2020 Outfall Benthic Monitoring Results

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EXECUTIVE SUMMARY

The Massachusetts Water Resources Authority (MWRA) has conducted long-term monitoring since 1992 in Massachusetts Bay and Cape Cod Bay to evaluate the potential effects of discharging secondary treated effluent 15 kilometers (km) offshore in Massachusetts Bay. Relocation of the outfall from Boston Harbor to Massachusetts Bay in September 2000 raised concerns about potential effects of the discharge on the offshore benthic (bottom) environment, which are addressed by the results reported here.

Benthic monitoring during 2020 included soft-bottom sampling for sediments and infauna at 14 nearfield and farfield stations, and video surveillance at 23 hard bottom locations.

Sediment conditions were characterized based on spore counts of the anaerobic bacterium, *Clostridium perfringens*, analyses of sediment grain size composition and total organic carbon (TOC). *C. perfringens* concentrations during 2020 were highest at sites closest to the discharge. These findings are consistent with those obtained since outfall relocation (e.g. Nestler et al. 2020, Maciolek et al. 2007, 2008). The results for *C. perfringens*, therefore, provide evidence of settlement of solids from the effluent at sites in close proximity (within 2 km) to the outfall. Neither sediment grain size nor TOC have exhibited appreciable changes from the baseline period and this pattern continued in 2020. These results indicate the absence of influence of the wastewater discharge on sediment conditions beyond *Clostridium* spores, consistent with prior monitoring results (Nestler et al. 2020, Rutecki et al. 2019, Maciolek et al. 2008).

As seen in previous years, there was no evidence of impacts to the infaunal communities in Massachusetts Bay from the offshore outfall in 2020. Monitoring results have consistently suggested that deposition of particulate organic matter from the wastewater discharge is not occurring at levels that disturb or smother animals near the outfall. There were no Contingency Plan threshold exceedances for any infaunal diversity measures in 2020. Multivariate analyses indicated that patterns in the distribution of faunal assemblages reflect habitat types at the sampling stations. Infaunal data in 2020 continue to suggest that the macrobenthic communities at sampling stations near the outfall have not been adversely impacted by the wastewater discharge.

Hard-bottom benthic communities near the outfall have not changed substantially during the post-diversion period as compared to the baseline period. Some modest changes in hard-bottom communities (e.g., coralline algae, upright algae cover, and sponge abundance) have been observed; nonetheless, factors driving these changes are unclear. Since declines in upright algae started in the late 1990s, it is unlikely that the decrease was attributable to diversion of the outfall.

The outfall 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. 2019), are the principal reasons that benthic habitat quality has remained high in the nearfield area.

1 INTRODUCTION

The Massachusetts Water Resources Authority (MWRA) has conducted long-term monitoring since 1992 in Massachusetts Bay and Cape Cod Bay to evaluate the potential effects of discharging secondary treated effluent 15 kilometers (km) offshore in Massachusetts Bay. Relocation of the outfall from Boston Harbor to Massachusetts Bay in September 2000 raised concerns about potential effects of the discharge on the offshore benthic (bottom) environment. These concerns focused on three issues: (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.

Under its Ambient Monitoring Plan (MWRA 1991, 1997, 2001, 2004, 2010) the MWRA has collected extensive information over a nine-year baseline period (1992–2000) and a twenty-year post-diversion period (2001–2020). These studies included 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). Data collected by this program allow for a more complete understanding of the bay system and provide a basis to explain any changes in benthic conditions and to address the question of whether MWRA's discharge has contributed to any such changes.

Benthic monitoring during 2020 was conducted following the current Ambient Monitoring Plan (MWRA 2010) as modified in July 2020 which is required under MWRA's effluent discharge permit for the Deer Island Treatment Plant. Under this modified plan, annual monitoring includes soft-bottom sampling for sediment conditions and infauna at 14 nearfield and farfield stations. Every third year, hard-bottom surveys are conducted at 23 nearfield stations. The July 2020 modification discontinued the SPI study in Massachusetts Bay and the sediment contaminant evaluation every third year in the nearfield and farfield stations as these studies had answered their monitoring questions fully. The hard-bottom survey was conducted in 2020. Monitoring results for 2020 indicated that hard-bottom benthic communities near the outfall have not changed substantially during the post-diversion period as compared to the baseline period.

This report summarizes key findings from the 2020 benthic surveys, with a focus on the most noteworthy observations relevant to understanding the potential effects of the discharge on the offshore benthic environment. Results of 2020 benthic monitoring were presented at MWRA's Annual Technical Workshop on March 30, 2021. This report builds on the presentations and discussions at that meeting.

2 METHODS

Methods used to collect, analyze, and evaluate all sample types remain largely consistent with those reported for previous monitoring years (Nestler et al. 2020, 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 12, 2020 (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, located in close proximity (less than 2 km) to the offshore outfall
- Nearfield stations NF04, NF10, NF12, NF20, NF21, and NF22, located in Massachusetts Bay but farther than 2 km (and less than 5 km) from the offshore outfall
- Transition area station FF12, located between Boston Harbor and the offshore outfall (just less than 8 km from the offshore outfall)
- Farfield reference stations FF01A, FF04, and FF09, 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-2016-003-A1.

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, and were rinsed with filtered seawater through a 300-µm-mesh sieve.

Video camera transects (Figure 2-2) were performed as in previous years. A *SAAB SeaEye Falcon ROV* (remotely operated vehicle) equipped with an analog video camera was used to survey the waypoints. A *GoPro Hero 6* camera mounted on the ROV was used to obtain simultaneous high definition (HD) video throughout each transect. All of the 23 hard-bottom waypoints were successfully surveyed during 2020, including an actively discharging diffuser head at the eastern end of the outfall. At least 16 usable minutes of both analog and HD video footage was obtained at all but one of the waypoints. The analog video was analyzed and the HD video was archived for potential future analysis.

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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.

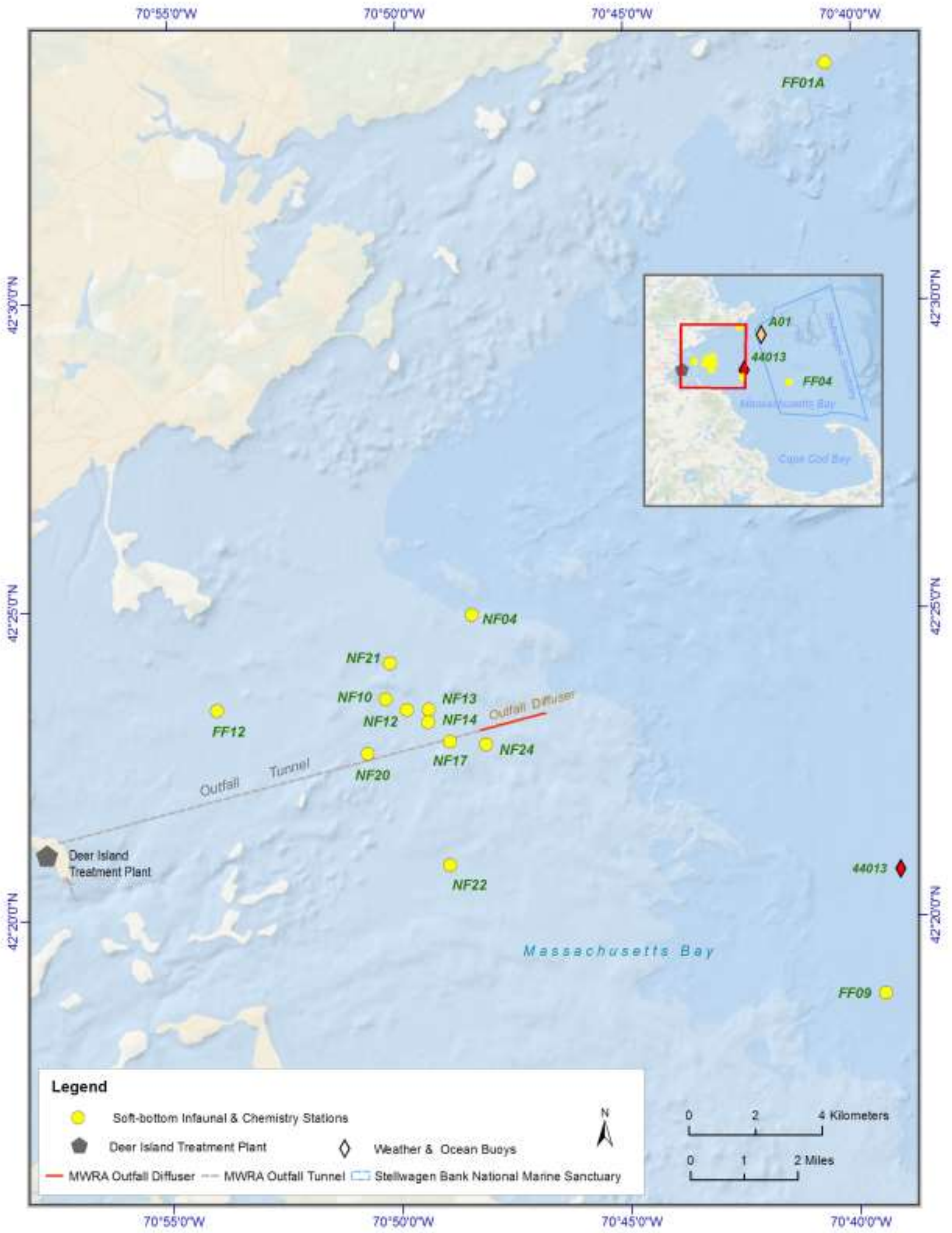

Figure 2-1. Locations of soft-bottom sampling stations for 2020. Inset map with farfield stations.

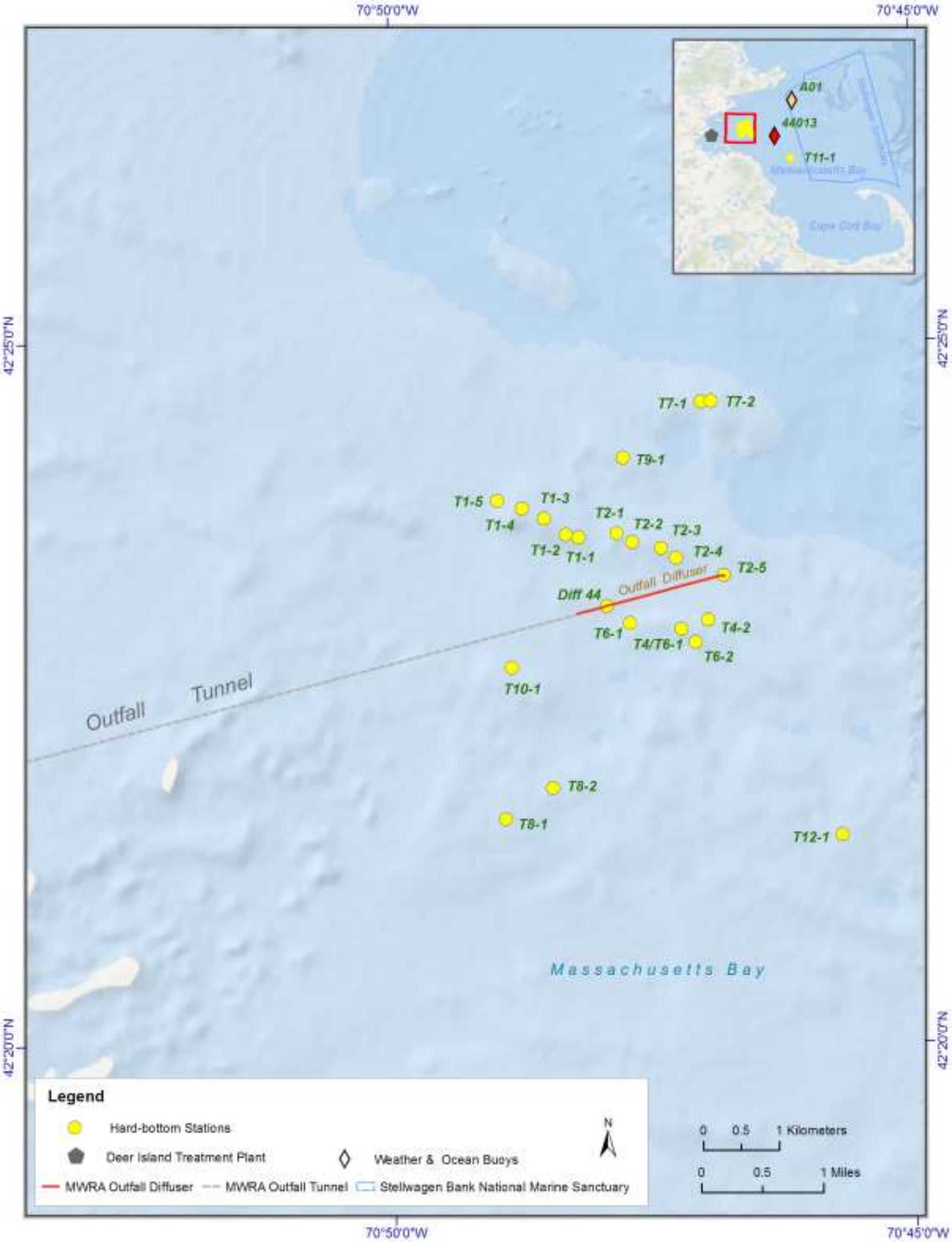

Figure 2-2. **Locations of hard bottom video transects for 2020.**

2.2 LABORATORY METHODS

All bacteriological, physical and chemical analyses were conducted by MWRA's DLS Laboratory 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 HOM 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 v6 (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 (MDS). 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.

