Previous assessments have indicated that changes in the benthic habitat quality and infaunal communities in the nearfield are related to physical processes associated with increased storminess (Nestler et al. 2020).

Multivariate analyses were also used to assess temporal patterns in the faunal assemblages at four Massachusetts Bay sampling stations. Samples from 1992 to 2023 at stations NF17, NF24, FF01A, and FF04, were analyzed using Bray-Curtis Similarity and an nMDS ordination (Figure 3-17). Relatively high levels of similarity over time among samples collected from each station were found. Characteristic assemblages were unique to each of the four stations analyzed; those assemblages appeared relatively stable over time (Figure 3-17). This analysis provided confirmation that the faunal assemblages in samples collected during 2023 were very similar to those that have been found in previous years.

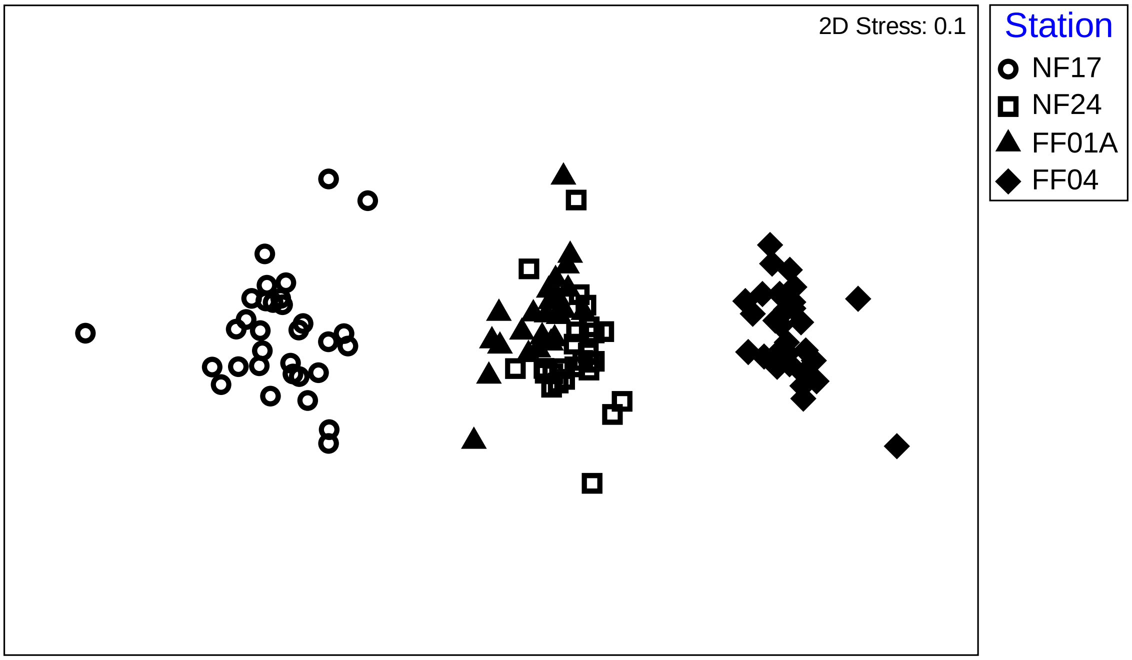

Figure 3-17. Results of an nMDS ordination of the infauna samples from 1992 to 2023 at stations NF17, NF24, FF01A, and FF04. Each point on the plot represents a sample; similarity of species composition is indicated by proximity of points on the plot. The ordination is based on Bray-Curtis Similarity.

3.3 HARD-BOTTOM BENTHIC HABITATS AND FAUNA

3.3.1 2023 Results

The sea floor of Massachusetts Bay was shaped by glaciers, which scoured the bottom and created what is now Stellwagen Basin to the east of the outfall, deposited rocky debris in elongated hills called drumlins, and left sand and gravel on what is now Stellwagen Bank. Tides and currents continue to shape the bay, particularly during large storms with waves large enough to resuspend and transport sediments. Seafloor habitats range from mud in depositional areas to rocky cobbles and boulders on the tops and flanks of the drumlins.

Photographic coverage of the hard bottom habitat in the vicinity of the outfall in 2023 ranged from 18 to 26 minutes of video footage at each waypoint for a total of 487 minutes of analog video, which was viewed and analyzed. The video footage was collected in the same manner as in previous years, but with a more powerful ROV. The vehicle used to survey the stations was a *SeaEye Falcon ROV* equipped with an analog video camera. The *SeaEye Falcon ROV*, which was also used in 2020, is more powerful than the *Benthos Mini-Rover* used in recent years and similar to the *Outland 1000 ROV* used during some of the earlier surveys. A *GoPro Hero 6* camera attached to the *Falcon ROV* was used to simultaneously collect high definition (HD) video images along the dive track for future use. A summary of the data extracted from the analysis of the 2023 analog video is provided in Appendix B.

3.3.2.1 Habitat

Data collected from the video taken during the 2023 survey was generally similar to data obtained from previous post-diversion surveys. The seafloor on the tops of drumlins, long narrow hills of rocky debris, consisted of a moderate to moderately high relief mix of glacial erratics in the boulder and cobble size categories, while the seafloor on the flanks of drumlins frequently consisted of a low to moderately low relief seafloor characterized by cobbles with occasional boulders. Sediment drape, which refers to the visible layer of detrital material that drapes many of the rock surfaces in the hard-bottom areas, generally ranged from moderate to moderately heavy on the tops of the drumlins and moderately heavy on the flanks of drumlins (Figure 3-18). This material likely consists of a combination of phytodetritus, zooplankton fecal material, fine-grained resuspended sediments, biogenic tubes, and possibly effluent particles. As has been observed in previous years, habitat relief and sediment drape were quite variable within many of the sites surveyed. The seafloor in the vicinity of both visited diffuser heads consisted of angular rocks in the small boulder size category. This resulted in a high relief island (the diffuser head) surrounded by a moderate relief field of small boulders. Drape at the diffuser sites was moderately heavy to heavy.

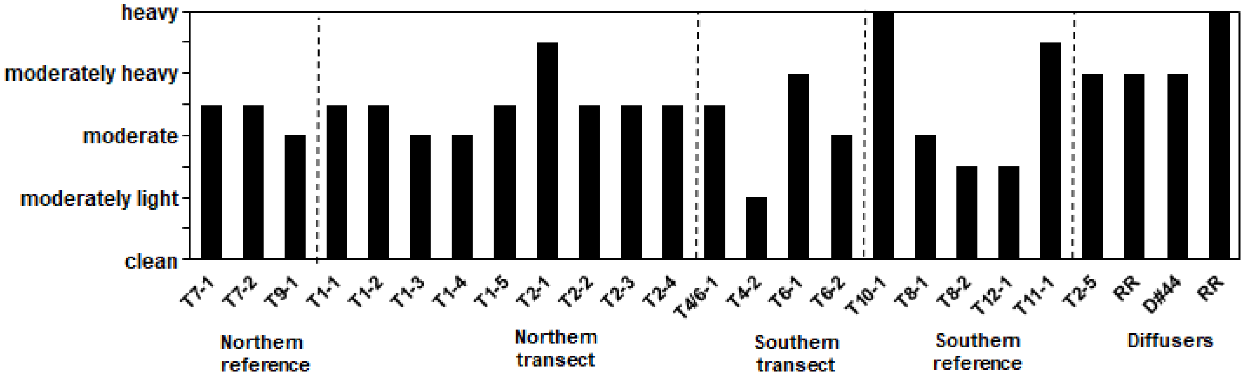

Figure 3-18. Coverage of drape observed on rock surfaces in video footage taken during the 2023 hard-bottom survey.

3.3.2.2 Species Composition and Number of Taxa

Species seen during the 2023 survey are shown in Appendix C. A total of 59 taxa, containing 3 algal species, 40 invertebrate species, 8 fish species, and 8 general categories were seen during the 2023 video analyses. The species composition and number of taxa have remained relatively constant over the course of this study. The distribution of the species has remained relatively constant during the last several years but has changed since the early years of this study.

Algae: Coralline algae was observed at 19 of the 23 waypoints and continued to be the most common and widespread component of the benthic communities (Figure 3-19a). This alga is likely composed of several crustose coralline species that cannot be differentiated on a visual basis. Coralline algae was most abundant on the tops of drumlins, where it was present in few to common abundances at both northern and southern reference sites and on drumlin top sites on either side of the outfall (T1-1 to T1-4, and T4/6-1). In contrast it was absent or rare at the drumlin flank sites (T1-5, T2-2 to T2-4, T4-2, T6-1 and T6-2) and totally absent from the diffuser sites. The qualitative abundance of *Palmaria palmata* (dulse), the other commonly observed alga, is shown on Figure 3-19b. This red alga was found at 15 of the 23 stations, being observed in few to common abundances at the northern and southern reference sites and rare to few abundances at the other drumlin top sites (T1-1 to T1-4, T4/6-1, and T2-1 to T2-3). Most of the dulse colonies seen in 2023 were composed of small juveniles. Only two fronds of the third algal species *Agarum cribrosum* (shot-gun kelp) were observed, one at T1-3 and the other at T12-1.

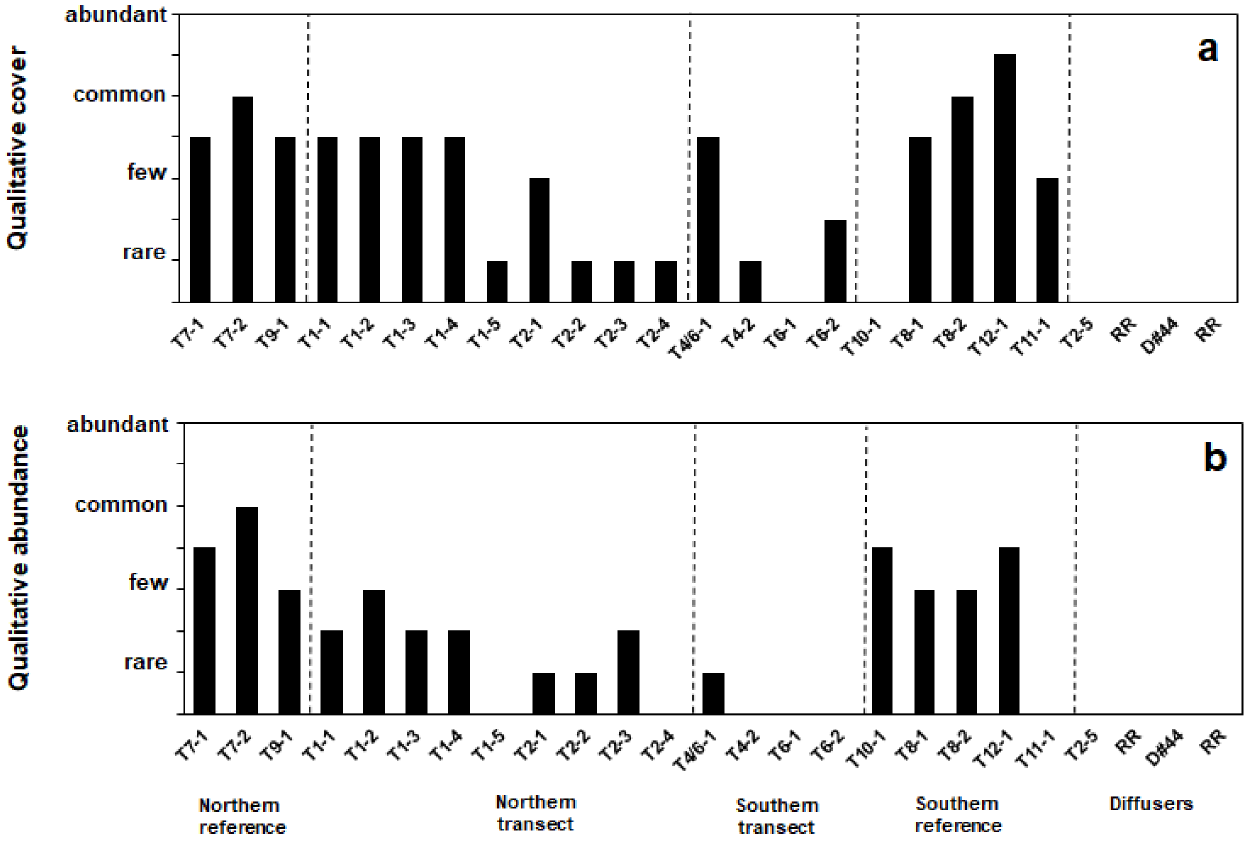

Figure 3-19. Qualitative cover of coralline algae (a) and qualitative abundance of *Palmaria palmata* (b) observed in video footage taken during the 2023 hard-bottom survey.

Fish and Invertebrates: The fish taxa were similar to those observed in previous years, with the Cunner (*Tautogolabrus adspersus*) being by far the most abundant and widely distributed fish encountered within the study area, followed by the Winter Flounder (*Pseudopleuronectes americanus*) and sculpin (*Myoxocephalus* spp.). Cunner were usually most abundant in areas of high relief, such as large boulders on the tops of drumlins or near the diffuser heads (Figure 3-20). The second most abundant fish observed in 2023 were Winter Flounder, which were most abundant at shallower drumlin top stations (Figure 3-21). The flounder frequently followed the ROV, apparently attracted to the sediment disturbance caused by the vehicle. The other commonly observed fish were sculpin, which were most abundant on top of the deep drumlin immediately north of the diffuser (T2-1 to T2-4) and the top of the drumlin immediately south of it (T4/6-1).

Common invertebrates seen in 2023 included: the horse mussel (*Modiolus modiolus*), the blue mussel (*Mytilus edulis*), adult northern sea stars (*Asterias rubens*), the blood star (*Henricia sanguinolenta*), white and cream encrusting tunicates (*Aplidium*/*Didemnum* spp.), the encrusting yellow sponge *Polymastia* sp. A, the Pacific tunicate (*Botrylloides violaceus*), and the brachiopod (*Terebratulina septentrionalis*). Their abundances and distributions were similar to those observed in previous years.