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. MDS 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 MDS ordination plot (Clarke 1993). Stress levels less than 0.05 indicate an excellent representation of relative similarities among samples with no 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 MDS 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). 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.

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).

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 2020 at each of the 14 sampling stations: (1) *Clostridium perfringens*, (2) grain size (gravel, sand, silt, and clay), and (3) total organic carbon (Table 3-1).

Spores of the anaerobic bacterium *Clostridium perfringens* (reported as colony forming units per gram dry weight, normalized to percent fines) provide a sensitive tracer of effluent solids. A sharp increase *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 have declined or remained comparable to the baseline at all other monitoring locations during the post-diversion period. 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 2020 were lower than the previous year at nearfield locations within two kilometers from the discharge and increased at the nearfield locations greater than two kilometers and the transition area of the Bay (Figure 3-1). The farfield locations had lower *C. perfringens* counts in 2020 compared to 2019. As in past years during the post-diversion period, *C. perfringens* concentrations during 2020 continued to indicate a footprint of the effluent plume at sites closest to the discharge. Normalized *C. perfringens* spore counts in samples collected in 2020 were highest at NF17 and NF04; two stations located within the nearfield (Table 3-1, Figure 3-2).

Sediment texture in 2020 varied considerably among the 14 stations, ranging from almost entirely sand (e.g., NF17, NF13, and NF04) to predominantly silt and clay (i.e., 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).

Concentrations of TOC in 2020 were similar or decreased slightly compared to the previous year at several nearfield stations (e.g., NF14, NF17, NF12), and are consistent with historically reported values (Figure 3-5). Higher TOC values were 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). Although there was a sharp increase in TOC at NF17 in 2018, TOC at NF17 in 2019 and 2020 were more similar to most previous years.

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

Table 3-1. Monitoring results for sediment condition parameters in 2020.

Monitoring Area	Station	*Clostridium perfringens* (cfu/g dry/%fines)	Total Organic Carbon (%)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Percent Fines (Silt + Clay)
Transition Area	**FF12**	44.2	0.34	4.1	71.2	19.0	5.7	24.7
Nearfield (<2 km from outfall)	**NF13**	96.8	0.09	6.8	91.0	0.1	2.1	2.2
	NF14	26.7	0.28	27.5	64.8	4.7	3.1	7.8
	NF17	133.3	0.19	0.0	97.9	0.1	2.0	2.1
	NF24	75.6	1.51	0.0	57.7	32.6	9.7	42.3
Nearfield (>2 km from outfall)	**NF04**	418.3	0.16	6.2	89.6	1.8	2.3	4.2
	NF10	27.4	0.67	0.0	62.0	28.1	9.9	38.0
	NF12	13.1	0.98	0.0	31.3	54.4	14.3	68.7
	NF20	11.1	1.07	7.0	48.1	24.7	20.3	44.9
	NF21	33.6	1.11	0.0	45.9	40.7	13.4	54.1
	NF22	38.2	0.78	0.0	63.6	27.1	9.3	36.4
Farfield	**FF01A**	3.5	0.20	0.0	88.0	9.9	2.1	12.0
	FF04	8.0	2.40	0.0	13.0	55.0	32.1	87.1
	FF09	33.9	0.30	0.2	87.1	7.9	4.8	12.7

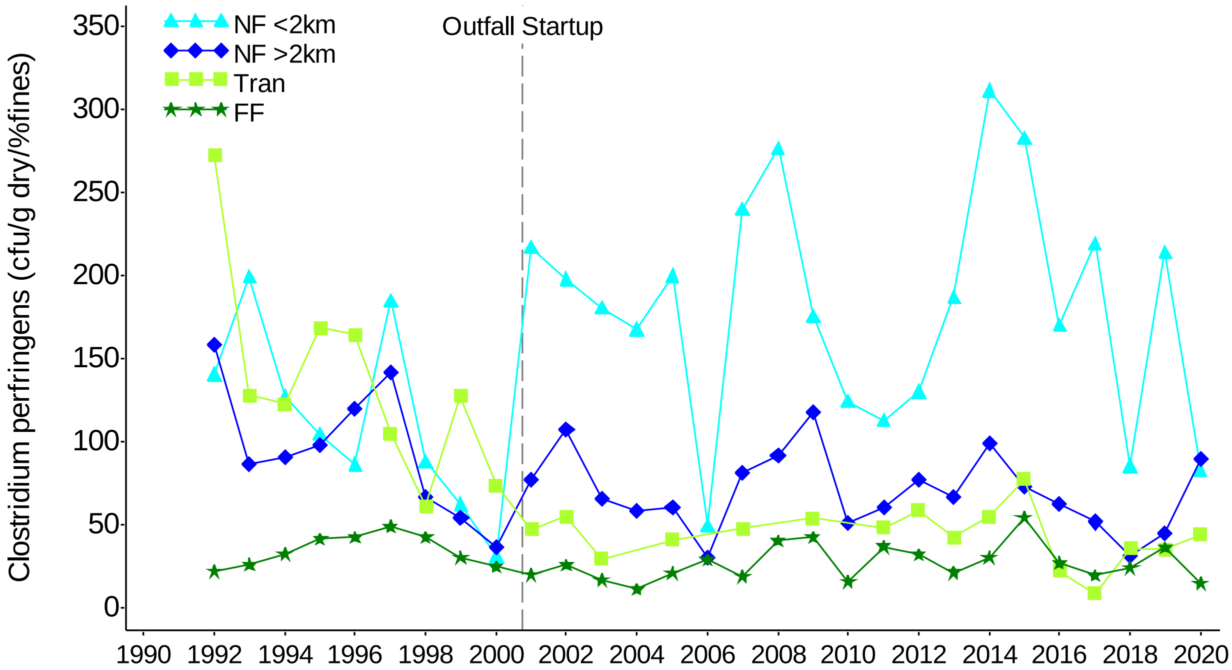

Figure 3-1. Mean concentrations of *Clostridium perfringens* in four areas of Massachusetts Bay, 1992 to 2020. Tran=Transition area; NF<2km=nearfield, less than two kilometers from the outfall; NF>2km=nearfield, more than two kilometers from the outfall; FF=farfield.

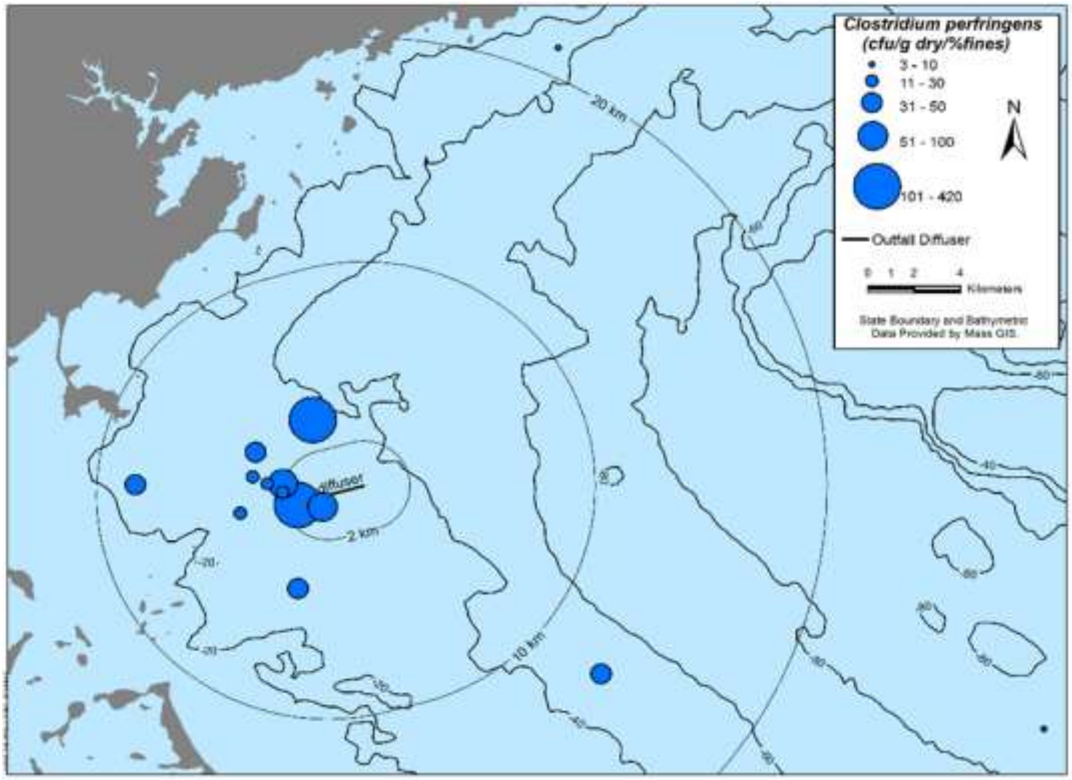

Figure 3-2. Monitoring results for *Clostridium perfringens* in 2020.

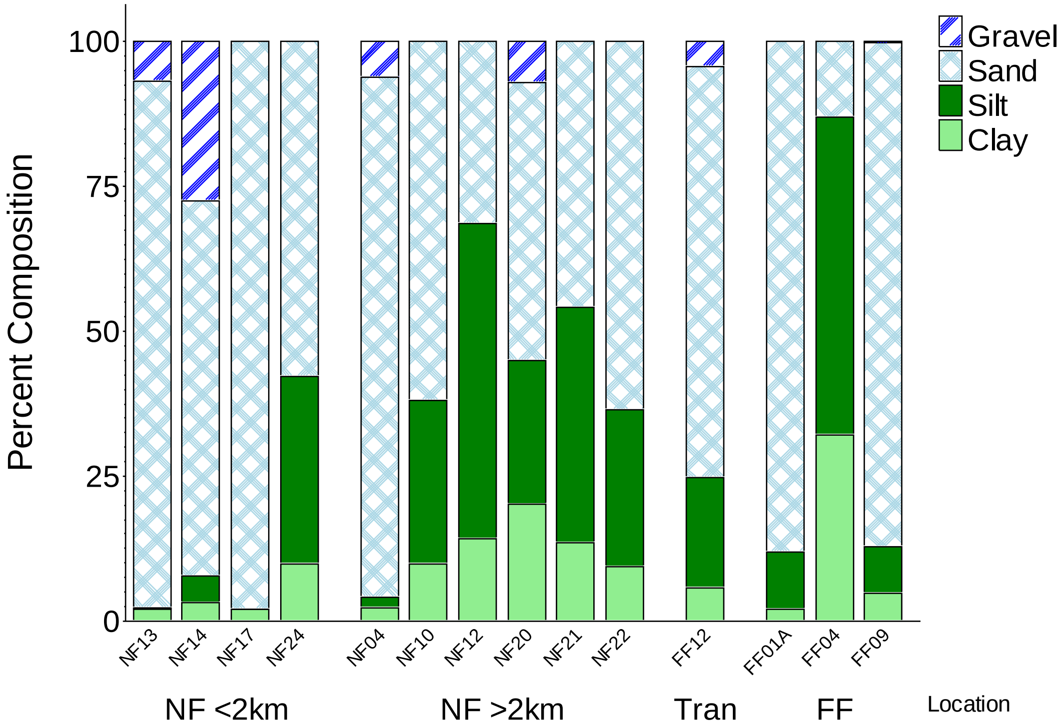

Figure 3-3. **Monitoring results for sediment grain size in 2020.**

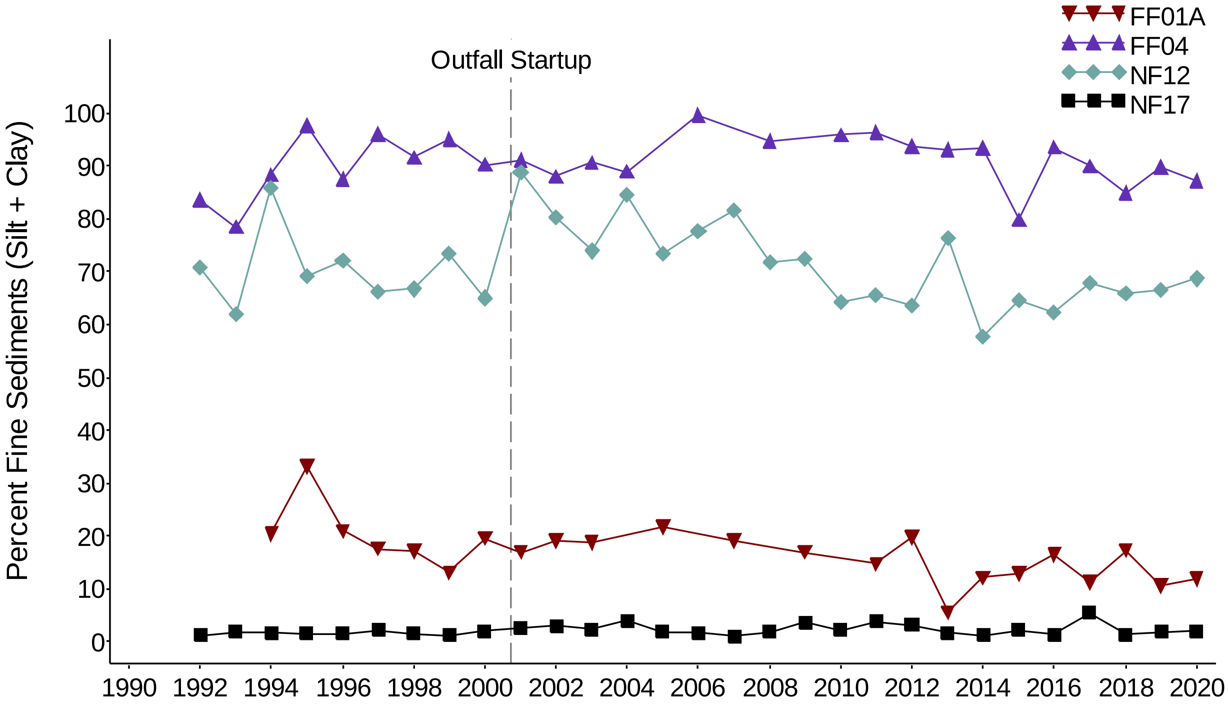

Figure 3-4. **Mean percent fine sediments at FF01A, FF04, NF12 and NF17; 1992 to 2020.**

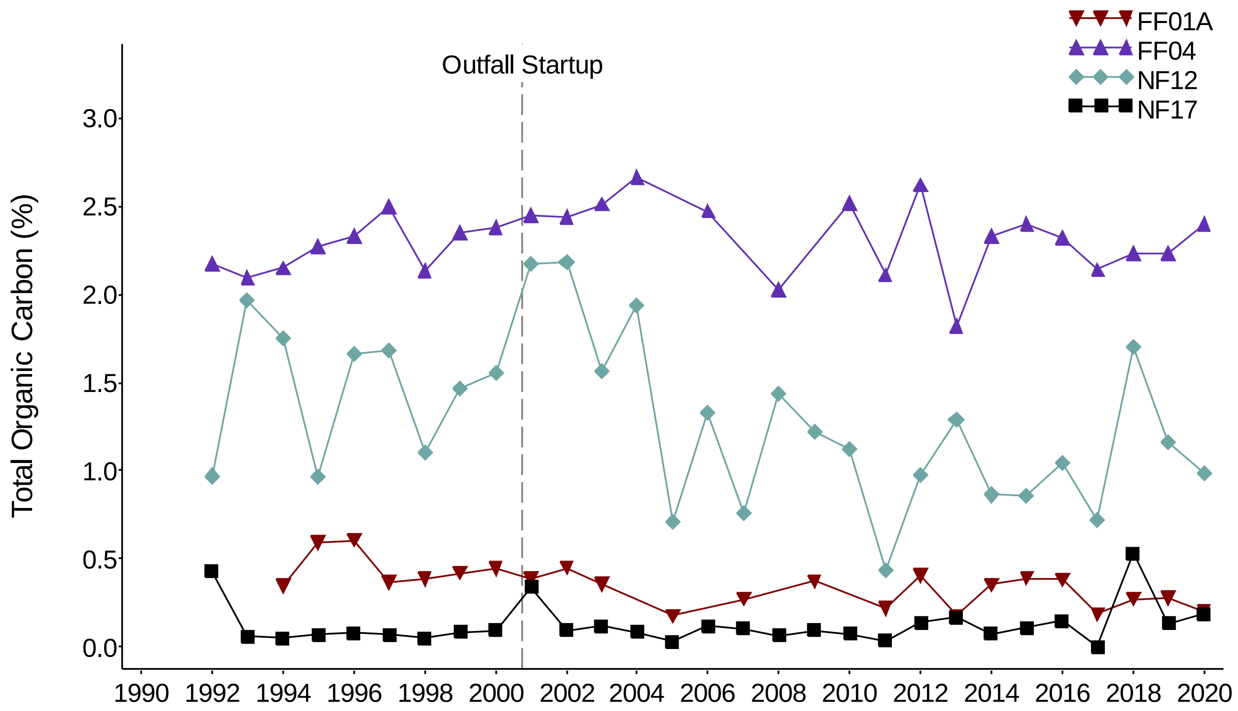

Figure 3-5. Mean concentrations of TOC at four stations in Massachusetts Bay, 1992 to 2020.

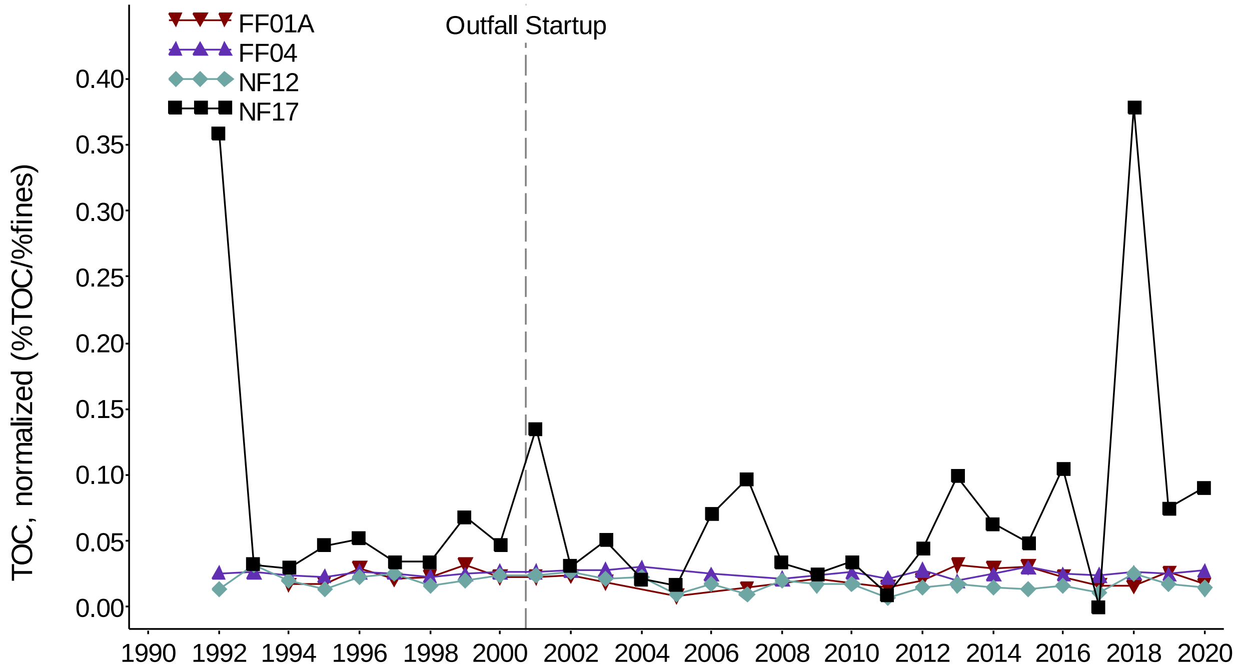

Figure 3-6. Normalized mean concentrations of TOC at four stations in Massachusetts Bay, 1992 to 2020.

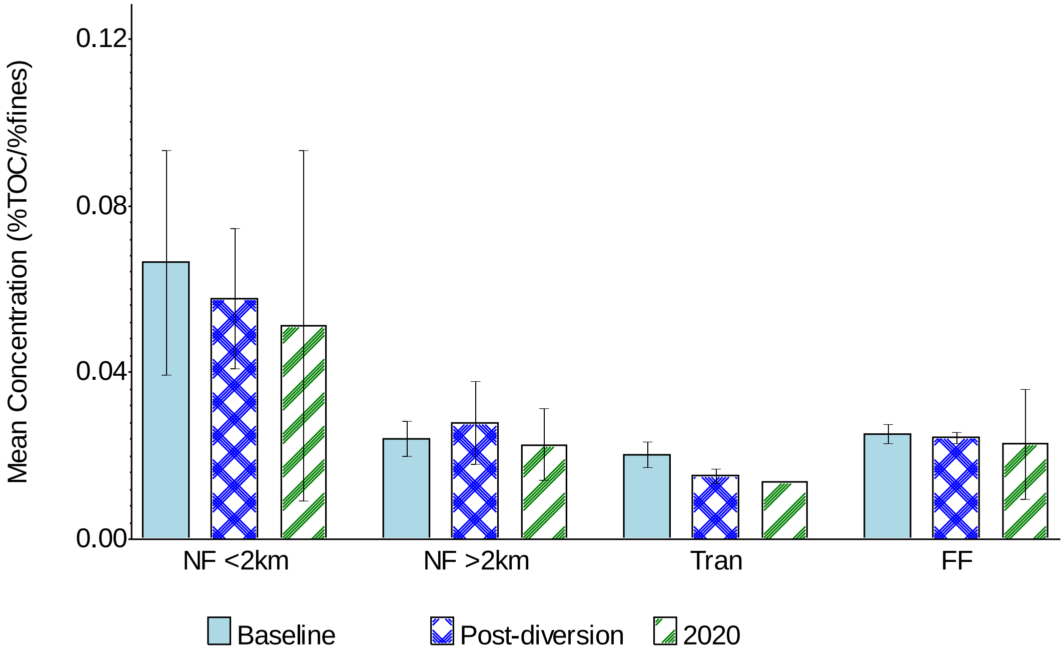

Figure 3-7. **Normalized mean (with 95% confidence intervals) concentrations of TOC at four areas in Massachusetts Bay during the baseline (1992 to 2000) and post-diversion (2001 to 2019) periods compared to 2020. Tran=Transition area; NF<2km=nearfield, less than two kilometers from the outfall; NF>2km=nearfield, more than two kilometers from the outfall; FF=farfield.**