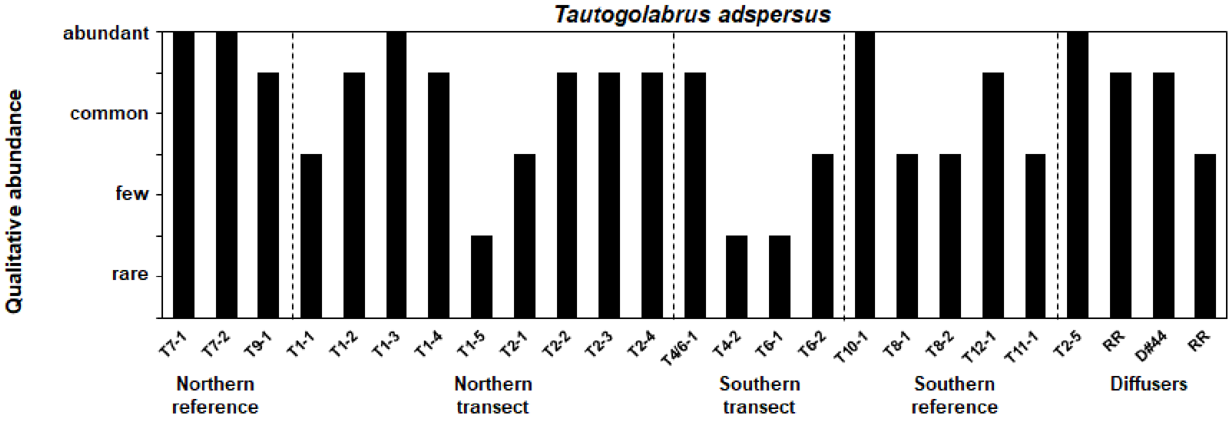

Figure 3-20. Qualitative abundance of *Tautogolabrus adspersus* (Cunner) observed in video footage taken during the 2023 hard-bottom survey.

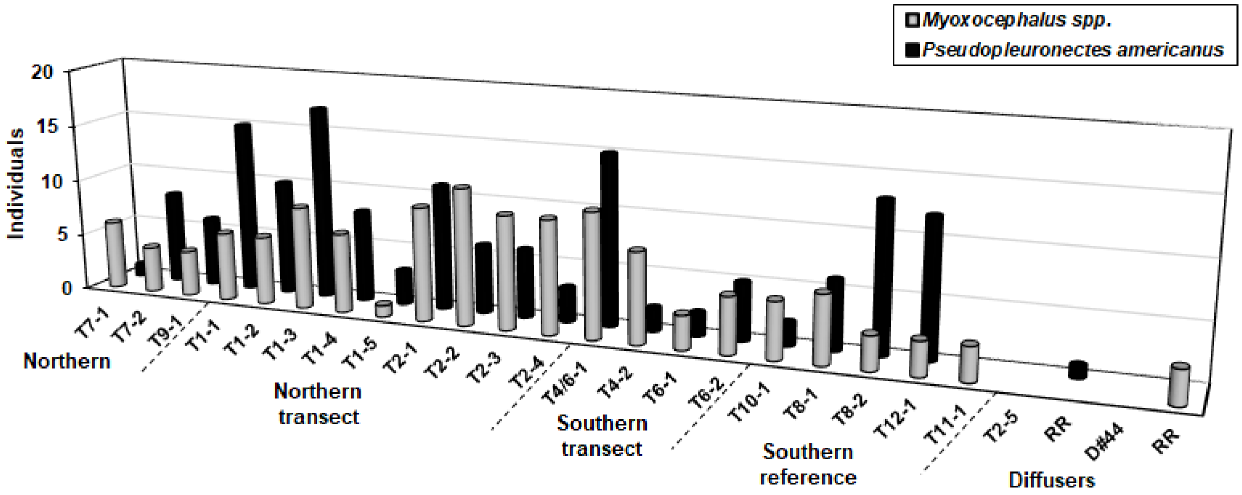

Figure 3-21. Number of *Pseudopleuronectes americanus* (Winter Flounder) and *Myoxocephalus* spp. (sculpin) observed in video footage taken during the 2023 hard-bottom survey.

During the 2023 survey, massive settlements of dead or dying off barnacle sets (*Balanus* sp.) were observed at many of the stations (Figure 3-22). Most of the boulders at 18 of the 23 stations were totally covered with the base plates and/or valves of dead barnacles and at another 2 stations the surfaces of some of the boulders were similarly covered. The exception to this was, few barnacles, dead or alive, were observed at the deepest stations (T4-2, T6-1, T11-1) or on the riprap surrounding the diffuser heads. Six sites also had dense stands of living barnacles and large numbers of adult northern sea stars (*Asterias rubens*) were frequently seen preying on them.

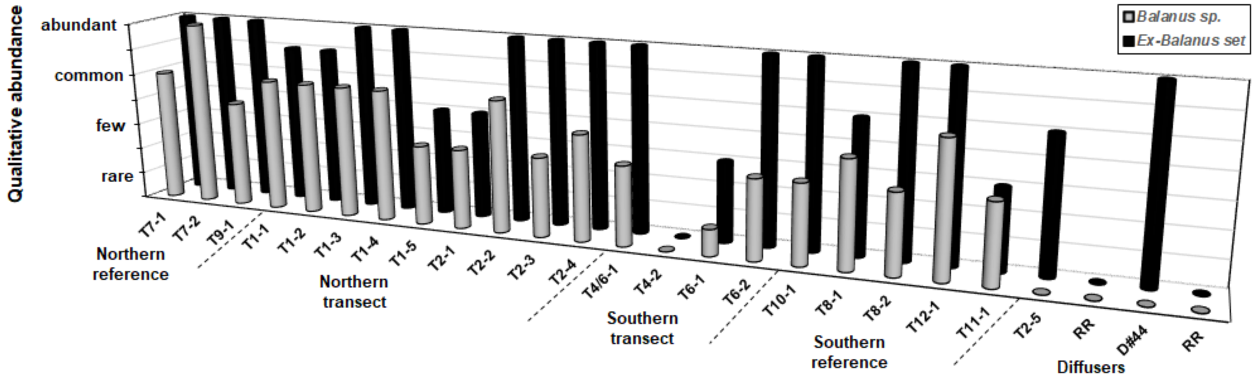

Figure 3-22. Qualitative abundance of live (*Balanus* sp.) and dead (Ex-*Balanus* set). *Balanus* sp. (barnacles) observed in video footage taken during the 2023 hard-bottom survey.

A few anomalies were observed in the sponge fauna. The most common sponge seen in the 2023 survey was a yellow encrusting sponge, *Polymastia* sp. A, which was common to abundant at 5 of the sites and few to common at another 5 sites. Another sponge, *Iophon nigricans*, a white sponge that usually encrusts the valves of brachiopods *Terebratulina septentrionalis*, was found in appreciable abundance at only 1 station in 2023 (T11-1) and only a few were observed at 3 other sites. The fig sponge (*Suberites* spp.), which had frequently been seen throughout the study area was totally absent in 2023.

Mussels were a large component of the benthic megafauna observed during the 2023 survey. The horse mussel, a cryptic species that occupies the sediment between the cobbles and boulders, was common to abundant at 17 of the stations (Figure 3-23). In contrast, the blue mussel, which frequently attaches to the surfaces of large boulders, was common to abundant at 8 of the sites and around several active ports of diffuser #2. Some blue mussels were also observed in the sediment nestled among horse mussels.

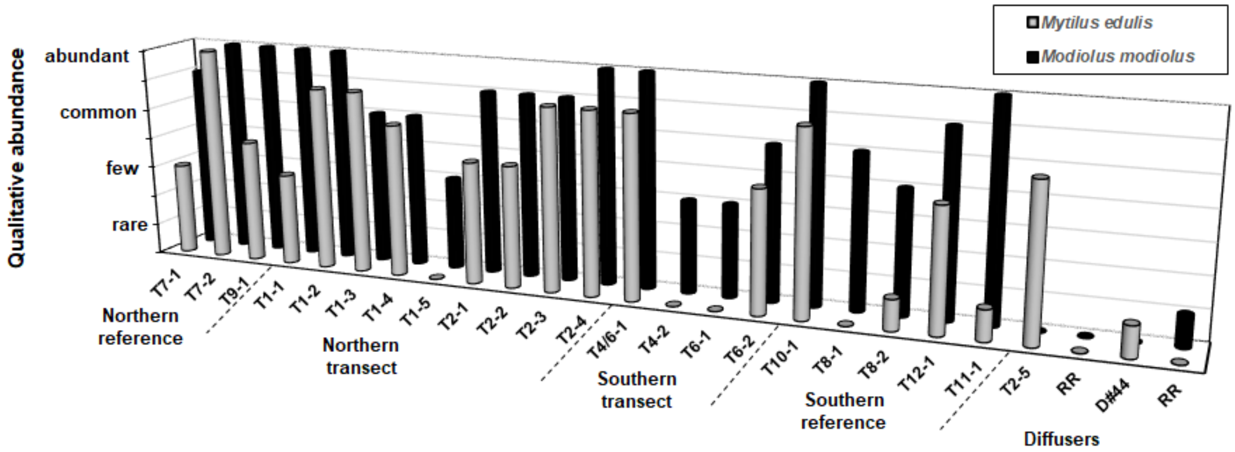

Figure 3-23. Qualitative abundance of mussels, *Modiolus modiolus* (horse mussel) and *Mytilus edulis* (blue mussel), observed in video footage taken during the 2023 hard-bottom survey.

The diffuser heads continued to support numerous frilled anemones (*Metridium senile*) and sea peach tunicates (*Halocynthia pyriformis)* in 2023. However, a few changes were noted. Namely the heavy barnacle settlement affected mostly the tops of the diffuser heads, but not the sides or the riprap. As a result, the top surface of both diffuser heads supported fewer *M. senile* than the side surfaces. The inactive diffuser head (#44) also supported a sparse population of *H. pyriformis*. The riprap at the base of the active diffuser head supported some *M. senile* and dense stands of the hydroid *Tubularia* sp. The riprap at the base of the inactive diffuser head (#44) mainly supports dense stands of unidentified hydroids.

3.3.2 Comparison of 2023 Data with Pre- and Post-Diversion Results

Previous general trends of decreased percent cover of coralline algae and declines in the number of upright algae observed in post-discharge years continued into 2023. Encrusting coralline algae has historically been the most abundant and widely distributed taxon encountered during the hard-bottom surveys. Table 3-5 presents the relative cover of coralline algae observed in video footage taken during the 1996 through 2023 surveys. Coralline algae were generally most abundant on the tops of drumlins on either side of the outfall (T1-2, T1-3, T1-4, and T4/6-1) and two southern reference sites (T8-1 and T8-2), and least abundant on the flanks of the drumlins (T2-2, T2-4, T4-2, and T6-1). The percent cover of coralline algae was quite stable during the baseline period and remained stable at most of the stations during the first four years of the post-diversion period. A decrease in cover of coralline algae started at the northern reference sites in 2002 and has persisted; a similar reduction has been evident at three drumlin top sites north of the diffuser (T1-2, T1-3, and T1-4) since 2004. Less pronounced decreases in cover of coralline algae are seen at several other sites since 2006. This pattern differs slightly from that observed in the analysis of the still images, where waypoints T1-2, T1-3, T1-4, T7-1, and T7-2, consistently had less percent cover of coralline algae since 2001. The subsequent decrease in cover of coralline algae in 2005 and the spread of this decrease to the southern areas was observed in both the video and still images, although less pronounced in the data collected from video images. The decreases in percent cover of coralline algae usually reflected increases in the amount of drape on the rock surfaces, but in 2023 it also reflected the heavy settlements of barnacles occupying much of the available rock surfaces.

The qualitative abundances of upright algae generally varied widely during both the pre- and post-diversion periods. At many sites the upright algae have shown a general decrease over time. The observed variability appears to reflect both patchiness in the spatial distributions of the upright algae and natural cycles in the composition of algal communities. Table 3-6 shows the qualitative abundance of *Palmaria palmata* (dulse) over the 1996 to 2023 time period. Dulse was consistently most abundant at the northern reference sites and common at two waypoints north of the outfall during the pre-diversion period. The qualitative abundance of dulse has decreased at these five sites during most of the post-diversion years, and additionally it dropped to an area wide low in 2003 and 2004. In contrast, since 2005 dulse has been seen in modest abundances at stations where it had historically been largely absent, such as on the drumlin immediately north of the outfall, and at two of the southern reference sites. By 2023 dulse numbers were widely reduced and it was only commonly seen at two reference stations.

Table 3-5. **Relative cover of coralline algae observed in video footage taken during the 1996 to 2023 hard-bottom surveys. An asterisk (*) denotes a very patchy distribution.**

		Pre-diversion					Post diversion														
		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2014	2017	2020	2023
Northern reference	**T7-1**	c-a	a	c-a	c	c-a	c-a	f-c	c	c	f-c	f-c	f-c	f-a	f-c	f-c	f-c	f	c	f	f-c
	T7-2	c-a	c-va	c-a	c	c-a	f-c	c	f-c	c	f-c	f-c	c	c-a	f-c	f-c	c	c	c	f-c	c
	T9-1		c-a	c-a	c	c	c-a	c	f-c	c	f-c	c	c	c	f-c	f-c	c	f-c	f-c	f-c	f-c
Northern transect	**T1-1**	va	c	c-a	c	c	f-c	f-c	f-c	c	f-c	f-c	f-c	f-c	f-c	f	f	f	f	f	f-c
	T1-2	a	va	a	c*	a	c-a	c	a	f-c	c-a	c	c-a	c-a	c-a	c	f-c	c-a	r	f	f-c
	T1-3	a	va	a	va	a	va	a	a	a	a	c	c-a	c	c-a	c-a	c	c-a	c	f-c	f-c
	T1-4	va	va	a	a	a	a	a	a	c-a	c-a	c-a	c-a	c-a	c-a	c-a	c	c	c-a	c-a	f-c
	T1-5	a*	c	c	c	c-a	f-c	f-c	c	c	f	r-f	f	r-f	f	f	f	r-f	c	r	r
	T2-1	f-a	f-c	r-f*	c	c	f-c	c	c-a	c	f	c	f-a	f-c	f	c	f-c	f-c	f	r-f	f
	T2-2	r	f	f-c*	r-c	c	f-c	r-f	f	f	f	r	r-f	f	f	f	f	r	f	r	r
	T2-3	c	r	c	c	f*	f-c	f-c	f-c	f	f	f-c	r-f	f-c	f	f	f	r	f-c	f	r
	T2-4	f	r	f	f	-	r	f	r-f	r	r	r	f	r-f	f	r	r	-	r	r	r
Southern transect	**T4/6-1**	va	c-a	a	a	a	va	a	a	a	a	a	c-a	c-a	a	a	a	a	c	f-c	f-c
	T4-1	r	f	r	-	f-c	-	r													
	T4-2	c	c-a	r-f*	f*	c	c	f-c	f	f-c	f-c	f-c	r	f	f	r-f	r-f	r	f	f	r
	T4-3	f	f	c	f-c	c	f-c	c													
	T6-1	r	r	r	r	r	r	-	r	-	-	-	-	-	r	r	-	-	r	-	-
	T6-2	c-a*	c	c-a	c	c	c	c	f-c	f-c	f-c	f	f	f-c	c	c-a	f	c	r-f	r	r-f
Southern reference	**T10-1**		r-f	-	r	r	-	r	-	r-c	r	-	-	-	-	r-f	r	-	-	-	-
	T8-1	a	c-a	a	c-a	c	a	c-a	c-a	c-a	a	c	c-a	f-c	c	c-a	c-a	f-c	f-c	f-c	f-c
	T8-2	a	a-va	a	c	a	c-a	c	a	a	a	c-a	c-a	c-a	c-a	c-a	c-a	f-c	c-a	c-a	c
	T12-1								c-a	c-a	c	c-a		c	c-a	c	c	c	c-a	c	c-a
	T11-1								-	f	f	f	r-f		f	r-f	f	f	f	f	f
Diffusers	**T2-5**	-	-				-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	RR	-	r	r			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	D#44			-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	RR			-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

a	c-a	c	f-c	f	r-f	r	-
abundant		common		few		rare	none

Table 3-6. Qualitative abundance of *Palmaria palmata* (dulse) observed in video footage taken during the 1996 to 2023 hard-bottom surveys. An asterisk (*) denotes a very patchy distribution.