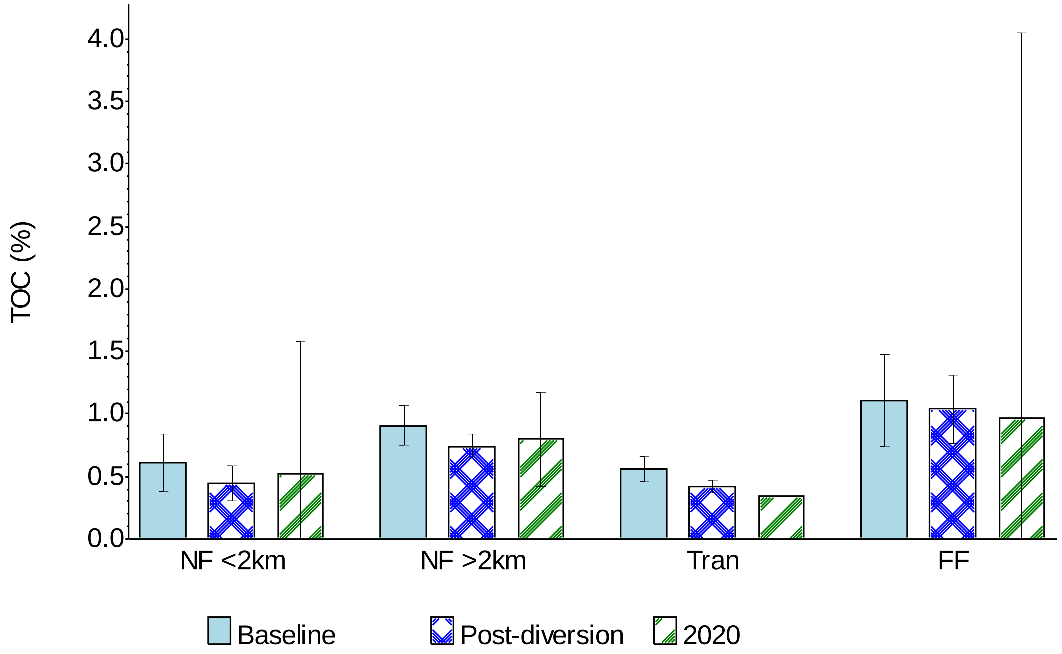

Figure 3-8. **Mean (with 95% confidence intervals) concentrations of TOC at four areas in Massachusetts Bay during the baseline (1992-2000) and post-diversion (2001 to 2019) compared to 2020.**

3.2 BENTHIC INFAUNA

3.2.1 Community Parameters

A total of 22,889 infaunal organisms were counted from the 14 samples in 2020. Organisms were classified into 201 discrete taxa; 178 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).

Total abundance values in 2020 were lower than the 2019 values at all areas in Massachusetts Bay except the farfield stations located farther than 13 km from the discharge (Figure 3-9). Abundance at the farfield stations was higher in 2020 due to the increase in abundance observed at Station FF01A (Table 3-2; Nestler et al. 2020). The numbers of species per sample in 2020 were slightly higher than in 2019 at “Nearfield >2 km” and the “Farfield” locations and lower at the “Nearfield < 2 km” and the “Transition” locations (Figure 3-10). Shannon-Wiener Diversity (H’) and Pielou’s Evenness (J’) values were higher in 2020 compared to the previous year at the nearfield stations, and similar to values reported in recent years (Figures 3-11 and 3-12). The spionid polychaete *Prionospio steenstrupi* was more abundant in 2019 and 2020 than it has been in a decade (Figure 3-13). This species was the numerical dominant at the nearfield stations during 2020, while other dominant polychaetes such as *Aricidea catherinae* and *Tharyx acutus* were less abundant than in the recent years (Figure 3-13).

There were no Contingency Plan threshold exceedances for any infaunal diversity measures in 2020 (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 3-2. Monitoring results for infaunal community parameters in 2020.

Monitoring Area	Station	Total Abundance (per grab)	Number of Species (per grab)	Log-series alpha	Shannon-Wiener Diversity (H′)	Pielou's Evenness (J')
Transition Area	**FF12**	1826	42	7.68	3.51	0.65
Nearfield (<2 km from outfall)	**NF13**	1637	55	11.00	3.38	0.58
	NF14	1992	71	14.43	3.98	0.65
	NF17	647	60	16.29	4.49	0.76
	NF24	1981	55	10.49	2.92	0.50
Nearfield (>2 km from outfall)	**NF04**	777	70	18.79	4.28	0.70
	NF10	2193	71	14.05	4.11	0.67
	NF12	1177	56	12.26	3.98	0.69
	NF20	2823	68	12.57	3.56	0.59
	NF21	1874	77	16.22	4.45	0.71
	NF22	1783	71	14.82	4.53	0.74
Farfield	**FF01A**	2339	64	12.32	3.98	0.66
	FF04	645	34	7.67	3.90	0.77
	FF09	1195	83	20.73	4.57	0.72

Table 3-3. Infaunal monitoring threshold results, August 2020 samples.

Parameter	Thresholds*		Result	Exceedance?
	Value	Limit		
Total species	42.99	Low	63.20	No
Log-series Alpha	9.42	Low	13.50	No
Shannon-Weiner H′	3.37	Low	3.93	No
Pielou's J'	0.57	Low	0.66	No
Percent opportunists	10% (Caution)	High	0.17	No
Percent opportunists	25% (Warning)	High	0.17	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.

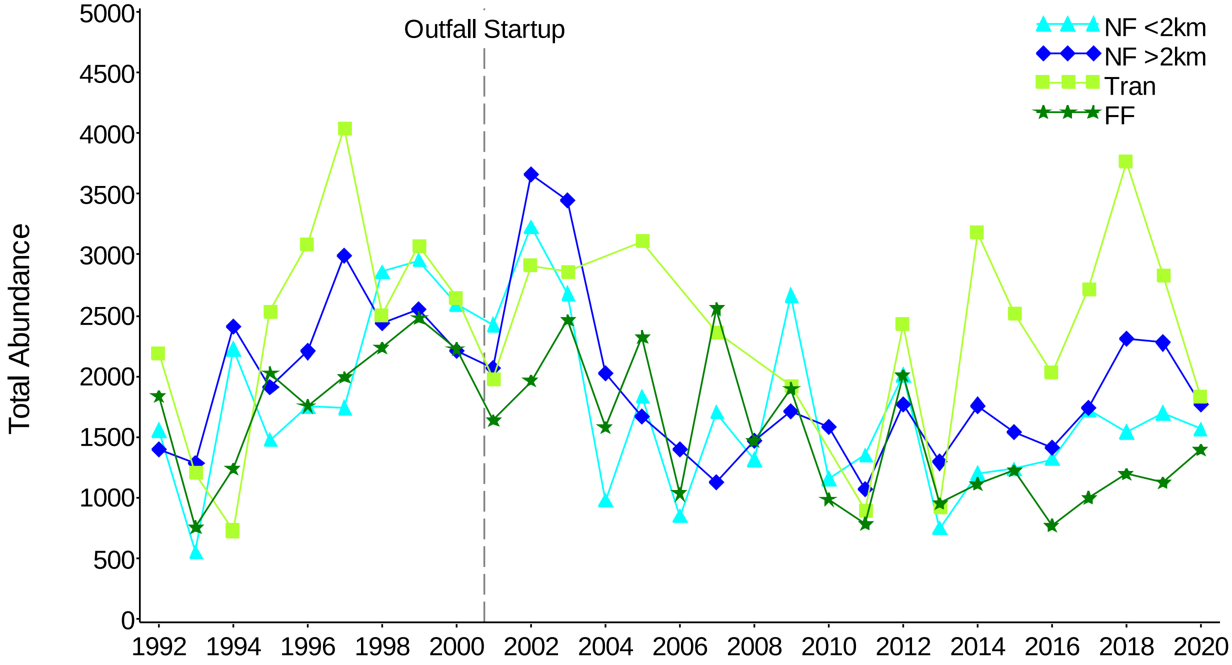

Figure 3-9. **Mean infaunal abundance per sample at four areas of Massachusetts Bay, 1992 to 2020. Tran=Transition area; NF<2km=nearfield, less than two kilometers from the outfall; NF>2km=nearfield, more than two kilometers from the outfall; FF=farfield.**

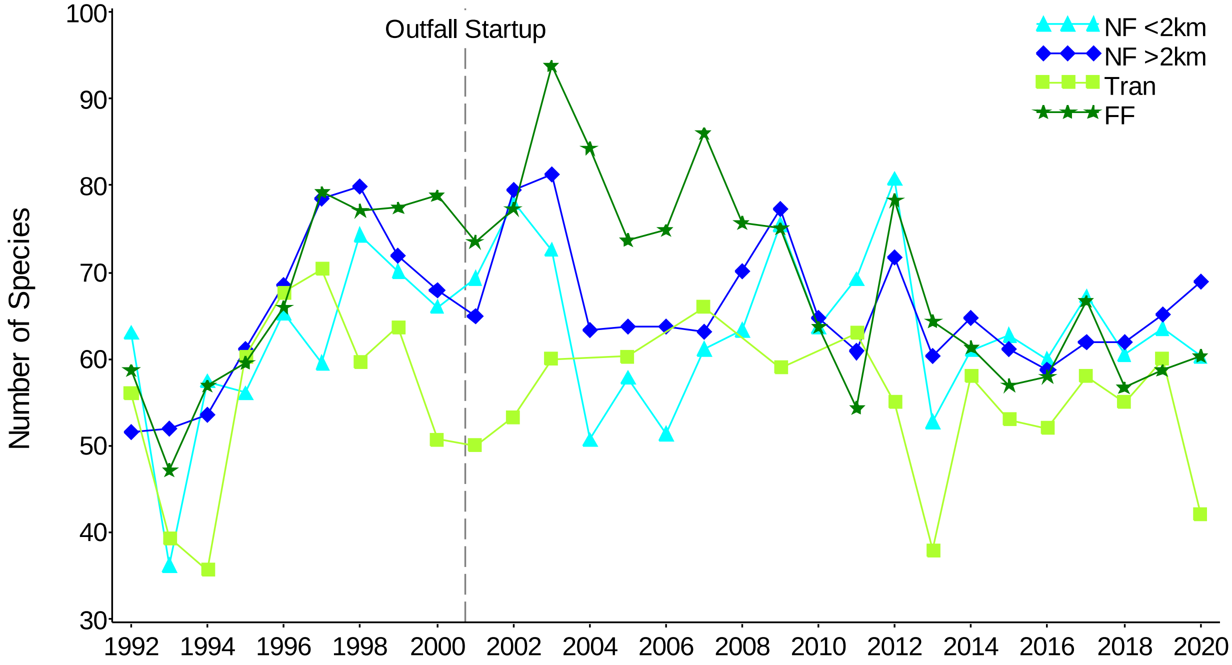

Figure 3-10. **Mean number of species per sample at four areas of Massachusetts Bay, 1992 to 2020. Tran=Transition area; NF<2km=nearfield, less than two kilometers from the outfall; NF>2km=nearfield, more than two kilometers from the outfall; FF=farfield.**

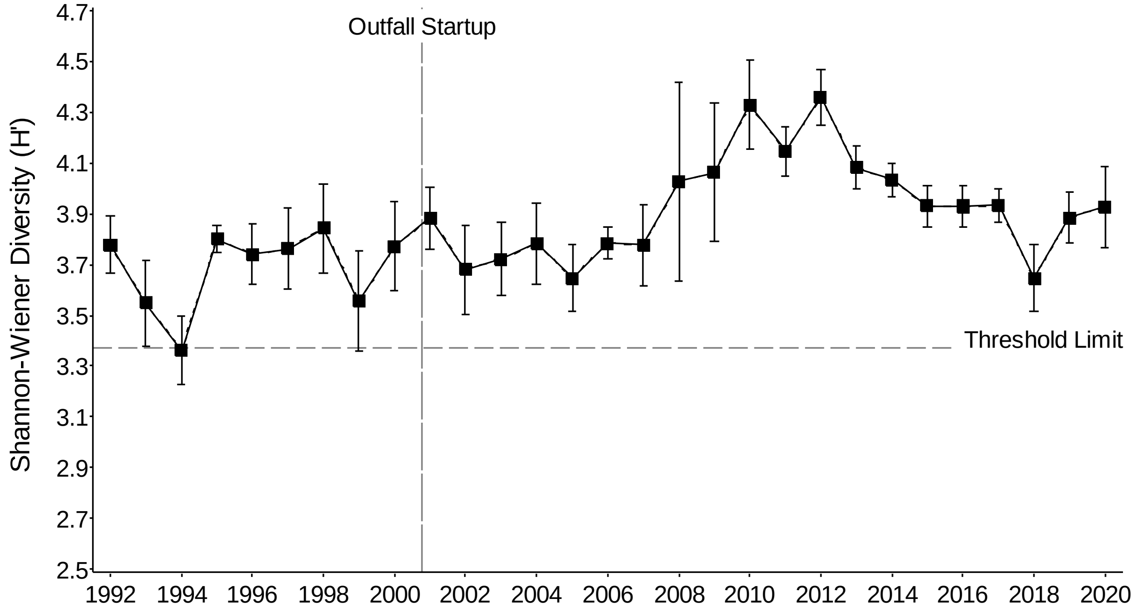

Figure 3-11. Mean (and 95% confidence intervals) Shannon-Wiener Diversity (H′) at nearfield stations in comparison to threshold limit, 1992 to 2020. The nearfield annual means and associated threshold limit are both based on the list of stations sampled following the 2010 revision to the Ambient Monitoring Plan (MWRA 2010).

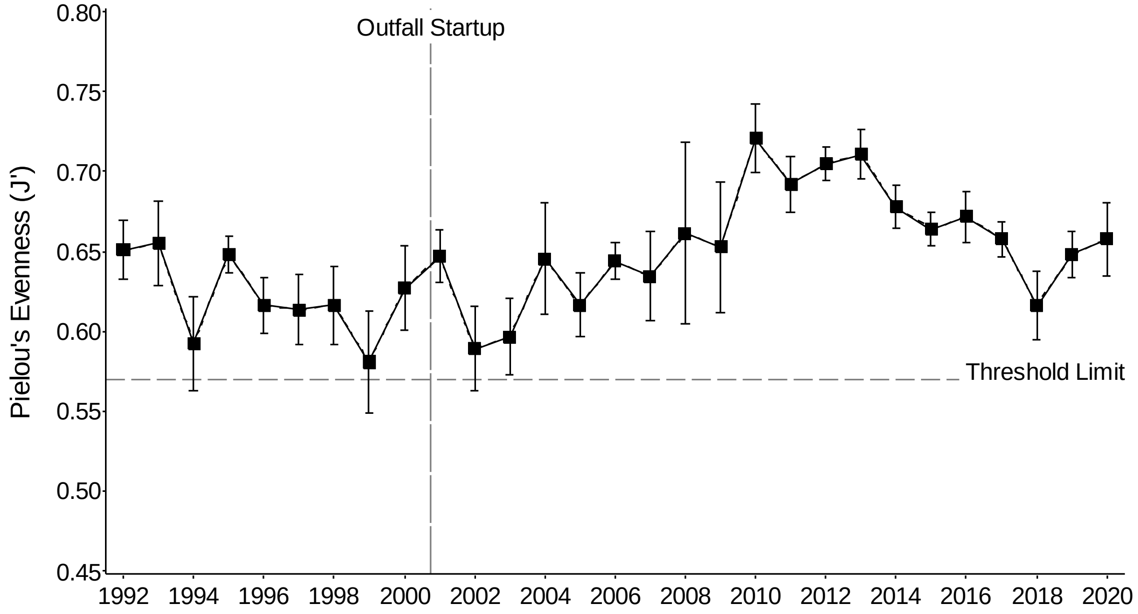

Figure 3-12. Mean (and 95% confidence intervals) Pielou's Evenness (J′) at nearfield stations in comparison to threshold limit, 1992 to 2020. The nearfield annual means and associated threshold limit are both based on the list of stations sampled following the 2010 revision to the Ambient Monitoring Plan (MWRA 2010).

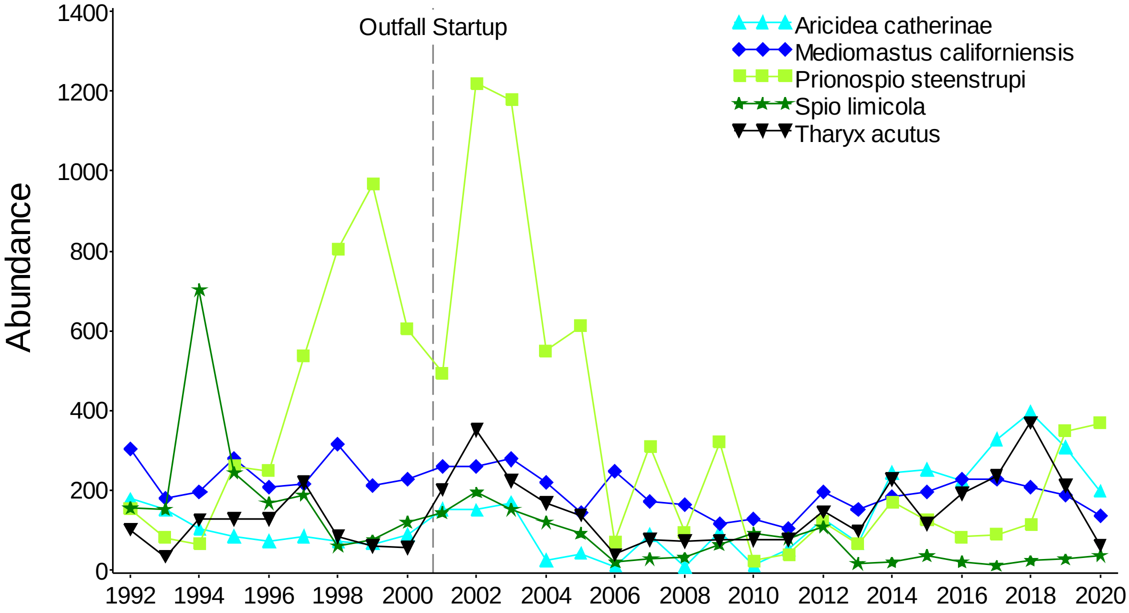

Figure 3-13. Mean abundance from 1992 to 2020, of the five numerically dominant taxa at nearfield stations in Massachusetts Bay.

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 2020 (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 two to three times lower than Group II (compare Figure 3-14 with Table 3-2). The three assemblages were dominated by polychaetes, although arthropods were a dominant in Group I and molluscs were dominants in Group IIA and B (Table 3-4). Several species were dominant only in Group I (e.g., *Exogone hebes, Crassicorophium crassiorne,and Tanaissus psammophilus*), while others were more prevalent in Group II (e.g., *Ennucula delphinodonta, Owenia artifex*, and cirratulids in the genus *Kirkegaardia*) or in Group III (e.g., *Chaetozone anasimus* and *Cossura longocirrata*). Group I was composed of three nearfield stations (Stations NF17, NF04 and NF13). The Group II assemblage included three subgroups (Group IIA: Station FF09; Group IIB: Stations FF01A and FF12; and Group IIC: Stations NF14, NF20, NF24, NF10, NF22, NF21, and NF12) 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, including *Levinsenia gracilis, Cossura longocirrata*, and *Chaetozone anasimus*, are characteristic of the soft sediment community observed throughout Stellwagen Basin (e.g., Maciolek et al. 2008).

Both main assemblages (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 effluent impacts. Comparisons of faunal distribution to habitat conditions indicated that patterns in the distribution of faunal assemblages follow differences in habitat types at the sampling stations and are associated with the sediment types at the sampling stations (Figure 3-16) and with station depth (not shown).

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, 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. 2019), 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).

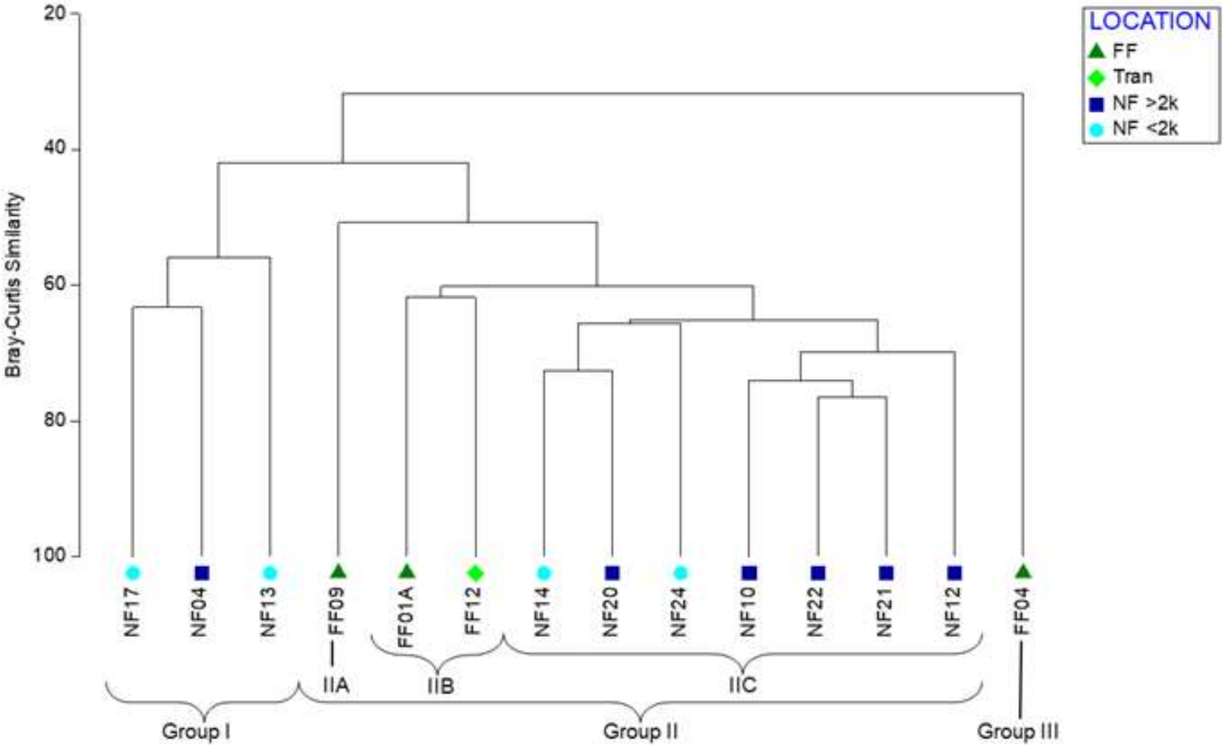

Figure 3-14. Results of cluster analysis of the 2020 infauna samples.

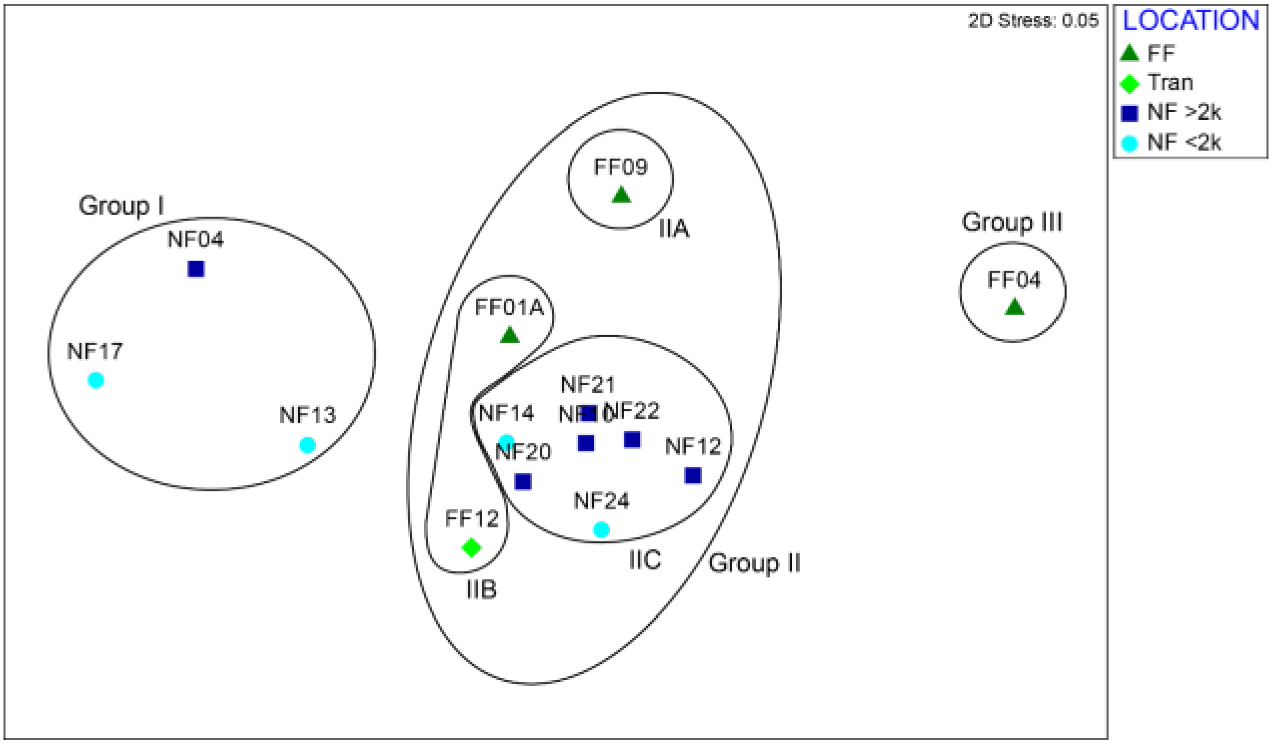

Figure 3-15. Results of a MDS ordination of the 2020 infauna samples from Massachusetts Bay showing distance from the outfall.