		Pre-diversion					Post diversion														
		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2014	2017	2020	2023
Northern reference	**T7-1**	c	c-a	f	c	c-a	c-a	c-a	c	f-c	c-a	c-a	f-c	c-a	f-a	f-c	f-a	f-c	f-c	a	f-c
	T7-2	c	c	c-a	c-a	c	a	c-a	c-a	a	c	f-c	f-c	f	r-c	f-a	f-c	c	c-a	c-a	c
	T9-1		a-va	c	a	a	c-a	c	r-f	f	r-c	f	f	f	f-c	f-c	f	f-c	r-f	f-c	f
Northern transect	**T1-1**	a	a	c	c	f-c	f-c	c	f	f	c	f	r-f	f-c	c	f-c	f-c	f-c	r-f	r-c	r-f
	T1-2	f	-	r	f	-	r-f	-	r	r	r	f-c	f	f-c	f	c-a	c	f	c	f-c	f
	T1-3	-	-	r	-	r	f	f	f	r	f-c	f-c	f-c	c-a	f-a	c-a	c-a	c	c-a	c-a	r-f
	T1-4	-	-	-	-	-	r	-	f	r	f	f	f	f-c	f-c	f-a	f-c	c	r-f	f-c	r-f
	T1-5	r*	-	-	-	-	-	-	r	-	-	-	r	r	r	r	r	r	-	r-f	-
	T2-1	-	c	-	f	r	f	r	r	-	-	r	-	r-f	r-f	r	f	r	r-f	r-f	r
	T2-2	-	va	c	c	-	-	c	-	-	r-f	-	-	r	-	-	-	-	r	r-c	r
	T2-3	c	c	c	c	c	f-c	c	-	f	f	f-c	f	f	f-c	f-c	f	r-f	f-c	c	r-f
	T2-4	c	c	f-c	r	-	r-f	-	-	-	-	-	-	r	-	-	-	-	r	r	-
Southern transect	**T4/6-1**	f	c*	-	r	r	r	-	r	-	-	r	r	r	r-f	r-f	f	f	f	c	r
	T4-1	-	-	-	-	-	-	-													
	T4-2	-	-	-	-	-	-	-	-	-	-	f	r	-	-	-	r-f	-	-	-	-
	T4-3	-	-	-	-	-	-	-													
	T6-1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	T6-2	c*	-	r	-	-	-	-	-	-	-	-	-	-	r-f	r-f	-	r	-	-	-
Southern reference	**T10-1**		c-a	r	c	c	r	f-c	r	f-c	f	f	r	-	f	f-c	f-c	-	f	f	f-c
	T8-1	-	-	-	-	-	-	-	-	r	f	r-c	f	f-c	r-f	f-c	f-c	r-f	f-c	c	f
	T8-2	-	-	-	-	-	-	-	-	-	r	f	r	r	r-f	r	f	r	f-c	f-c	f
	T12-1								f	f	f	f-c		f-a	f-c	f-c	c	c	f-c	c-a	c
	T11-1								-	-	-	-	-		r-f	r	r	-	-	r	-
Diffusers	**T2-5**	-	-				-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	RR	-	-	-			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	D#44			-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	RR			-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

a	c-a	c	f-c	f	r-f	r	-
abundant		common		few		rare	none

Table 3-7 shows the qualitative abundance of *Ptilota serrata* (filamentous red algae) over the 1996 to 2023 time period. Historically, this filamentous red alga was consistently most abundant at the northern reference sites, and only occasionally common to abundant at sites on drumlins on either side of the outfall. The qualitative abundance of *P. serrata* decreased at the northern reference sites over time and had virtually disappeared at many of the other sites during most of the post-diversion years. Abundances of *P. serrata* reached an all-time low at almost all stations during 2007 and again in 2017. In 2020, this alga showed a substantial rebound at the northern reference sites, two southern reference sites and several other drumlin top sites on either side of the outfall. Some of the rebound in 2020 likely reflected the appearance of an invasive filamentous red alga, since many of the colonies observed at T12-1 had a more fibrous and turf-like form. By 2023 it had totally disappeared from the study area. Similar patterns early in the study were also observed in data collected from still images between 1996 and 2008. The observed patterns in algal increases and decreases may reflect different stages in a successional sequence of the benthic communities.

Another upright alga, the shotgun kelp (*Agarum clathratum*), has historically been consistently abundant only at the northern reference sites. This species was frequently quite patchily distributed even within a station, with many shotgun kelp fronds observed in some areas while none were observed in adjacent areas. There has been a general decrease in shotgun kelp at all the northern reference sites. This species was occasionally encountered at a few of the other waypoints during the pre-diversion period but has rarely been encountered elsewhere in the post-diversion period. Data collected from the slide images showed a dramatic decline in shotgun kelp at T7-1 from a high in 2000, when it was heavily overgrown by the invasive bryozoan *Membranipora membranipora*. This decline was much less evident in the data collected from video images. Specifics of the abundance and distribution of shotgun kelp over the time course of this study can be seen in Table 3-8.

Some of the decline in both coralline and upright algae at the northern reference sites during the early post-diversion period initially may have reflected post September 11, 2001, increases in anchoring activity of tankers at these sites. Disturbed areas of the seafloor were observed at all three northern reference sites at several instances during the post-diversion period. This may have resulted in a seafloor that is a mosaic of areas in differing stages of recovery from substantial physical disturbance. More recent decreases likely reflect successional changes in the benthic community, particularly as a result of space competition.

Table 3-7. Qualitative abundance of *Ptilota serrata* (filamentous red alga) observed in video footage taken during the 1996 to 2023 hard-bottom surveys. An asterisk (*) denotes a very patchy distribution.

		Pre-diversion					**Post diversion**														
		1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2014**	**2017**	**2020**	**2023**
Northern reference	**T7-1**	va	c-a	a	a	c	c-a	c-a	c-a	f-a	c-a	c-a	f-c	c-a	f-a	f-c	f-c	f	f	a	-
	T7-2	va	c-a	a	a	c-a	a	c	c-a	a	a	f-a	f-c	f-c	r-c	f-a	f-c	f-c	f	c-a	-
	T9-1		a-va	c-a	a	c-a	c	f-c	r	f	r-c	-	-	-	f-c	f-c	f	-	-	f-a	-
Northern transect	**T1-1**	a	-	c-a	-	-	-	f	-	-	-	-	-	-	f	-	-	-	-	r-f	-
	T1-2	a	-	f	-	-	-	-	-	-	-	-	-	-	f-c	f-c	c	-	-	f-c	-
	T1-3	f	-	f	-	-	f	-	r	c-a	r	r-c	f-c	c-a	c-a	c-a	a	c	c	c-a	-
	T1-4	r-f	-	-	-	-	-	-	-	r-f	-	f	-	f-c	c-a	f-a	f-c	c-a	-	c-a	-
	T1-5	f-c*	-	-	-	-	-	-	-	-	-	r-f	-	-	r-f	-	-	-	-	r-f	-
	T2-1	f	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	T2-2	f	c	a*	c	-	-	-	-	-	-	-	-	-	-	-	-	-	r	r-f	-
	T2-3	a	-	c-a	f-c	f-c	-	r-f	-	-	-	r	-	-	-	-	-	-	-	r	-
	T2-4	a	r	c	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Southern transect	**T4/6-1**	c-va	c-a	f	f	-	-	-	-	-	-	-	-	r	r-f	r-f	f-c	f-c	-	c-a	-
	T4-1	-	-	-	-	-	-	-													
	T4-2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	T4-3	-	-	-	-	-	-	-													
	T6-1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	T6-2	c-va*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Southern reference	**T10-1**		c-a	f-c	f	-	-	-	-	-	-	-	-	-	r	r	-	-	-	r	-
	T8-1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	r	-	-	f	-
	T8-2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	f	-
	T12-1								f-c	f-c	-	f		f-a	f-c	c-a	c-a	a	f-a*	a	-
	T11-1								-	-	-	-	-		-	-	-	-	-	-	-
Diffusers	**T2-5**	-	-				-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	RR	-	-	-			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	D#44			-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	RR			-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

a	c-a	c	f-c	f	r-f	r	-
abundant		common		few		rare	none

Table 3-8. Qualitative abundance of *Agarum clathratum* (shot-gun kelp) observed in video footage taken during the 1996 to 2023 hard-bottom surveys. An asterisk (*) denotes a very patchy distribution.

		Pre-diversion					Post diversion														
		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2014	2017	2020	2023
Northern reference	T7-1	c	f	a	c	a	f-c	c	c	c	c	f-c	f-c	c	c	c	f-c	-	-	-	-
	T7-2	va	f-c	a	c-a	a	c-a	c	c	c-a	a	c	r	-	f	r-a	c-a	r-f	r	f-c	-
	T9-1		va	c-a	a	c	c	f	-	r	r	-	-	-	r	r	-	-	-	-	-
Northern transect	T1-1	f	f	f	-	r	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	T1-2	c	f	r	-	-	r	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	T1-3	-	-	-	r	r	-	r	-	-	-	-	-	r	-	f-c	f-c	-	-	-	r
	T1-4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	T1-5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	T2-1	-	-	-	r	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	T2-2	-	-	c*	c	-	-	r	-	-	-	-	-	-	-	-	-	-	-	-	-
	T2-3	r	r	f	r	c*	f	r	-	-	-	-	-	-	-	-	-	-	-	-	-
	T2-4	-	-	r	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Southern transect	T4/6-1	f	c*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	T4-1	-	-	-	-	-	-	-													
	T4-2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	T4-3	-	-	-	-	-	-	-													
	T6-1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	T6-2	c*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Southern reference	T10-1		a	-	c	c	-	r	-	r	-	r	-	-	-	-	-	-	-	-	-
	T8-1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	T8-2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	T12-1								-	r	-	-		-	-	-	-	-	r	r	r
	T11-1								-	-	-	-	-		-	-	-	-	-	-	-
Diffusers	T2-5	-	-				-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	RR			-			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	D#44			-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	RR			-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

a	c-a	c	f-c	f	r-f	r	-
abundant		common		few		rare	none

Examples of the visual changes observed in the study area can be seen in images taken over time at three representative sites. The plates in Appendix D show the seafloor during representative years at a northern control station (T7-1), a shallow drumlin top station (T1-3), and a southern control station (T8-1). At northern reference site, T7-1, dense upright algal populations were present in the pre-diversion years and the algae generally decreased during the post-diversion years. Also, instances of severe physical disturbance in the form of anchor scars started to be noticed in 2007 and upright algae started to sporadically increase and decrease. In 2023, few upright algae were observed at the northern sites and numerous dead barnacles can be seen covering the rock surfaces. At shallow drumlin top site, T1-3, very little sediment drape and exceptionally high percent cover of coralline algae dominated in the pre-diversion period. Sediment drape started increasing and percent cover of coralline algae started decreasing at this site during the post-diversion period. Additionally, upright algae gradually started being observed, but had disappeared by 2023. At the southern reference station, T8-1, the pre-diversion years were characterized by moderately light sediment drape and high percent cover of coralline algae. Sediment drape started noticeably increasing and percent cover of coralline decreasing by 2005-6, and some upright algae (mainly dulse) started appearing but had largely disappeared by 2023.

One noticeable difference seen during the 2014, 2017, 2020, and 2023 surveys was the widespread presence of dead or dying barnacles at many of the stations (Table 3-9). Large areas of rock surfaces covered by dead or dying barnacles were observed at 15 stations in 2014, 16 stations in 2017, 12 stations in 2020 and 18 stations in 2023. These stations were spread throughout the study area, including the two diffuser stations. While heavy sets of dead barnacles were observed in the past, the numbers seen in 2023 far exceeded previous observations. Dead and live barnacles covered much of the available hard surface area at many of the stations, including the tops of the diffuser heads as well as the surfaces of the blue mussels. In some areas, the dead barnacles were so dense that they appeared to have crowded out other components of the benthos. The die off of heavy barnacle sets is likely an early stage in the succession of the benthic community, it opens up available space on the rocky substrate for other species to settle upon. Similar instances of large areas of dead barnacle sets have been noted several times in previous years, but never as predominantly or as widespread as those observed in 2023. Additionally, the presence of numerous live barnacles at some of these stations resulted in a dramatic increase in the abundance of adult northern sea stars that were seen preying on the barnacles. In contrast, the deeper southernmost reference site (T11-1) evidenced only a few barnacles and no dense dead or live sets.

In 2020 and 2023, the blue mussel became a more dominant component of the fauna inhabiting large boulders at several of the stations than in previous years. In 2020, dense aggregations were observed covering much of the upper surface area of large boulders and were also found in clumps near the open ports of the active diffuser head. In 2023, these aggregations were diminished likely due to the heavy cover of dead or dying barnacles, but they were still an important component of the benthic community. Additionally, blue mussels were also seen inhabiting the sediment alongside the horse mussel near the base of boulders at quite a few of the stations. This is in contrast to the years prior to 2020 where the blue mussel was largely restricted to the surfaces of large boulders. It is interesting to note that the number of blue mussels has been increasing in the deeper water, while at the same time drastically decreasing in the intertidal zone (Sorte et al. 2017). The disappearance of blue mussels from the intertidal has been suggested to be related to increasing water temperatures due to climate change.

Table 3-9. **Qualitative abundance of dead barnacles observed in video footage taken during the 1996 to 2023 hard-bottom surveys.**

		Pre-diversion					Post diversion														
		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2014	2017	2020	2023
Northern reference	**T7-1**								f	f	-	-	a	c	-	r	a	a	a	a	va
	T7-2								f	r	f	-	-	-	f	a	c	a	a	a	a
	T9-1								a	f	c	f	-	-	c	f	f	a	a	a	a
Northern transect	**T1-1**								-	-	-	-	r	-	-	-	-	a	a	c	c-a
	T1-2								f	c	-	-	f	-	-	-	r	a	a	a	c-a
	T1-3								-	-	-	-	f	f	-	c	-	a	a	a	a
	T1-4								f	f	-	-	c	f	f	-	-	a	a	f-c	a
	T1-5								-	-	-	-	c	-	-	r	f	f	f	f	f-c
	T2-1								-	-	r	-	c	-	-	a	r	c	a	f-c	f-c
	T2-2								-	-	-	-	a	-	-	-	-	a	a	c	a
	T2-3								-	c	-	-	c	-	-	r	-	a	a	a	a
	T2-4								-	-	-	-	-	-	-	-	-	f	a*	c	a
Southern transect	**T4/6-1**								a	a	a	-	f	-	-	c	r	a	a	a	a
	T4-1																				
	T4-2								a	f	f	f	f	-	-	-	-	f-c	f	r	-
	T4-3																				
	T6-1								-	-	-	-	-	-	-	-	-	a	-	-	f
	T6-2								-	a	-	-	a	-	-	a	r	a	a	a	a
Southern reference	**T10-1**								c	a	a	c	a	-	a	a	a	a	a	a	va
	T8-1								f	-	-	-	-	-	-	-	-	f	f	r	c
	T8-2								-	-	-	-	f	-	-	-	-	f	-	f-c	a
	T12-1								-	f	c	-		-	-	-	f	c	-	f	a
	T11-1								c	c	-	-	f		-	r	r	r	-	f	f
Diffusers	**T2-5**								-	-	-	-	-	-	-	-	-	-	-	-	c
	RR								-	-	-	-	-	-	-	-	-	-	-	-	-
	D#44								a	-	-	-	-	-	-	-	r	-	c	-	a
	RR								-	-	-	-	-	-	-	-	-	-	-	-	-

a	c-a	c	f-c	f	r-f	r	-
abundant		common		few		rare	none

The pronounced decrease in two of the sponge taxa, the fig sponge *Suberites* spp. and the white sponge encrusting brachiopod valves *Iophon nigricans*, is somewhat perplexing. *Suberites* spp. was observed at only the southernmost reference station in 2017 and 2020, and none were observed in 2023. This sponge typically attaches onto larger boulders and may have been outcompeted by the massive barnacle sets occupying available settlement space. Although, if this were the sole reason for the decline in *Suberites* spp. then we would have also expected a similar decline in 2014, which did not happen (Table 3-10). An explanation for the decrease in *I. nigricans* is even more perplexing. This sponge is only found encrusting brachiopod valves and it was commonly observed at 2 to 15 stations prior to 2017 (Table 3-11). Since 2017 substantial numbers of *I. nigricans* have been found at only the southernmost reference station (T11-1). Brachiopods have been observed at more stations but most of them did not have a sponge covering. Whether the brachiopods were newly attached and had not yet acquired a sponge covering is presently unknown. It is interesting to note that sponges are filter feeders and might be expected to be more sensitive to changes in their environment than other taxa. However, the brachiopods themselves are also filter feeders. Another common sponge, *Polymastia* sp. A has remained present in high abundances over the entire time period (*Polymastia*) but was present in slightly reduced numbers in 2023. Another sponge, *Halichondria panecia* (breadcrumb sponge) which was abundant at five sites in 2020 was almost totally absent in 2023. The observed changes in the sponge populations may simply be related to competition for available settlement space with the heavy influx of barnacle sets and some sponges being better competitors than others.

Table 3-12 shows long-term trends that have been noted in the abundances of several of the larger mobile taxa over time. These trends appear to reflect widespread temporal changes in abundances rather than changes related to the outfall, since they were evident throughout the survey area (at both outfall and reference sites). The numbers of *Cancer* crabs, American lobster (*Homarus americanus*), Atlantic Cod (*Gadus morhua*), and Winter Flounder observed during the surveys generally increased over time. The number of *Cancer* crabs seen annually ranged from 0.6 to 3.6 individuals per 100 minutes of video between 1996 and 1999, to 6.4 to 39.1 individuals per 100 minutes of video between 2001 and 2023. The abundance of crabs varies widely and appears to undergo several-year cycles of higher and lower abundances, but the general trend has been towards more crabs over time. The number of lobsters seen during the surveys also increased over time, ranging from 0.5 to 4.1 individuals per 100 minutes of video per year in the pre-diversion period to 2.3 to 18 individuals per 100 minutes of video per year in the post-diversion period. Cod show a similar pattern with 0 to 5.2 individuals per 100 minutes of video seen annually during the pre-diversion years and 6.7 to 20.3 individuals per 100 minutes of video seen annually during all but four of the post-diversion years. The low number of cod seen during the 2014, 2017, and 2023 surveys may reflect high levels of suspended matter reducing visibility during those surveys. Winter Flounder increased in abundance only since 2008, ranging from 2.5 to 8.1 individuals per 100 minutes of video seen during the pre-diversion period, 1.9 to 5.3 individuals per 100 minutes video between 2001 and 2007, 8.7 to 17.1 individuals per 100 minutes of video between 2008 and 2017, 45.8 individuals per 100 minutes video in 2020, and 31.2 individuals per 100 minutes video in 2023. Flounder are usually much less skittish than cod, frequently allowing the ROV to closely approach them or actually following the ROV to feed off organisms kicked up into the water column by the passage of the vehicle.

Table 3-10. **Qualitative abundance of the fig sponge *Suberites* spp. observed in video footage taken during the 1996 to 2020 hard-bottom surveys.**

		Pre-diversion					Post diversion														
		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2014	2017	2020	2023
Northern reference	**T7-1**	-	-	-	-	-	-	f	-	r	-	-	-	-	-	r	-	-	-	-	-
	T7-2	r	r	-	-	-	-	f	r	r	-	-	-	r	-	r	-	-	-	-	-
	T9-1		f	f	-	f	r	f	-	-	r	-	c	r-f	-	f	-	f	-	-	-
Northern transect	**T1-1**	r	-	f	c	f	c	f	c	c	f	f	f	f-c	f	f-c	f-c	f	-	-	-
	T1-2	-	-	-	c	f	-	-	-	f	-	-	-	-	-	-	r	-	-	-	-
	T1-3	-	-	-	f	-	r	-	-	-	-	-	-	-	-	-	-	r	-	-	-
	T1-4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	T1-5	-	r	f	c	f	f	f	c	f	f	f-c	c	f-c	c	c	f-c	f	-	-	-
	T2-1	r	f	f-c	c	f	c	c	f	f-c	f	c	f-c	f-c	f	c	f	f	-	-	-
	T2-2	a	c	-	c	c	c	f	c	f-c	f	c	c	c	c	c	c	f	-	-	-
	T2-3	c	r	c	c	f	c	c	c	f	f	f	f-c	c	f-c	c	f-c	r	-	-	-
	T2-4	a	f	c	c	c	c	c	f-c	f-c	f	f	f-c	f	f	f-c	f-c	c	-	-	-
Southern transect	**T4/6-1**	-	r	-	-	-	-	-	-	-	-	-	r	-	-	-	-	-	-	-	-
	T4-1	-	-	-	r	r-c	-	r													
	T4-2	c	r	f	c	c-a	f-c	r	c	f	f-c	f	f	f	r-f	r	c	f	-	-	-
	T4-3	f	c	f	f	c	c	c													
	T6-1	-	r	f	f-c	f-c	r	f	f	f	f	-	-	-	r	r	-	-	-	-	-
	T6-2	-	r	f-c	c	c	c	f-c	c	f	f	c	f-c	f-c	f	r	c	r	-	-	-
Southern reference	**T10-1**		-	-	-	-	-	-	r	-	f	f	c	c	f	f	c	f-c	-	-	-
	T8-1	-	-	-	r	-	-	-	-	-	-	-	-	f	-	-	r	r	-	-	-
	T8-2	r	-	f	r	-	-	r	-	-	-	f	r	r	r	r	-	f	-	-	-
	T12-1								-	r	-	r	-	r	-	-	r	-	-	-	-
	T11-1								c	c	c	f-c	f-c	-	f	c	c	c	c	c	-
Diffusers	**T2-5**	-	-				-	-	-	-	-	r	-	-	r	f	f	-	-	-	-
	RR	-	-	c			-	-	-	-	-	r	-	-	r	f	r	-	-	-	-
	D#44			-		-	-	-	-	-	-	-	-	-	-	-	r	-	-	-	-
	RR			-		-	-	-	-	-	-	-	-	-	-	-	r	-	-	-	-

a	c-a	c	f-c	f	r-f	r	-
abundant		common		few		rare	none

Table 3-11. Qualitative abundance of *Iophon nigricans* observed in video footage taken during the 1996 to 2020 hard-bottom surveys. An asterisk (*) denotes a very patchy distribution.

		Pre-diversion					Post diversion														
		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2014	2017	2020	2023
Northern reference	T7-1	-	r	-	-	-	-	-	-	f	-	-	f-c	-	-	r	r	c	-	r*	-
	T7-2	-	-	c	f	a	a*	f	f-c	c	c	r-c	f	-	f	c	f-c	f	-	r*	-
	T9-1		c	a	-	c	a	c	f-c	c	c	c	c	f-c	c	c-a	f-a	c	-	r*	-
Northern transect	T1-1	-	-	-	-	-	-	-	-	f	-	-	r	f	f	-	r	r-f	-	-	-
	T1-2	-	-	-	-	-	-	-	-	r	-	-	f	f-c	-	-	-	-	-	-	-
	T1-3	-	-	-	-	-	-	-	-	-	-	-	-	-	r	c	f-c	-	-	-	-
	T1-4	-	-	-	-	-	-	-	-	-	-	-	r	-	-	-	-	-	-	-	r
	T1-5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	r	r	-	-	-	-
	T2-1	-	-	-	-	-	-	-	-	-	r	-	r	-	r	r	f	r	-	r	-
	T2-2	-	-	c	-	-	f	f-c	r	r	f	f	f	f	c	f-c	f	r-f	r-c*	-	-
	T2-3	f	r	c	-	-	c*	a	f	c	f	f	c	f	f-c	c	c	f-c	-	r	-
	T2-4	r	c	c	c	a	c	c	c-a	a	c-a	c-a	c-a	c	c-a	c-a	c	f-a	-	r	r
Southern transect	T4/6-1	-	-	c	-	-	c*	c	-	-	f	-	f-c	f	-	-	-	-	-	-	-
	T4-1	-	-	-	-	0-a	-	-													
	T4-2	-	-	f	f	f	c	-	f-c	-	f	c	f-c	f-c	c	r	f	f-c	-	-	r
	T4-3	-	-	-	-	-	r	-													
	T6-1	-	-	-	-	-	-	-	-	-	-	-	-	-	r	-	r	-	-	-	-
	T6-2	-	-	-	-	-	-	-	-	-	r	-	f	-	f	-	f	-	-	-	-
Southern reference	T10-1		-	-	-	c	c*	r	-	-	c	c	f	f-c	f-c	c	f	f	-	-	-
	T8-1	-	-	-	-	-	-	-	-	-	-	-	-	r	-	-	-	-	-	-	-
	T8-2	-	-	-	-	-	-	-	-	-	-	-	-	-	r	-	r	-	-	-	-
	T12-1								-	c	c-a	f		f-c	f-c	f	r-c	f	-	-	-
	T11-1								a	a	c	a	c-a		c-a	a	a	c	c	c-a	c
Diffusers	T2-5	-	-			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	RR	-	-	f		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	D#44			-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	RR			-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

a	c-a	c	f-c	f	r-f	r	-
abundant		common		few		rare	none

Table 3-12. Number of several large mobile commercially important species observed in video footage taken during the 1996 to 2023 hard-bottom surveys (standardized to number seen per 100 minutes of video).

	Pre-discharge					**Post-discharge**														
	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2014**	**2017**	**2020**	**2023**
***Cancer* spp. (rock crab)**	1.4	0.6	0.9	3.6	20.9	27.5	33.9	30.7	25.3	14.4	19.3	24.5	6.3	19.0	6.4	7.1	39.1	10.7	17.5	32.2
***Homarus americanus* (lobster)**	1.4	0.5	2.5	0.9	4.1	4.8	7.1	7.5	2.7	2.3	8.0	8.2	2.7	18.0	8.0	9.4	9.1	9.6	7.0	9.4
***Gadus morhua* (cod)**	-	1.4	2.7	5.2	2.5	9.2	10.7	2.1	11.5	13.7	14.1	9.1	14.4	20.3	7.2	6.7	2.0	2.3	15.3	2.3
***Pseudopleuronectes americanus* (winter flounder)**	4.6	2.9	6.8	8.1	2.5	4.0	3.8	1.9	5.3	3.6	2.6	3.6	10.6	8.9	17.1	12.9	9.4	8.7	45.8	31.2

In 2023 the top surfaces of the diffuser riser caps were covered with dead barnacle bases and valves, while the sides of the caps and the riprap surrounding them were not. Prior to 2023, the faunal communities inhabiting the riser caps have not changed much. Figure 3-24 shows the top and side of the active diffuser head (Diffuser #2) in 2020 and 2023. This riser cap has historically been almost completely covered by a dense stand of the frilled anemone *Metridium senile*, numerous *Tubularia* sp. hydroids, and a few large sponges. Far fewer *M. senile* and *Tubularia,* and no sponges, were seen on the top surface of the diffuser head in 2023 and much of the space was occupied by dead barnacles. The dense stands of *M. senile* were still present on the sides of the diffuser where fewer of the barnacles had settled. The inactive riser cap (Diffuser #44) has traditionally been colonized by a sparser population of *M. senile*, and a few sea peach tunicates, *Halocynthia pyriformis* as seen in 2020 in Figure 3-25. In 2023, the top surface of diffuser #44 was also colonized by barnacles, but it did not appear to impact the existing population of *M. senile* as much. Again, the sides of the riser caps were not covered with as many barnacles and the fauna inhabiting them did not appear to change much.