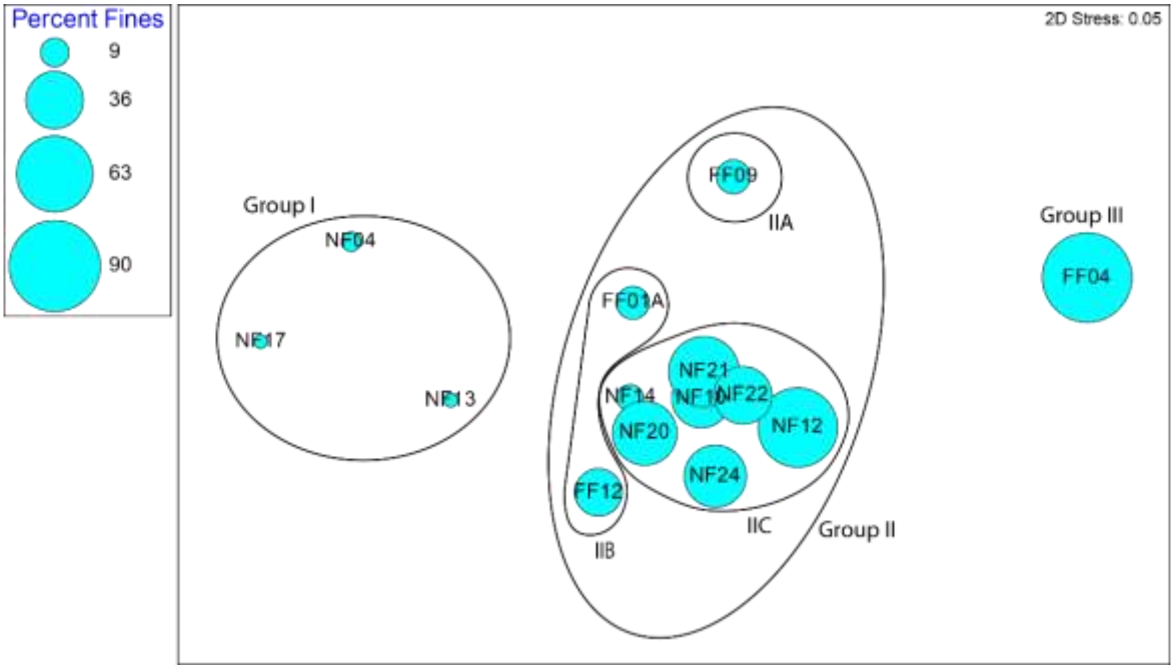

Figure 3-16. Percent fine sediments superimposed on the MDS ordination plot of the 2020 infauna samples. Each point on the plot represents one of the 14 samples; similarity of species composition is indicated by proximity of points on the plot. Faunal assemblages (Groups I-II, and sub-groups) identified by cluster analysis are circled on the plot. The ordination and cluster analysis are both based on Bray-Curtis Similarity.

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 2020 samples.

Family	**Species**	**Group I**	**Group II**			**Group III**
			IIA	**IIB**	**IIC**	**FF04**
Mollusca (Bivalvia)						
Mytilidae	*Crenella decussata*	-	99.0	-	-	-
Nuculidae	*Ennucula delphinodonta*	17.3	157.0	141.0	18.1	-
Annelida (Polychaeta)						
Ampharetidae	*Anobothrus gracilis*	-	94.0	13.5	1.6	115.0
Capitellidae	*Mediomastus californiensis*	10.7	26.0	96.5	192.4	17.0
Cirratulidae	*Chaetozone anasimus*	18.7	2.0	-	0.1	84.0
	Kirkegaardia baptisteae	8.3	-	76.0	89.4	-
	Kirkegaardia hampsoni	4.7	2.0	108.5	69.7	-
	Tharyx acutus	30.0	26.0	47.0	78.7	-
Cossuridae	*Cossura longocirrata*	-	1.0	1.0	4.8	46.0
Lumbrineridae	*Ninoe nigripes*	2.0	54.0	61.0	58.6	13.0
Maldanidae	*Rhodine loveni*	-	28.0	-	17.4	-
Nephtyidae	*Aglaophamus circinata*	19.7	9.0	24.5	3.0	-
Orbiniidae	*Leitoscoloplos acutus*	0.7	7.0	16.0	56.4	20.0
Oweniidae	*Owenia artifex*	7.7	13.0	287.0	15.8	-
Paraonidae	*Aricidea catherinae*	188.7	2.0	261.5	167.8	-
	Aricidea quadrilobata	-	27.0	6.0	7.7	42.0
	Levinsenia gracilis	9.3	45.0	139.0	118.3	87.0
Phyllodocidae	*Phyllodoce mucosa*	19.0	13.0	7.5	39.0	-
Polygordiidae	*Polygordius jouinae*	46.0	5.0	51.5	5.7	-
Sabellidae	*Euchone incolor*	0.3	28.0	85.5	78.1	34.0
Spionidae	*Prionospio steenstrupi*	13.3	202.0	375.5	517.0	50.0
	Spiophanes bombyx	87.0	2.0	54.0	100.4	-
Syllidae	*Exogone hebes*	223.3	6.0	1.0	37.8	-
Trochochaetidae	*Trochochaeta multisetosa*	-	2.0	-	0.3	28.0
Arthropoda (Amphipoda)						
Corophiidae	*Crassicorophium*	55.3	-	0.5	1.6	-
Arthropoda (Tanaidacea)						
Nototanaidae	*Tanaissus psammophilus*	43.7	-	-	0.1	-

3.3 HARD-BOTTOM BENTHIC HABITATS AND FAUNA

3.3.1 2020 Results

Photographic coverage of the hard bottom habitat in the vicinity of the outfall in 2020 ranged from 16 to 25 minutes of video footage at each waypoint and a total of 487 minutes of analog video was viewed and analyzed. The video footage taken this year was collected in the same manner as was utilized in previous years. The vehicle used to survey the stations was a *SeaEye Falcon ROV* equipped with an analog video camera. The *SeaEye Falcon ROV* is more powerful than the *Benthos Mini-Rover* used in recent years and more on par with 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 HD video images along the dive track for future use if deemed necessary. A summary of the analysis of the 2020 analog video is included in Appendix A.

Data collected from the video taken during the 2020 survey was generally similar to data obtained from previous post-diversion surveys. The seafloor on the tops of drumlins 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 generally ranged from moderately light to moderate on the tops of drumlins and moderate to moderately heavy on the flanks of drumlins. 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 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.

The species seen during the 2020 survey are shown in Appendix B. A total of fifty-seven taxa, 4 algal species, 37 invertebrate species, 8 fish species, and 8 general categories were seen during the 2020 video analyses. The species and the number of species have remained relatively constant over the course of this study. The distribution of the species has also remained relatively constant during the last several years. Coralline algae continued to be the most common and widespread component of the benthic communities, being found at 19 of the 23 waypoints. Another algal species, *Palmaria palmata* (dulse) was also seen in numbers similar to those observed in previous years. This red alga was found at 18 of the stations and was commonly seen at seven of them. *Ptilota serrata*, a filamentous red alga was seen at 15 stations and was present in sizable numbers at seven of the sites. Very few of the fourth algal species *Agarum cribrosum* (shot-gun kelp) were seen, with only a few fronds observed at two locations.

Common invertebrates seen in 2020 included: the horse mussel (*Modiolus modiolus*), juvenile and adult northern sea stars (*Asterias vulgaris*), the blood star (*Henricia sanguinolenta*), white and cream encrusting tunicates (*Aplidium*/*Didemnum* spp.), the encrusting yellow sponge *Polymastia* sp. A, the sea peach tunicate (*Halocynthia pyriformis*), and the brachiopod (*Terebratulina septentrionalis*). Their abundances and distributions were also similar to those observed in previous years. Two invertebrates that were more common in 2020 than in previous years were the blue mussel (*Mytilus edulis*) and the crumb-of-bread sponge (*Halichondria panecia*). The similarity to previous years also extended to the fish taxa, with the cunner (*Tautogolabrus adspersus*) being by far the most abundant and widely distributed fish encountered within the study area.

The taxa inhabiting the diffuser heads of the outfall continue to remain stable over time and did not change when the outfall went online. The inactive diffuser head (Diffuser #44) continues to support sparse populations of the frilled anemone (*Metridium senile*) and the sea peach tunicate (*Halocynthia pyriformis*; Figure 3-17 a & b), while the riprap at the base mainly supports dense stands of hyroids. Dead barnacles were also observed on top of the diffuser head. In contrast, the active diffuser head (Diffuser #2 at T2-5) supports a very dense population of *M. senile*, with anemones covering much of the available surfaces of the diffuser head (Figure 3-17 c & d). Additionally, numerous *M. senile* and dense stands of the hydroid *Tubularia* sp. have colonized the riprap around the base of the diffuser.

Several other observations were made during the 2020 survey. Massive settlements of barnacles (*Balanus* sp.), many of which were in the process of dying-off, were found at many of the stations. At 12 of the stations, numerous boulders were totally covered with the base plates and/or valves of dead barnacles and at another 3 stations the surfaces of some of the boulders were similarly covered. The exception to this was that few barnacles, dead or alive, were observed at the three near-field southern reference sites (T8-1, T8-2 and T12-1). In areas of massive settlements of barnacles, adult northern sea stars (*Asterias vulgaris*) were frequently seen preying on the barnacles.

Anomalies were also noted in the numbers and distribution of several commonly seen sponge species. During the 2020 survey, the fig sponge (*Suberites* spp.) was observed at only 1 station, the southernmost reference station T11-1 off Scituate, MA. This species was traditionally most abundant on the drumlins located immediately north and south of the outfall (T1, T2, T4 and T6). 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 2020 (T11-1). Two other sponges, *Polymastia* sp. A and the crumb-of-bread sponge (*Halichondria panecia*), were present at a number of stations in 2020.