The data obtained from an analysis of the video images showed similar patterns to that observed in data obtained from analysis of the slides earlier in the study (1996 to 2008). The data from the video analysis was not quite as sensitive as that obtained from the slides, and also showed a time lag in discerning changes. This is not surprising since the data from the video is frequently a range of qualitative abundances encountered at a waypoint rather than a discrete number that represents an average of 25 to 30 slides. Ranges would be much less sensitive to subtle changes in the relative abundances of the biota. However, both techniques showed similar patterns, so the video analysis appears to be sensitive enough to discern more dramatic changes.

Has the hard-bottom community changed?

The hard-bottom benthic communities near the outfall remained relatively stable over the 1996–2000 baseline time period and have not changed substantially with activation of the outfall in September 2000. Major departures from baseline conditions have not occurred during the post-diversion years; however, some changes have been observed. Increases in sediment drape, and concurrent decreases in cover of coralline algae, were observed at several drumlin-top sites north of the outfall and at the two northernmost reference sites during all of the post-diversion years. The decrease in coralline algae became more pronounced in 2005 and spread to a number of additional sites south of the outfall. Decreased cover of coralline algae at the stations close to the outfall may be related to the diversion, or may just reflect long-term changes in sedimentation, and hence coralline algae patterns. Additionally, a decrease in the number of upright algae was observed at many of the stations. However, it is unlikely that this decrease was attributable to diversion of the outfall, since the general decline had started in the late 1990s and the number of upright algae increase and decrease on a regular basis. The decline had been quite pronounced at the northern reference stations and may reflect physical disturbance of the seafloor, possibly due to anchoring of tankers at these locations following September 11, 2001. Disturbance of the seafloor in the form of overturned boulders and areas of shell lag had been noticed at the northern reference sites in the earlier post-diversion years.

In recent years, we have noticed several other changes. Lush epifaunal growth continues to thrive on the diffuser heads surveyed for this study and throughout many of the other stations visited. The most noticeable changes observed recently may reflect natural variability in the benthic communities or may represent other shifts in the environment. The massive and widespread barnacle settlement events observed in 2014, 2017, 2020 and 2023 may likely reflect natural cycles in the population. In contrast, the observed decrease in abundance and distribution of two of the sponge taxa may reflect competition among sessile fauna for settlement space or may be the result of cumulative habitat degradation. So, while outfall impacts have appeared to be minimal over time, changes in the hard-bottom communities could be chronic and/or cumulative and may take longer to manifest themselves.

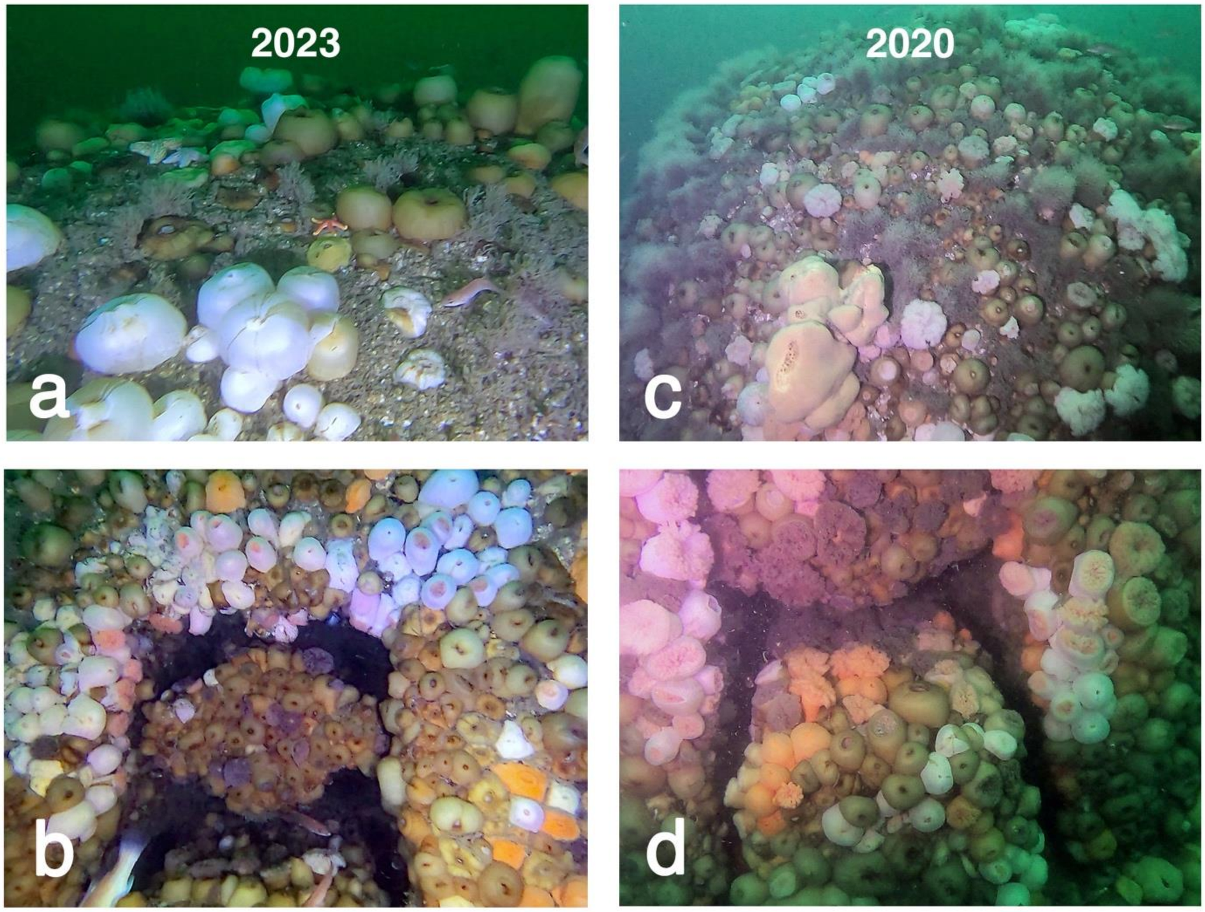

Figure 3-24. Still images taken at active diffuser head #2 in 2023 and 2020. (a) The top surface of the riser cap supported numerous frilled anemones *Metridium senile* and a few hydroids, but also showed the remnants of a dense dead barnacle set in 2023. (c) In contrast, in 2020 the top of the riser cap was almost entirely covered with *M. senile*, some *Tubularia* sp. hydroids, and several large globular sponges. Far fewer barnacles settled on the sides and ports of the riser cap, so equivalent numbers of *M. senile* were seen in 2023 (b) when compared to 2020 (d).

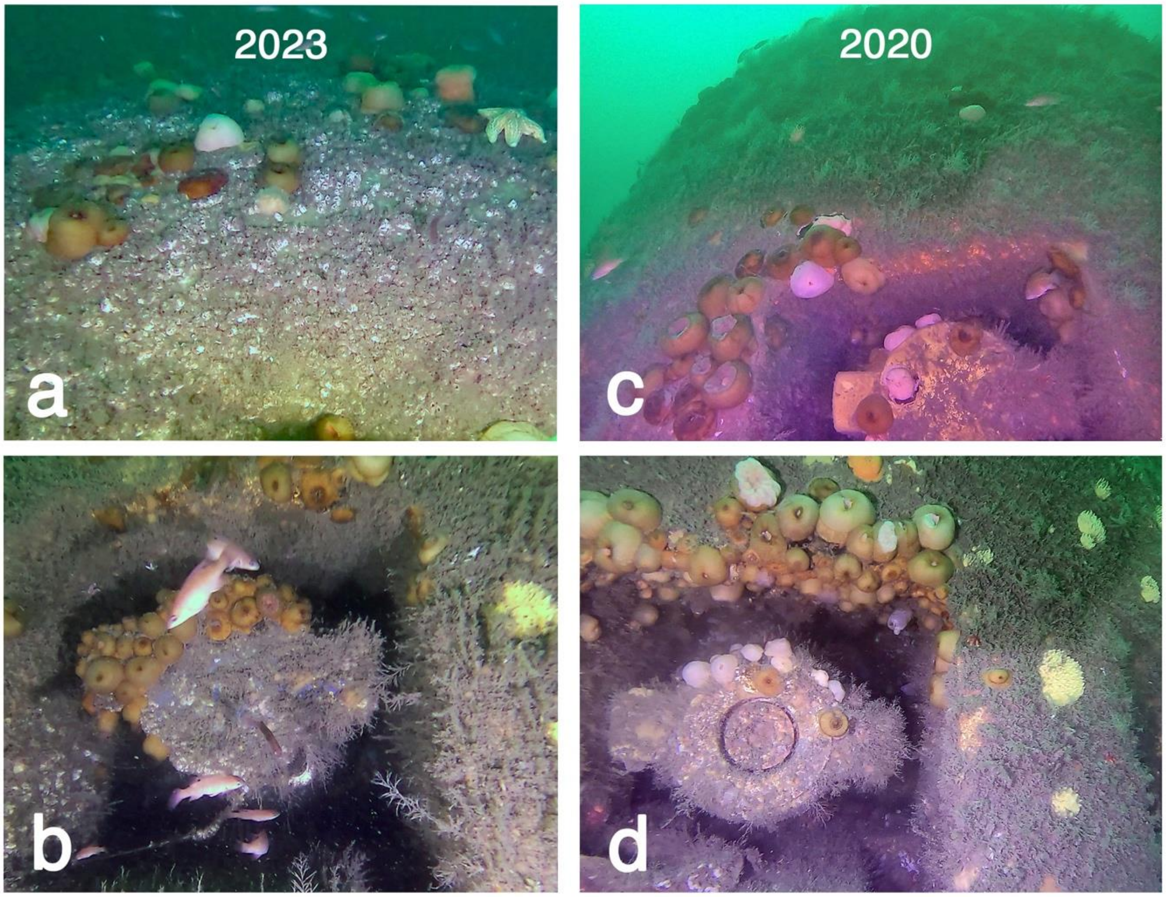

Figure 3-25. Still images taken at inactive diffuser head #44 in 2023 and 2020. (a) The top surface of the riser cap was almost entirely covered by dead barnacles in 2023. It also supported a sparse population of frilled anemones *Metridium senile* and a few adult northern sea stars *Asterias rubens*. (c) An equally sparse population of *M. senile* was also observed in 2020, as well as numerous hydroids and only a few dead barnacles. The sides and ports of the riser cap had only a few dead barnacles and supported roughly equal densities of *M. senile*, hydroids, sea peach tunicates *Halocynthia pyriformis*, and *Polymastia* sp. sponges in 2023 (b) and 2020 (d).

4 SUMMARY OF RELEVANCE TO MONITORING OBJECTIVES

Benthic monitoring for MWRA's offshore ocean outfall focused on addressing three primary concerns regarding potential impacts to the benthos from the wastewater discharge: (1) eutrophication and related low levels of dissolved oxygen; (2) accumulation of toxic contaminants in depositional areas; and (3) smothering of animals by particulate matter.

Findings from previous assessments found no indication that the wastewater discharge has resulted in low levels of dissolved oxygen or the accumulation of toxic contaminants in nearfield sediments (Nestler et al. 2024, 2020; Maciolek et al. 2008). As result, SPI surveys in Massachusetts Bay and the sediment contaminant evaluation every third year at the nearfield and farfield stations were discontinued in 2020.

Surveys of soft-bottom benthic communities presented in this report continue to suggest that animals near the outfall have not been smothered by particulate matter from the wastewater discharge or experienced stress resulting from increased deposition of organic matter. The percentage of fine grain sediments has not increased at stations closest to the discharge since the diversion, indicating no pattern of settlement of particulate matter from the discharge. There were no Contingency Plan threshold exceedances for any infaunal diversity measures in 2023.

Hard-bottom benthic community monitoring in 2023 also found no evidence that particulate matter from the wastewater discharge has smothered benthic organisms. Although some changes in this community (e.g., decreased coralline algae, temporal variability in upright algae cover, decreased sponge abundance, and increases in barnacle settlement events) have been observed, comparisons between the post-diversion and baseline periods indicate that these changes are not substantial. These changes may reflect natural variability in the benthic communities from multi-year population cycles and interspecies competition or may represent other environmental shifts.

Benthic monitoring results continued to indicate that the three potential impacts of primary concern have not occurred at the MWRA stations. Results also continue to demonstrate that the benthic monitoring program can detect both the influence of the outfall and the subtle natural changes in benthic communities. The spatial extent of particulate deposition from the wastewater discharge is measurable in the *Clostridium perfringens* concentrations in nearfield sediments. The *C. perfringens* concentrations provide evidence of the discharge footprint at stations close to the outfall. Within this footprint, no other changes to sediment composition and infaunal communities have been detected. Patterns identified in analyses of sediments and infauna in 2023 were largely consistent with previous years. Nonetheless, subtle variations in the species composition of infaunal assemblages clearly delineate natural spatial variation in the benthic community based on habitat (e.g., associated with different sediment grain sizes) and bottom energy (e.g., turbulence and sediment transport associated with storm events). Changes over time have also been detected including region-wide shifts in diversity, with peaks from 2010 to 2012, in the Massachusetts Bay infaunal assemblages. Detection of these spatial and temporal patterns in the benthos suggests that any ecologically significant adverse impacts from the outfall would be readily detected by the monitoring program if those impacts had occurred.