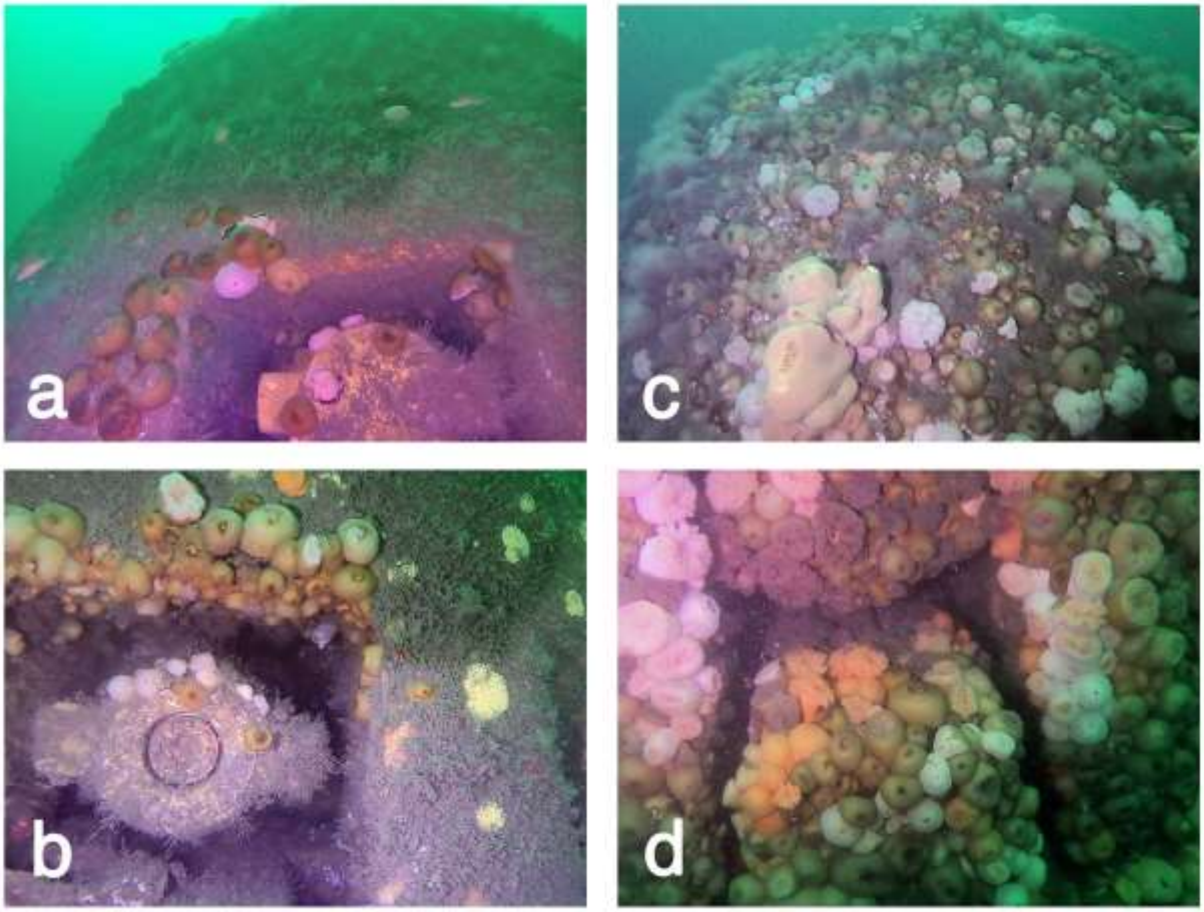

Figure 3-17. Still images taken at inactive diffuser head #44 (a & b) and active diffuser head #2 (c & d) during the 2020 hard-bottom survey. (a) A sparse population of frilled anemones (*Metridium senile*) and numerous hydroids colonizing the top of diffuser head #44. A few cunner (*Tautogolabrus adspersus*) are also visible. (b) A port of diffuser head #44 showing the heavy drape on this diffuser head. Sparse populations of *M. senile,* the sponge *Polymastia* A, sea peaches *Halocynthia pyriformis* and hydroids colonizing the side of the diffuser head. (c) Numerous frilled anemones (*M. senile*) and a few large globular sponges colonizing the top of active diffuser head #2. Several colonies of the hydroid *Tubularia* sp. are also visible. (d) Numerous *M. senile* colonizing a port of diffuser head #2.

3.3.2 Comparison of 2020 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 previous post-discharge years continued into 2020. 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 2020 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 have 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 reflect increases in the amount of drape on the rock surfaces.

The relative abundances of upright algae generally varied widely during both the pre- and post-diversion periods. Additionally, 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 relative abundance of *Palmaria palmata* over the 1996 to 2020 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 relative abundance of *P. palmata* 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. This pattern follows that observed in data collected from still images between 1996 and 2008.

Table 3-7 shows the relative abundance of *Ptilota serrata* over the 1996 to 2020 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 relative 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 may partially reflect the appearance of a filamentous red algal species that is new to the program. Many of the colonies observed at T12-1 in 2020 had a more fibrous and turf-like form than is typical of *P. serrata*, suggesting a new (possibly invasive) species. Similar patterns early on in the study were also observed in data collected from still images between 1996 and 2008. The presence of a new algae species at station T12-1 cannot be confirmed at this time. The observed patterns in algal increases and decreases may simply reflect different stages in a successional sequence of algal communities.

Table 3-5. Relative cover of coralline algae 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
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
	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
	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
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
	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
	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
	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
	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
	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
	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
	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
	T2-4	f	r	f	f	-	r	f	r-f	r	r	r	f	r-f	f	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
	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
	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
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
	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
	T12-1								c-a	c-a	c	c-a		c	c-a	c	c	c	c-a	c
	T11-1								-	f	f	f	r-f		f	r-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. Relative abundance of *Palmaria palmata* (dulse) 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
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
	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
	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
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
	T1-2	f	-	r	f	-	r-f	-	r	r	r	f-c	f	f-c	f	c-a	c	f	c	f-c
	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
	T1-4	-	-	-	-	-	r	-	f	r	f	f	f	f-c	f-c	f-a	f-c	c	r-f	f-c
	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
	T2-2	-	va	c	c	-	-	c	-	-	r-f	-	-	r	-	-	-	-	r	r-c
	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
	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
	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
	T8-1	-	-	-	-	-	-	-	-	r	f	r-c	f	f-c	r-f	f-c	f-c	r-f	f-c	c
	T8-2	-	-	-	-	-	-	-	-	-	r	f	r	r	r-f	r	f	r	f-c	f-c
	T12-1								f	f	f	f-c		f-a	f-c	f-c	c	c	f-c	c-a
	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. Relative abundance of *Ptilota serrata* (filamentous red alga) 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
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**

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 *A. clathratum* fronds observed in some areas while none were observed in adjacent areas. There has been a general decrease in shotgun kelp at all of 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 *A. clathratum* at T7-1 from a high in 2000, when it was heavily overgrown by the invasive bryozoan *Membranipora membranacea*. This decline was much less evident in the data collected from video images. In 2010 and 2011 this algae had also been seen at one site north of the outfall. In 2014 and 2017, the number of *A. clathratum* was at an all-time low, with only a few fronds being observed at one or two sites. This alga was slightly more abundant at one of the northern reference sites (T7-2) in 2020. Specifics of the abundance and distribution of shotgun kelp over the time course of this study can be seen in Table 3-8.

Table 3-8. Relative abundance of *Agarum clathratum* (shotgun kelp) 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
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	-	-	-
	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
	T11-1								-	-	-	-	-		-	-	-	-	-	-
Diffusers	T2-5	-	-				-	-	-	-	-	-	-	-	-	-	-	-	-	-
	RR			-			-	-	-	-	-	-	-	-	-	-	-	-	-	-
	D#44			-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	RR			-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

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

Part of the decline in both coralline and upright algae at the northern reference sites during the 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.

Table 3-9 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, Atlantic cod (*Gadus morhua*), American lobster (*Homarus americanus*), and winter flounder (*Pseudopleuronectes americanus*) 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 2020. 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 none 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 three of the post diversion years. The low number of cod seen during the 2014 and 2017 surveys may in part reflect cod shying away from the acoustically noisier *Benthos Mini-Rover* and 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, and 45.8 individuals per 100 minutes video in 2020. 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. Hence, their observed abundances might not be as easily influenced by the acoustic characteristics of the ROV.

Table 3-9. Number of several large mobile commercially important species observed in video footage taken during the 1996 to 2020 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**
***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
***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
***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
***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

One noticeable difference seen during the 2014, 2017 and 2020 surveys was the widespread presence of dead or dying barnacle sets at many of the stations. Large areas of rock surfaces covered by dead or dying barnacles were observed at 15 stations in 2014, 16 stations in 2017 and 12 stations in 2020. These stations were spread throughout the study area with the exception of the southern reference sites in 2017. Additionally, live barnacles were only observed in high numbers at one site (T4/6-1) in 2014, 12 sites in 2017 and two northern reference sites in 2020. 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 2014, 2017 and 2020.

In 2020, the blue mussel (*Mytilus edulis*) became a more dominant component of the fauna inhabiting large boulders at several of the stations than in previous years. 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. Additionally, *M. edulis* were also seen inhabiting the sediment near the base of boulders at several of the stations. This is in contrast to previous years where the blue mussel was largely restricted to the surfaces of large boulders. It is interesting to note that the number of *M. edulis* have been increasing in the deeper water, at the same time they are practically disappearing from intertidal sites (Sorte et al. 2017).

The pronounced decrease in two of the sponge taxa, the fig sponge *Suberites* spp. and the white sponge encrusting brachiopod valves *Iophon nigricans*, is more perplexing (Tables 3-10 and 3-11). *Suberites* spp. was observed at only a single station in each of 2017 and 2020. 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 only 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). The explanation for the decrease in *I. nigricans* is a bit more perplexing. This brachiopod-encrusting sponge was commonly observed at 2 to 15 stations prior to 2017. In 2017, substantial numbers of *I. nigricans* were restricted to only 1 station (T2-2), as they were in 2020. Brachiopods were present in 2017 and 2020 but most of them did not have a sponge covering. Whether the brachiopods were newly attached and had not yet acquired a sponge covering, or *I. nigricans* is more sensitive to environmental changes is presently not known. Two other common sponges, *Polymastia* sp. A and the crumb-of-bread sponge *Halichondria panecia*, have either remained present in high abundances over the entire time period (*Polymastia*) or have recently been increasing (*H. panecia*). The observed changes in some of the sponge species 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.

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 relative 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. Examples of the visual changes observed over time at a few representative sites can be seen in the plates in Appendix C.

Table 3-10. Relative 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
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. Relative abundance of *Iophon nigricans* 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
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	-	-	-	-	-	-	-
	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
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	-	-
	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
Diffusers	T2-5	-	-			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	RR	-	-	f		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	D#44			-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	RR			-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

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

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 appears to be increasing again at a number of stations. 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 been noticing 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 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 and 2020 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.

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 (Rutecki et al. 2019, Maciolek et al. 2008). As result, SPI surveys in Massachusetts Bay and the sediment contaminant evaluation every third year in the nearfield and farfield stations have been discontinued beginning 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 in the nearfield stations 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 2020.

Hard-bottom benthic community monitoring in 2020 also found no evidence that particulate matter from the wastewater discharge has smothered benthic organisms. Although some modest changes in this community (e.g., coralline algae, upright algae cover, and sponge abundance) have been observed, comparisons between the post-diversion and baseline periods indicate that these changes are not substantial. Factors driving changes in the algal cover are unclear, but, since declines in upright algae started in the late 1990s (prior to wastewater diversion to the outfall), it is unlikely that the decrease was attributable to diversion of the outfall.

Benthic monitoring results continued to indicate that the three potential impacts of primary concern (decreased oxygen; accumulation of contaminants; and particulate deposition that smothers the benthos) have not occurred at the MWRA stations. Results also continue to demonstrate that the benthic monitoring program comprises a sensitive suite of parameters that 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. *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. 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 SUMMARY OF DATA RECORDED FROM VIDEO FOOTAGE TAKEN ON THE 2020 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	23	19	23	22	21	23	20	23	22	23	20	20	16	20	21	20	21	21	20	21	21	22		25		487
Begin depth (m)	28.3	26.9	23.7	24.6	30.5	29	31.3	26.7	30.4	25.7	32.4	34.6	32.1	25.5	24.2	27.6	27.1	25.3	26.5	24.2	35.5	33.5		34.9		
End depth (m)	27.9	26.2	24	25.3	26.5	28.7	25.6	25.6	30.7	22.6	33.9	30.1	31.2	26.2	25	24.3	25.9	24.8	26.8	22.7	34.6	30.7		36		
Substrate[1]	mix	b+c	b	b+c	cp+ob	mix	b+c	b+c	c+b	b+c	cp+g	cp+b	mix	b+c+g	b+c	b+c	b	cp+b	mix	b+c	c+b	dif	rr	dif	rr	
Drape[2]	m-mh	m-mh	mh	l-lm	m-mh	m-mh	m-mh	mh	mh	m	m	mh-h	m	mh	m	m	mh-h	m-mh	lm	lm	mh-h	mh	mh	h	h	
Relief[3]	LM-M	LM-MH	MH	LM-M	LM	L-M	M	M-MH	LM-M	M-MH	L	L-LM	LM	M-MH	M-MH	M-MH	H	LM	LM	M-MH	LM-M	H	M	H	L	
Suspended matter[4]	vh	h	h	h	h	h	vh	h	h	vh	vh	vh	vh	vh	vh	vh	vh	h	vh	vh	vh	vh	vh	vh	vh	
Coralline algae	f	f	f-c	c-a	r	r-f	r	f	r	f-c	f		r	f	f-c	f-c		f-c	c-a	c	f					
Ptilota serrata	r-f	f-c	c-a	c-a	r-f		r-f	r		c-a				a	c-a	f-a	r	f	f	a						
Hydroids	c	a	a	f-c	f-c	r-c	c-a	a	c	f-c	f	r-f	f	c	c	f-c	c-a	c-a	f	c	c	c	a	a	a	
Spirorbids/barnacles	c	r	f	c		f		c	c	c	f	f	f	c	a	c	c-a	f	c	c-a	c		c		r	
Palmaria palmata	r-c	f-c	c-a	f-c	r-f	r-f	r-c	c	r	c				a	c-a	f-c	f	c	f-c	c-a	r					
Agarum cribosum															10					3						13
general sponge							2	2	5	1				3*	1	f*	3			2		5	2	3	1	27
Polymastia sp. A	c-a	f-c			f	r-c	c	c-a	a	f	r	r-c	c	c*	c	c	c-a	r	r-f	f	f			c		
Polymastia sp. B	7																									7
Haliclona oculata			3					6*												1				3	4	11
Suberites spp.																					c					
Iophon nigricans						r		r	r					r*	r*	r*					c-a					
Melonanchora elliptica		1						1	1	1									6	1			1			12