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APPENDIX A SUPPLEMENTAL INFORMATION ON THE POTENTIAL ERRONEOUS TOTAL ORGANIC CARBON VALUES REPORTED AT STATIONS FF04 AND NF22

The 2023 total organic carbon (TOC) results from two stations, FF04 (a depositional site in Stellwagen Basin) and NF22 (approximately 4 km from outfall), had unusual values and were investigated as potentially being swapped either due to mislabeling in the field or in the laboratory. Sample swaps are uncommon due to the multiple data checks that occur during sample collection and analysis, but can happen. This brief overview provides the reasoning behind the belief that a sample swap may have occurred. Ultimately, it was decided to remove the data from the subsequent analyses and figures. The data has been qualified in the database as suspect data and not fit-for-use.

The reported total organic carbon component of the sediment was unusual at these two stations. Station FF04 typically has a high percentage of total organic carbon, but in 2023 it was much lower than historically reported (Figure A-1). The reverse was true at station NF22, which typically has a low percentage of total organic carbon, but in 2023 it was much higher than historically reported (Figure A-2).

Station FF04 is historically a site with very fine sediments, and data from 2023 continue to show fine sediments (Figure 3-4, Figure A-3). Station NF22 is historically a site characterized as mixed sediments, with sand, silt and clay present, and data from 2023 continued to show these substrate characterizations (Table 3-1). The total solids measured at both sites are consistent throughout the time series including 2023 (Figure A-3). The relationship between total organic carbon and sediment size is such that the finer the sediment, the more organic carbon is generally present. Therefore, it is unusual that the total organic carbon percentages would have changed so drastically, without a corresponding change in sediment size. Two scatterplots relating TOC and % silt and clay (Figure A-4), and TOC and total solids (Figure A-5), show that the TOC value reported at each of these stations would be more consistent with the relationship if the two reported values were in fact swapped.

Finally, linear regression was used to estimate the TOC value based on the percent clay measurement using all of the years of data for each station. An analysis of the residuals was then performed based on this regression equation. The residuals (the difference between the reported TOC value and the predicted TOC value) were normally distributed. Residuals were ‘studentized’ by dividing each residual by the standard deviation of the residuals. These studentized residuals can be interpreted as standard deviations away from the mean of the residuals, such that most of the residuals should fall within 2 standard deviations of zero. All predicted TOC values had residuals that fell within 2 standard deviations of the mean at both stations, FF04 and NF22, except in 2023. The recorded TOC values at FF04 and NF22 in 2023 were near to 4 (Figure A-6) and close to 5 (Figure A-7) standard deviations away from the mean, respectively. This suggests that the two reported TOC values are outliers and are likely erroneous.

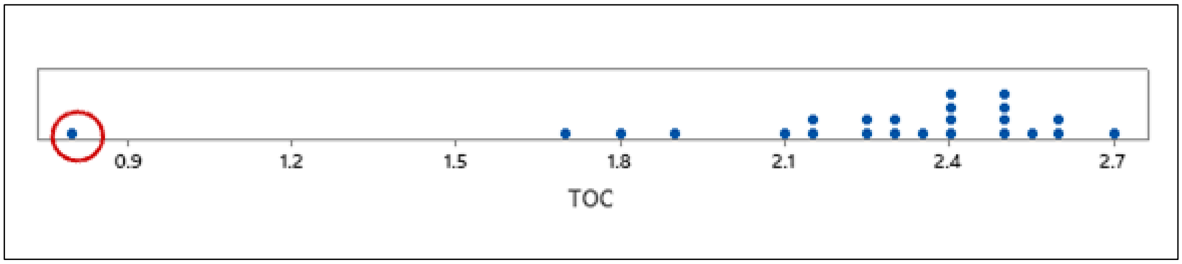

Figure A-1: Dot plot of TOC at FF04 from 1999 to 2023 with the 2023 concentration as reported (0.79% dry weight). The red circle shows the 2023 value compared to values in other years.

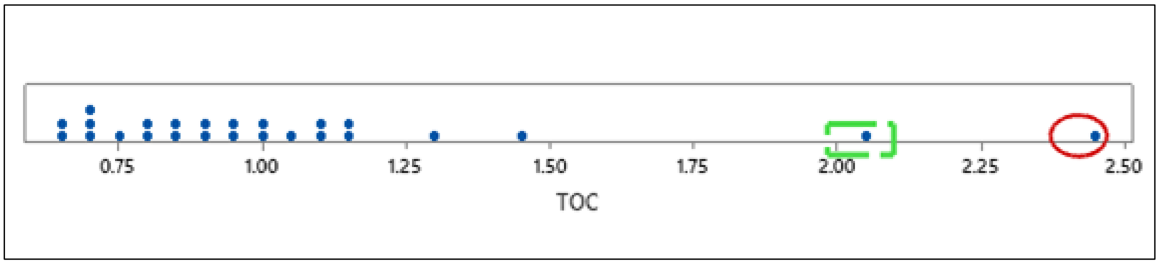

Figure A-2: Dot plot of TOC at NF22 from 1998 to 2023 with 2023 concentration as reported (2.45% dry weight). The red circle shows the 2023 value compared to values in other years. The green rectangle shows a measurement in August 2002 that also had a high value.

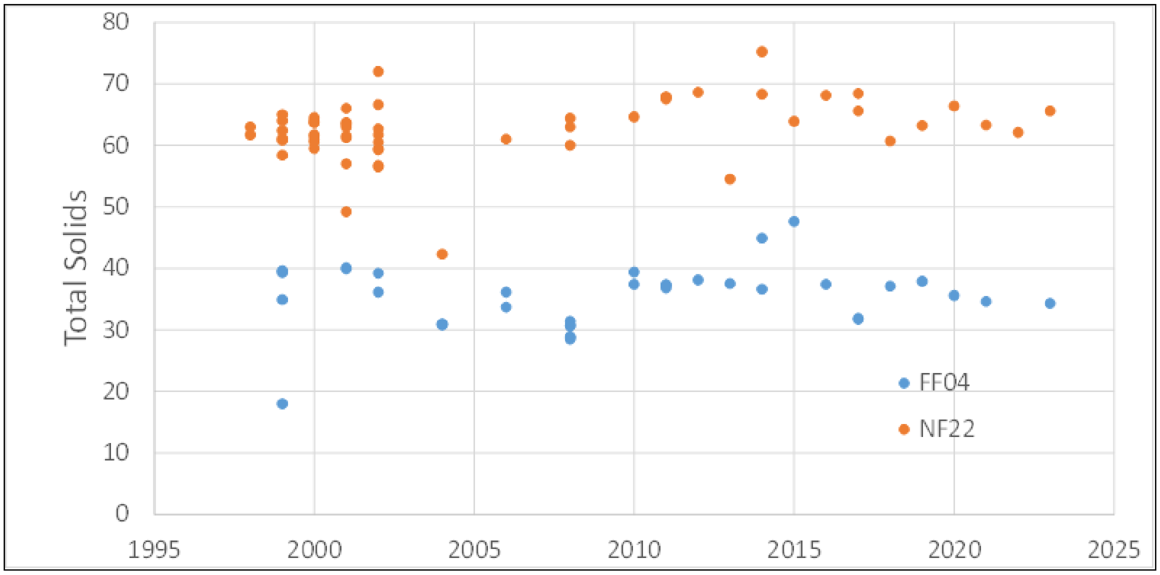

Figure A-3: The total solids measured at site FF04 (blue) and NF22 (orange) from 1998 to 2023.

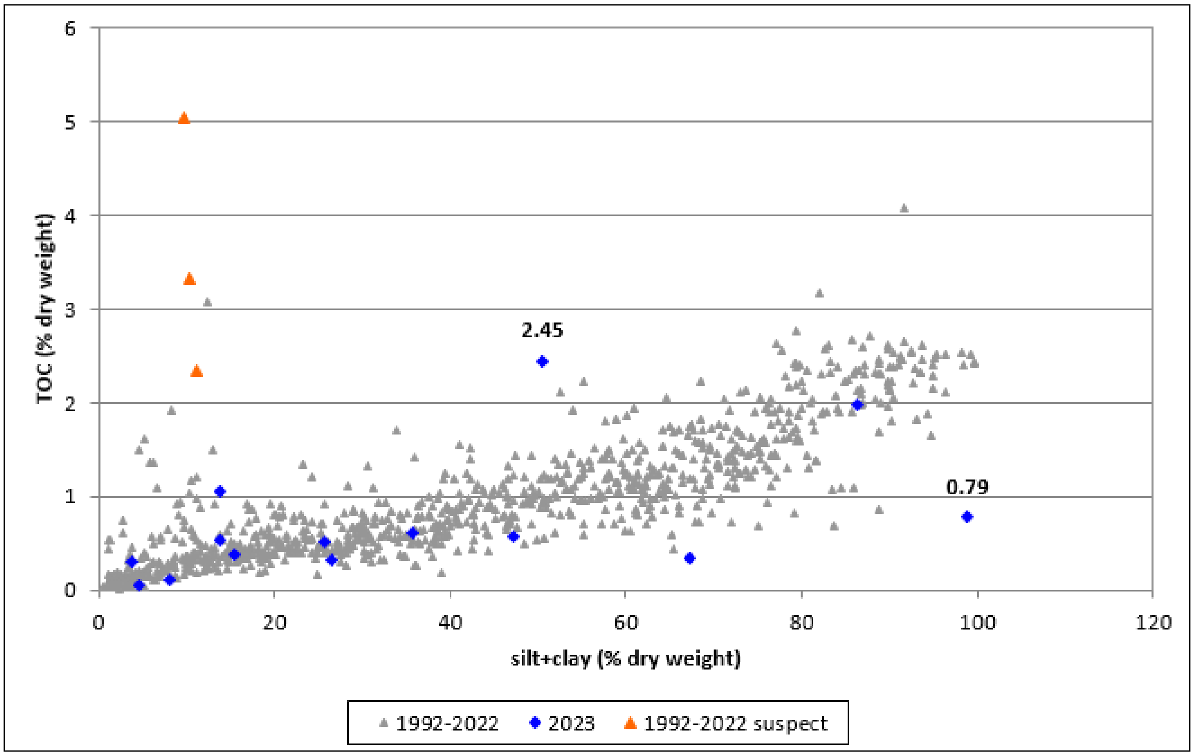

Figure A-4: A scatterplot showing the relationship between the percentage of TOC and the percentage of fine sediments (silt and clay). All measurements from the time series are shown in grey, with year 2023 measurements shown in blue. The two measurements in question are labeled: Station FF04 TOC = 0.79 = and Station NF22 TOC = 2.45.

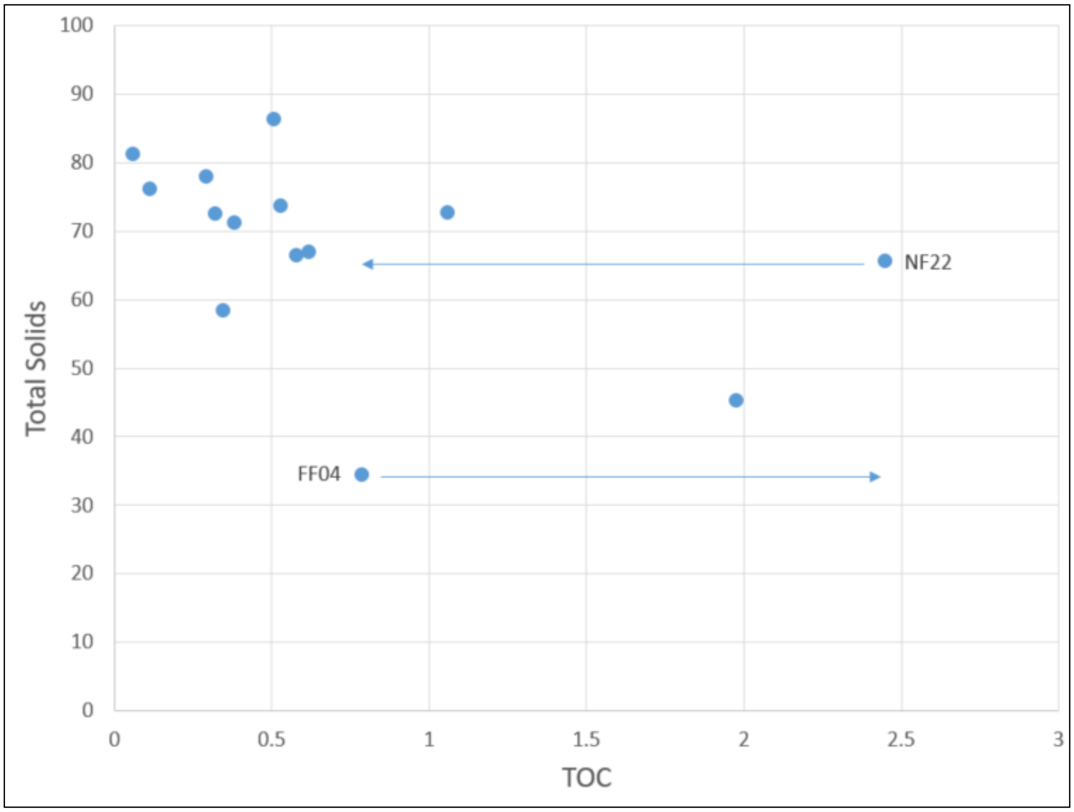

Figure A-5: A scatterplot showing the relationship between the percentage of TOC and the total solids for year 2023. All 2023 station measurements are shown in blue. The two measurements in question are labeled. Arrows show where the data point would be if we assumed that a sample swap did occur; they would be more in line with the other data.

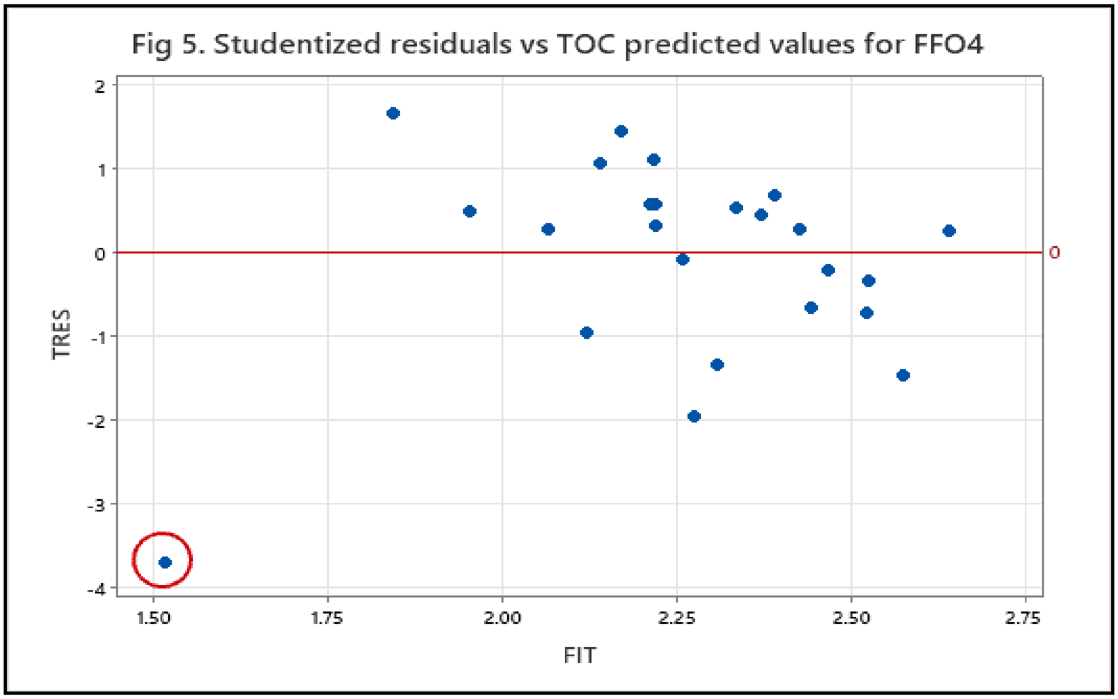

Figure A-6: Studentized residuals (TRES), calculated as the residuals between the predicted TOC value and the actual TOC value divided by the standard deviation of the residuals, vs TOC predicted values for FF04 (FIT). Y = 0 along the red horizontal line shows a perfect prediction of the TOC value. The further from zero, the farther a particular measurement strays from the expected value. Studentized residuals greater than 3 are considered outliers. The red circle shows the studentized residual for 2023.

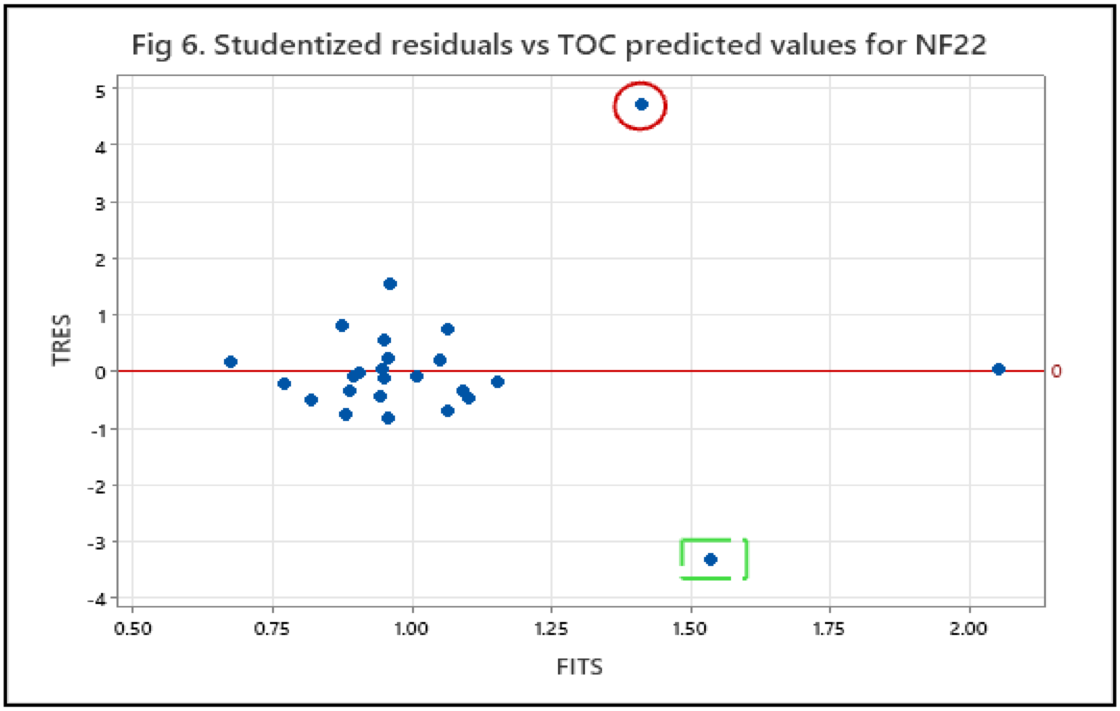

Figure A-7: Studentized residuals (TRES), calculated as the residuals between the predicted TOC value and the actual TOC value divided by the standard deviation of the residuals, vs TOC predicted values for NF22 (FIT). Y = 0 along the red horizontal line shows a perfect prediction of the TOC value. The further from zero, the farther a particular measurement strays from the expected value. Studentized residuals greater than 3 are considered outliers. The red circle shows the studentized residual for 2023, and the green rectangle shows the studentized residual for 2002.

APPENDIX B SUMMARY OF DATA RECORDED FROM VIDEO FOOTAGE TAKEN ON THE 2023 HARD-BOTTOM SURVEY

Station	**T1-1**	**T1-2**	**T1-3**	**T1-4**	**T1-5**	**T2-1**	**T2-2**	**T2-3**	**T2-4**	**T4/6-1**	**T4-2**	**T6-1**	**T6-2**	**T7-1**	**T7-2**	**T9-1**	**T10-1**	**T8-1**	**T8-2**	**T12-1**	**T11-1**	**T2-5**	**T2-5**	**D#44**	**D#44**	**Total**
Minutes	20	22	23	20	20	22	18	19	21	21	22	21	20	20	20	20	23	18	22	24	26	16	7	12	10	487
Begin depth (m)	24.8	22.6	21	24.1	30.8	25.7	31.1	27.9	30.9	26.4	31.4	34	28.1	23.5	23.7	25.1	25.7	24	24.3	23.4	35.1	33.6	33.6	34.7	34.7	
End depth (m)	24.1	22	20.1	22.6	30.8	30	25.6	28.3	28.9	28.3	32.1	33	26'2	23.7	22.4	24.7	25.5	24.1	23.7	21.5	33.8	28.3	33.6	31.5	34.7	
Substrate[1]	mx	c+b	b	b+c	cp+ob	mx	c+b	b+c	b+c	b+c	cp	cp+ob	mx	b+mx	b+mx	b+c	b	cp+mx	mx	b+mx	b+c	d	rr	d	rr	
Drape[2]	m-mh	m-mh	m	m	m-mh	mh-h	m-mh	m-mh	m-mh	m-mh	lm	mh	m	m-mh	m-mh	m	h	m	lm-m	lm-m	mh-h	mh	mh	mh	h	
Relief[3]	L-M	LM-M	MH	LM-M	L-LM	LM-M	LM-M	M	LM-M	LM-M	L	L-LM	LM-M	LM-MH	M-MH	M-MH	MH-H	L-LM	LM	LM-M	M-MH	H	M	H	ML	
Suspended matter[4]		h		h		h	vh	vh	vh	vh		h		vh	vh	h	vh		h	h	vh	vh	vh	vh	vh	
Coralline algae	f-c	f-c	f-c	f-c	r	f	r	r	r	f-c	r		r-f	f-c	c	f-c		f-c	c	c-a	f					
Ptilota serrata																										
Hydroids	f-c	f	f-c	f-c	f	f-c	c	c-a	c	c	f	c	f-c	f-c	a	c-a	a	c	f-c	c	a	a	a	a	a	
Spirorbids/barnacles							r			f		f		f	f		r	f	r	c						
Palmaria palmata	r-f	f	r-f	r-f		r	r	r-f		r				f-c	c	f	f-c	f	f	c						
Agarum cribosum			1																	1						2
general sponge			1				1	1	1							1				1						6
Polymastia sp. A	f	f	f	f		c-a	f-c	c	c	f-c	r	f	f-c	f	f-c	f-c	a		f	f	r	f		c		
Haliclona oculata																								5	10	15
Iophon nigricans				r					r		r										c					
Haliclona spp. (encrusting)								2	1																	3
thick cream sponge with projections																					f					
yellowish-cream encrusting sponge																					r					

Station	T1-1	T1-2	T1-3	T1-4	T1-5	T2-1	T2-2	T2-3	T2-4	T4/6-1	T4-2	T6-1	T6-2	T7-1	T7-2	T9-1	T10-1	T8-1	T8-2	T12-1	T11-1	T2-5	T2-5	D#44	D#44	Total
Halichondria panicea																r										
Obelia geniculata																				r						
general anemone							1														4					5
Metridium senile		r							r						r							a	f	f-c	r	
Urticina felina	8	10	6	5	1	6	7	10	11	8		6	6	2	5	5	6	1		2	4	2	4	5	4	124
Pachycerianthus borealis					1						9															10
Tubularia sp.									c*													a	c	r		
Gersemia fruticosa																					r					
gastropod														1												1
Tonicella marmorea																1										1
Crepidula plana			r																f	c						
Busycotypus canaliculatus															1											1
Buccinum undatum											1		1								1					3
Neptunea decemcostata														1												1
nudibranch	1							1												2						4
Modiolus modiolus	a	a	c	c	f	c-a	c-a	c-a	a	a	f	f	c	c-a	a	a	a	c	f-c	c-a	a				r	
Mytilus edulis	f	c-a	c-a	c		f-c	f-c	c-a	c-a*	c-a			f-c*	f	a	f-c	c-a		r	f-c*	r	c		r		
Placopecten magellanicus					3	6					11	4													3	27
Arctica islandica											r															
crab						1							1													2
Balanus sp.	c	c	c	c	f	f	c	f	f-c	f		r	f	c	a	f-c	f	f-c	f	c	f					
Homarus americanus	2	2	1			6	4	4	3	1		1	2	2	2	3	3	4	1	3	2					46
hermit crab	5	5	6	4	6	8	16	7	1	12		9	20	2	1	8	5	22	15	5						157

Station	**T1-1**	**T1-2**	**T1-3**	**T1-4**	**T1-5**	**T2-1**	**T2-2**	**T2-3**	**T2-4**	**T4/6-1**	**T4-2**	**T6-1**	**T6-2**	**T7-1**	**T7-2**	**T9-1**	**T10-1**	**T8-1**	**T8-2**	**T12-1**	**T11-1**	**T2-5**	**T2-5**	**D#44**	**D#44**	**Total**
Strongylocentrotus droebachiensis		r	f	r		f				f			r			r			r	f		r		r		
small white starfish	r	r	r	r	f-c	r	r	r		r	c	c	r	r	f	r	f	f	r	r	c-a	f	f	c	f	
Asterias rubens	a	c	c-a	c	c	c	a	c	a	c	f-c	f-a	f-c	c-a	c-a	r-c	c	f	f-c	c	f-c	c	c	f-c	f	
Henricia sanguinolenta	r-f	f	f	f	f	r-f	f	r	f	f-c	f-c	f-c	f-c	f	f-c	f	c	c	a	f	f-c	f	f	c	c	
Porania pulvillus insignis																	1									1
Psolus fabricii	r						r	r			r					f			r	r	f-c					
Botrylloides violaceus		6	22	4		3	26	15	63	12	5		15	7	50	29	52	26	10	31	42			5	2	425
tunicate																					c					
Aplidium/Didemnum	f-c	f-c	f-c	c-a	c	f	f-c*	c	f	f-c	f-c	f-c	f-c	f	c-a	c-a	c	f	f-c	f	f-c		f	r	f	
Dendrodoa carnea		r									f	f		r	f	r	r	f	f	f						
Halocynthia pyriformis	f	r	r	f		r	f*	f		r	r		r			r					f	f		r		
Membranipora sp.	r						r			r							f		r							
Myxicola infundibulum	r	r			r	f			r			r			r	r					r					
Terebratulina septentrionalis				f			a*	f	f	r	f					r	f				c-a					
general fish			1			1	3	1	1		1	3						2	1							14
Tautogolabrus adspersus	f-c	c-a	a	c-a	r-f	f-c	c-a	c-a	c-a	c-a	r-f	r-f	f-c	a	a	c-a	a	f-c	f-c	c-a	f-c	a	c-a	c-a	f-c	
Myoxocephalus spp.	6	6	9	7	1	10	12	10	10	11	8	3	5	6	4	4	5	6	3	3	3				3	135
Zoarces americanus								1																	1	2
Hemitripterus americanus						1																				1

Station	**T1-1**	**T1-2**	**T1-3**	**T1-4**	**T1-5**	**T2-1**	**T2-2**	**T2-3**	**T2-4**	**T4/6-1**	**T4-2**	**T6-1**	**T6-2**	**T7-1**	**T7-2**	**T9-1**	**T10-1**	**T8-1**	**T8-2**	**T12-1**	**T11-1**	**T2-5**	**T2-5**	**D#44**	**D#44**	**Total**
Pseudopleuronectes americanus	15	10	17	8	3	11	6	6	3	15	2	2	5	1	8	6	2	6	13	12			1			152
Pholis gunnellus											1		1							1						3
Gadus morhua			2												5	1	1	1					1			11
Pollachius virens		1	1						1					1						2		2			1	9
whelk egg case	1	1	10	2						1		3		2	1	1			2	1						25
nudibranch egg mass	14	8	7	2		1	15	29	68	9		1	3		2	5	6		1	26	11		2	1		211
ex barnacles	c-a	c-a	a	a	f-c	f-c	a	a	a	a		f	a	va	a	a	va	c	a	a	f	c		a		

[1] b=boulder, ob=ocassional boulders, c=cobble, cp=cobble pavement, g=gravel, d=diffuser head, r=riprap.

[2] l=light; lm=moderately light; m=moderate; mh=moderately heavy; h=heavy.

[3] L=low; LM=moderately low; M=moderate; MH=moderately high; H=high.

[4] h=high, vh=very high.

Values a=abundant, c=common, f= few, r = rare.

APPENDIX C: TAXA OBSERVED DURING THE 2023 NEARFIELD HARD-BOTTOM VIDEO SURVEY

Name	Common name	Name	Common name
Algae		**Crustaceans**	
Coralline algae	pink encrusting algae	*Balanus* sp.	barnacle
Palmaria palmata	dulse	*Cancer* spp.	Jonah or rock crab
Agarum clathratum	shotgun kelp	*Homarus americanus*	lobster
		hermit crab	
Invertebrates		unidentified crab	
Sponges			
general sponge		**Echinoderms**	
Halichondria panicea	breadcrumb sponge	*Strongylocentrotus droebachiensis*	green sea urchin
Haliclona oculata	finger sponge	small white starfish	juvenile *Asterias*
Haliclona spp. (encrusting)	sponge	*Asterias rubens*	northern sea star
Iophon nigricans	sponge on brachiopod	*Henricia sanguinolenta*	blood star
Polymastia sp. A	encrust yellow sponge	*Porania pulvillus*	red cushion star
cream sponge/projections	sponge	*Psolus fabricii*	scarlet holothurian
yellowish-cream encrusting	sponge		
		Tunicates	
Coelenterates		general tunicate	
Hydroids		*Aplidium/Didemnum* spp.	cream encrust tunicate
Obelia geniculata	zig-zag hydroid	*Botrylloides violaceus*	Pacific tunicate
Tubularia sp.	hydroid	*Dendrodoa carnea*	drop-of-blood tunicate
general anemone		*Halocynthia pyriformis*	sea peach tunicate
Metridium senile	frilly anemone		
Urticina felina	northern red anemone	**Miscellaneous**	
Pachycerianthus borealis	northern cerianthid	*Membranipora membranacea*	lacy bryozoan
Gersemia fruticosa	white *Gersemia*	*Myxicola infundibulum*	slime worm
		Spirorbids/barnacles	
Molluscs		*Terebratulina septentrionalis*	northern lamp shell
gastropod			
Crepidula plana	flat slipper limpet	**Fishes**	
Tonicella marmorea	mottled red chiton	general fish	
Buccinum undatum	waved whelk	*Gadus morhua*	Atlantic Cod
Busycotypus canaliculatus	channeled whelk	*Hemitripterus americanus*	Sea Raven
Neptunea decemcostata	ten-ridged whelk	*Myoxocephalus* spp.	sculpin
nudibranch		*Pholis gunnellus*	Rock Gunnel
Arctica islandica	ocean quahog	*Pollachius virens*	Pollock
Modiolus modiolus	horse mussel	*Pseudopleuronectes americanus*	Winter Flounder
Mytilus edulis	blue mussel	*Tautogolabrus adspersus*	Cunner
Placopecten magellanicus	sea scallop	*Zoarces americanus*	Ocean Pout
		Other	
		whelk egg case	
		nudibranch egg case (frilly white)	
		ex barnacles	

APPENDIX D: REPRESENTATIVE HARD-BOTTOM STILL IMAGES OF SELECTED STATIONS THROUGH TIME

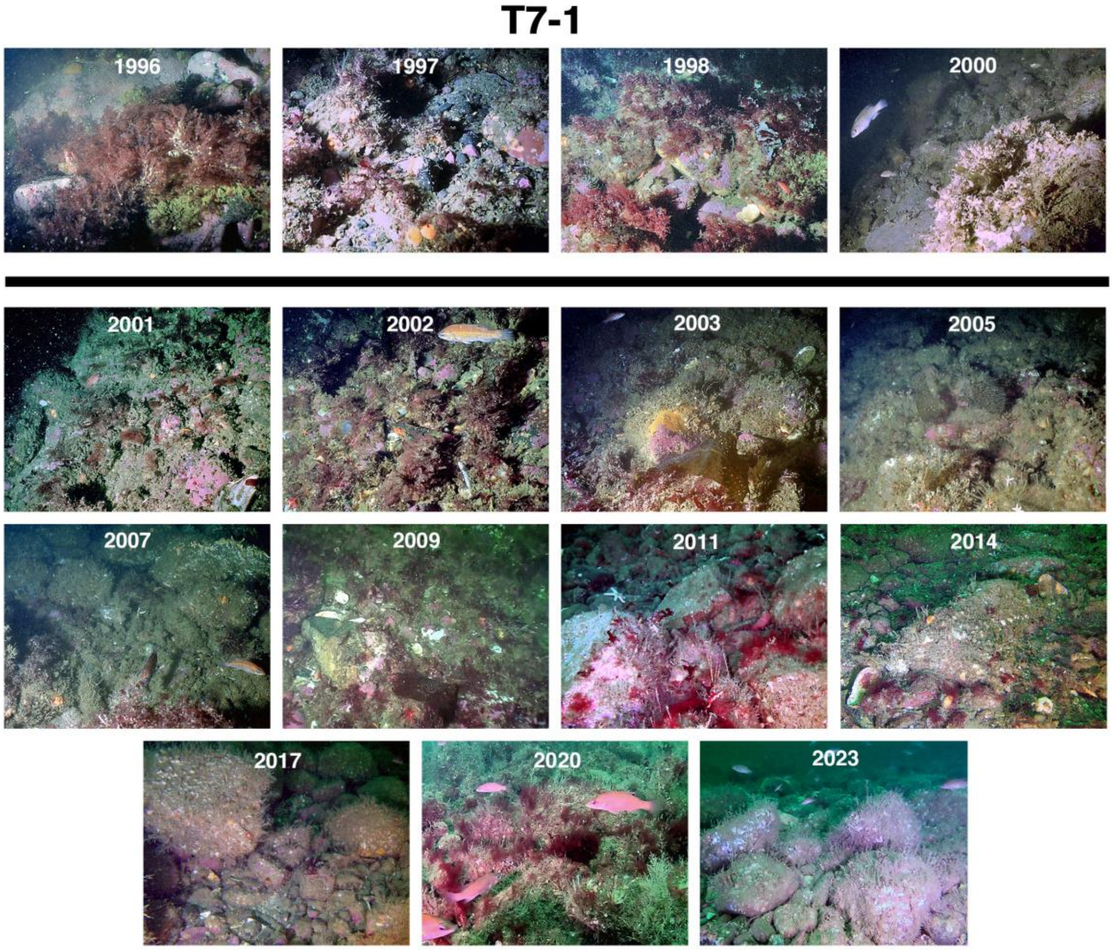

Plate 1. Representative images through time at T7-1 one of the northern reference sites. The four images above the bold line (1996, 1997, 1998 and 2000) show this site during the pre-diversion years. The benthic community was dominated by upright algae during this period. The eleven images below the bold line show representative images from the post-diversion period. The number of upright algae and the percent cover of coralline algae generally decreased over time. Some of these changes may reflect physical disturbance of the seafloor by tankers anchoring at the northern reference sites. By 2020 the benthic community was again dominated by upright algae, which may have partially reflected an invasive alga since the filamentous red algae observed appeared coarser and more fibrous than *Ptilota serrata*, the red alga commonly observed in the area. By 2023 no red filamentous algae were observed, and the surfaces covered by the dead barnacle set were very evident.

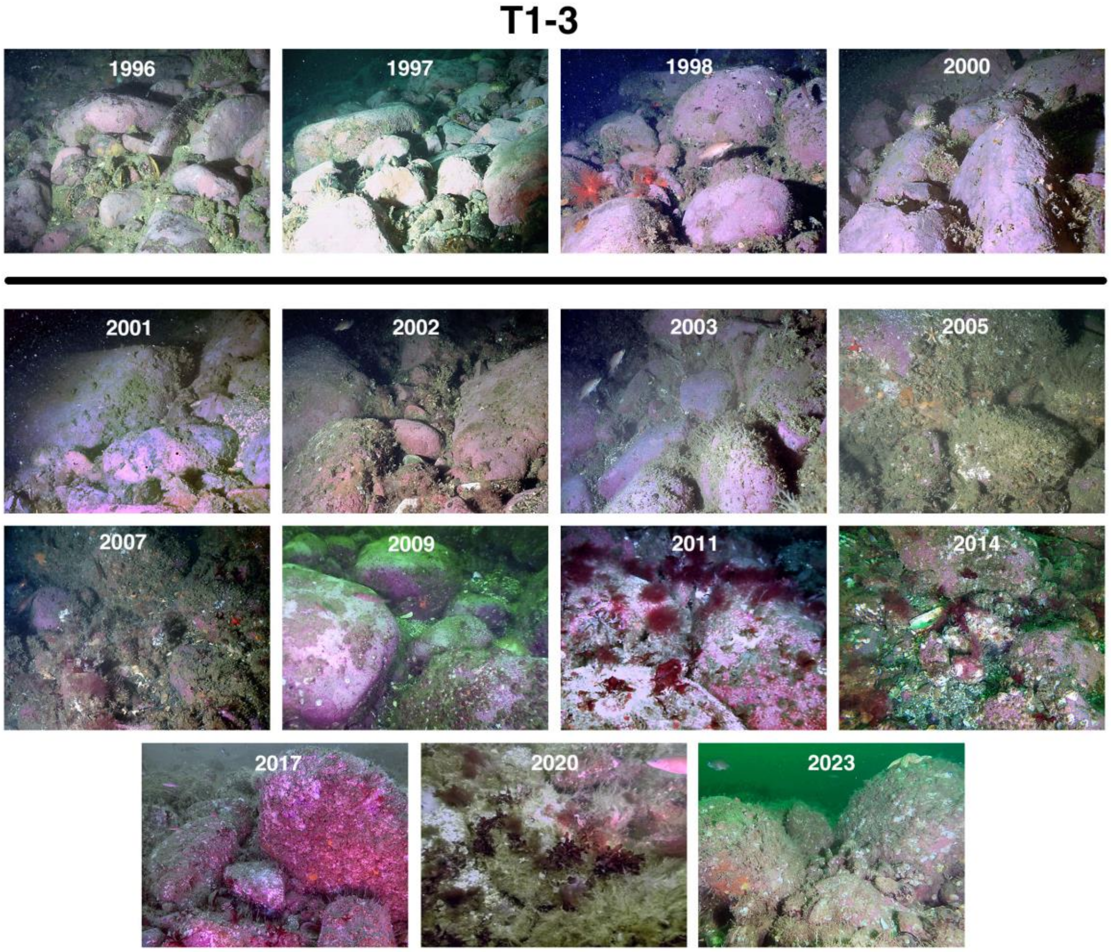

Plate 2. Representative images through time at T1-3 a drumlin top site north of the outfall. The four images above the bold line (1996, 1997, 1998 and 2000) show this site during the pre-diversion years. The benthic community was totally dominated by coralline algae and the rocks had very little drape during this period. The eleven images below the bold line show representative images from the post-diversion period. The percent cover of coralline algae generally decreased over time and the amount of drape on the rock surfaces increased. Additionally, upright algae was commonly observed at this site between 2011 and 2020. In 2023, only a few upright algae were observed at this site, and the surfaces covered by the dead barnacle set were very evident.

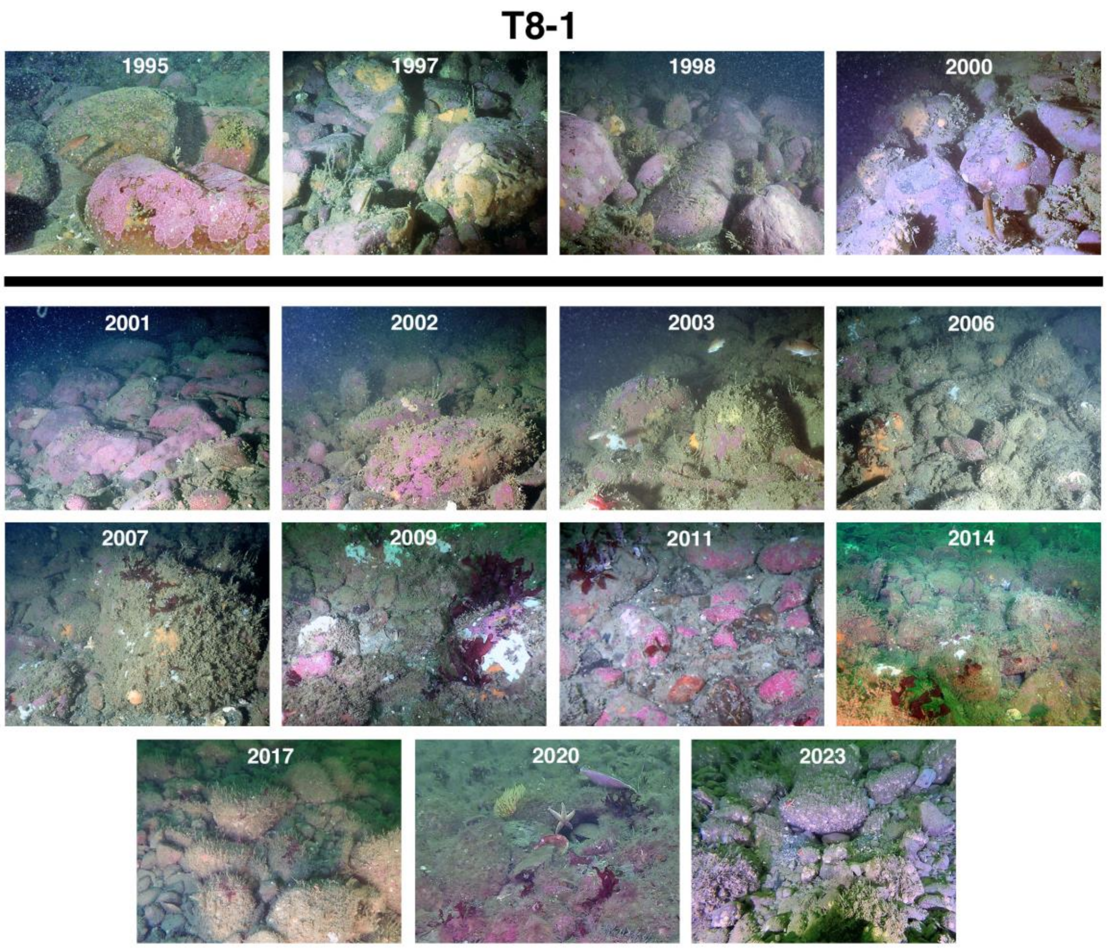

Plate 3. Representative images through time at T8-1 one of the southern reference sites. The four images above the bold line (1995, 1997, 1998 and 2000) show this site during the pre-diversion years. The benthic community was dominated by coralline algae during this period. The eleven images below the bold line show representative images from the post-diversion period. The percent cover of coralline algae generally decreased over time and more drape can be seen on the rock surfaces. Additionally, numerous colonies of dulse (*Palmaria palmata*) were observed between 2007 and 2020. By 2023 very few juvenile dulse colonies were present.

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