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
Haliclona spp. (encrusting)	1								1										2							4
thick cream sponge with projections																					c					
yellowish-cream encrusting sponge																					c					
Halichondria panicea	f					r	c	c-a	c-a				r	c*	c*	f*	f				f					
Obelia geniculata															r					r						
general anemone							2										1									3
Metridium senile	r		r			r	r	f*		c*				c*		r*			r*	r*		a	c-a	c		
Urticina felina	2	4	3		1	2	10	6	7	5	1	3	3	2		1				1	4		5	2	2	64
Pachycerianthus borealis											13	1									3					17
Gersemia rubiformis																	r									
Tubularia sp.								c*		a*				c*	c*	f*				f*		c-a	a	c	r	
Alcyonium digitalum			r				r		r		r							r								
Gersemia fruticosa								r*													c					
gastropod											1															1
Crepidula plana	f	f	f				f		f	f	f			f				f-a	f-c	f						
Buccinum undatum											1				1											2
Neptunea decemcostata						1					1		1					1								4
nudibranch									2									1								3
Modiolus modiolus	c-a	c	f-c	f	f-c	f	c-a	a	c	a	f	r	f-c	f-c	f-c	c-a	f	c	f	c	c-a					
Mytilus edulis	r		f			r	f	a	f	c*				a*	c*	a*	a			c*	r	c	f			
Placopecten magellanicus	4				2	2					16	3						1	1						5	34
Balanus sp.	r			f				f	f	f				f	f-c	f-c*	f					f				

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**
Homarus americanus		3	1	1	5		3	3	4	2		1		1		3	1		2	2	3		1			36
Cancer spp.	9	10	2	1	6	7	8	1	5	3	1	4	7	6	1	2	2	3		1						79
hermit crab											1															1
Strongylocentrotus droebachiensis			f					r		f-c			r			r			r	f						
small white starfish	c	f	r	f	f	f	c	c	r	f	a	c	f	c	f	f-c	f	f	f	f	c-a		f	f		
Asterias rubens	c	f-c	f-c	c	f-c	r-c	f	c	c	f	f-c	f-c	f-c	c	f-c	f-c	r	c-a	f-c	a	f	f	f	r	r	
Henricia sanguinolenta	c	c	f-c	c	c	r-c	c	c	c	c-a	c	f-c	c	c	c	f-c	c-a	f-c	c	c	c	f	f	c	f	
Psolus fabricii								r*	r	r						r			r	r						
Botrylloides violaceus	2					2	6	22*	35	3		7	13	8	5	19	28	13	4	19	30					194
Aplidium/Didemnum	c-a	r-c	f	r-f	f-c	r-f	f-c	c	c	f	a	f-c	f-c	c	f-c	c	f-c	r	f-c	f	f			f	f	
Dendrodoa carnea	r				r		r	c*	f				r	f*	f*	f*			f*	c*	f			f	r	
Halocynthia pyriformis		r-f	c	f			f							f	r	r		f	r	f						
Membranipora sp.	f-c	f	f	r	r-f	r	r	c	f	r	r	r	r	r	r	f	r	f-c		f	f					
Myxicola infundibulum						r		c*	r	r*	r		r	f-c*	c*	c-a*	r			a*	c-a					
Terebratulina septentrionalis				1										1					3				1			6
general fish	f-c	c-a	a	c-a	f-c	f-c	c-a	c-a	f-c	a	r-f	r-f	f-c	a	a	a	c-a	f	f-c	f-a	f-c	a	c-a	c	c	
Tautogolabrus adspersus	3	7	1	4	9	7	8	1	8	8	2	7	13	2		3	2	6	3	5	9		3		5	116
Myoxocephalus spp.																				1						1
Zoarces americanus										1																1
Hemitripterus americanus		3	1	1	5		3	3	4	2		1		1		3	1		2	2	3		1			36

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	4	4	27	7		16	4		15	11	20	57		7		4	1	9	9	3			5		4	207
Pholis gunnellus		1			1							1	1			1										5
Gadus morhua		6	18	3	1	1	1	9		8				1	6	2	6		1	3	2			2	3	73
Pollachius virens		10	4	8		1	1	26	4	22				1	3					3			68		8	159
whelk egg case		1			2			1		1	1	5	1		1		5	4	1							23
nudibranch egg mass		1	2					3			1								2	4				1	7	21
ex barnacles	c	a	a	f-c	f	f-c	c	a	c	a	r		a	a	a	a	a	r	f-c	f	f					

[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 B: TAXA OBSERVED DURING THE 2020 NEARFIELD HARD-BOTTOM VIDEO SURVEY

Name	Common name	Name	Common name
Algae		**Crustaceans**	
Coralline algae	pink encrusting algae	*Balanus* sp.	barnacle
Ptilota serrata	filamentous red algae	*Cancer* spp.	Jonah or rock crab
Palmaria palmata	dulse	*Homarus americanus*	lobster
Agarum clathratum	shotgun kelp	hermit crab	
Invertebrates		**Echinoderms**	
Sponges		*Strongylocentrotus droebachiensis*	green sea urchin
general sponge		small white starfish	juvenile *Asterias*
Halichondria panicea	bread-of-crumb sponge	*Asterias rubens*	northern sea star
Haliclona oculata	finger sponge	*Henricia sanguinolenta*	blood star
Haliclona spp. (encrusting)	sponge	*Psolus fabricii*	scarlet holothurian
Iophon nigricans	sponge on brachiopod		
Melonanchora elliptica	warty sponge	**Tunicates**	
Polymastia sp. A	encrust yellow sponge	*Aplidium/Didemnum* spp.	cream encrust tunicate
Polymastia sp. B	soft substrate sponge	*Botrylloides violaceus*	Pacific tunicate
Suberites spp.	fig sponge	*Halocynthia pyriformis*	sea peach tunicate
cream sponge/projections	sponge		
yellowish-cream encrusting	sponge	**Miscellaneous**	
		Membranipora membranacea	lacy bryozoan
Coelenterates		*Myxicola infundibulum*	slime worm
Hydroids		Spirorbids/barnacles	
Obelia geniculata	zig-zag hydroid	*Terebratulina septentrionalis*	northern lamp shell
Tubularia sp.	hydroid		
general anemone		**Fishes**	
Metridium senile	frilly anemone	general fish	
Urticina felina	northern red anemone	*Gadus morhua*	cod
Pachycerianthus borealis	northern cerianthid	*Hemitripterus americanus*	sea raven
Alcyonium digitalum	dead mans fingers coral	*Myoxocephalus* spp.	sculpin
Gersemia fruticosa	white *Gersemia*	*Pholis gunnellus*	rock gunnel
Gersemia rubiformis	red soft coral	*Pollachius virens*	pollock
		Pseudopleuronectes americanus	winter flounder
Molluscs		*Tautogolabrus adspersus*	cunner
gastropod		*Zoarces americanus*	ocean pout
Crepidula plana	flat slipper limpet		
Buccinum undatum	waved whelk	**Other**	
Neptunea decemcostata		whelk egg case	
nudibranch		nudibranch egg case (frilly white)	
Modiolus modiolus	horse mussel	ex barnacles	
Mytilus edulis	blue mussel		
Placopecten magellanicus	sea scallop		

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

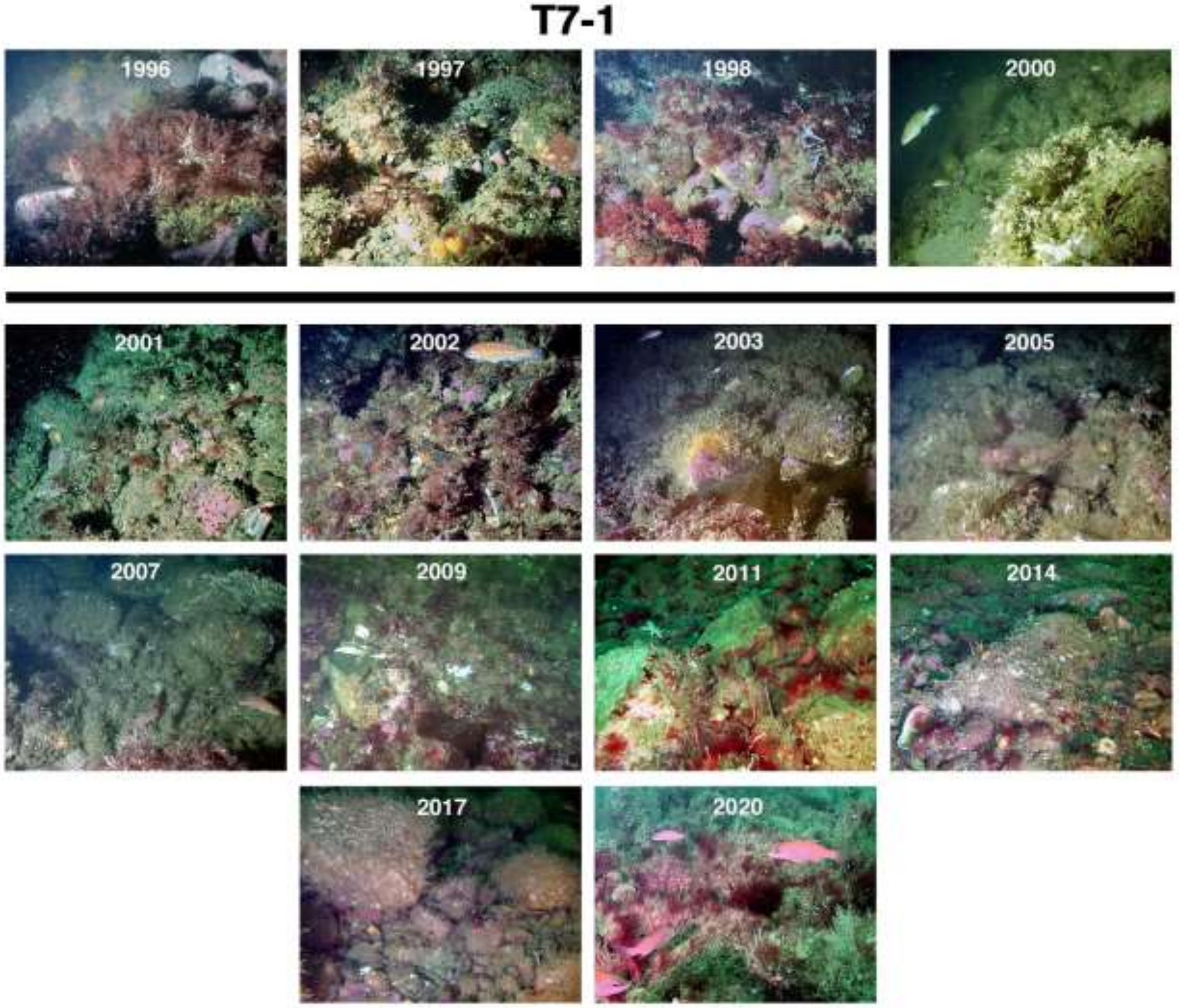

Plate 1. Representative images through time at T7-1 one of the northern reference sites. The four images above the bold line (1996, 1997, 1998 and 2000) show this site during the pre-diversion years. The benthic community was dominated by upright algae during this period. The ten images below the bold 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 partially reflect the occurrence of a red alga species that is new to the program. Some of the filamentous red algae observed appeared coarser and more fibrous than *Ptilota serrata*, the red alga commonly observed in the area.

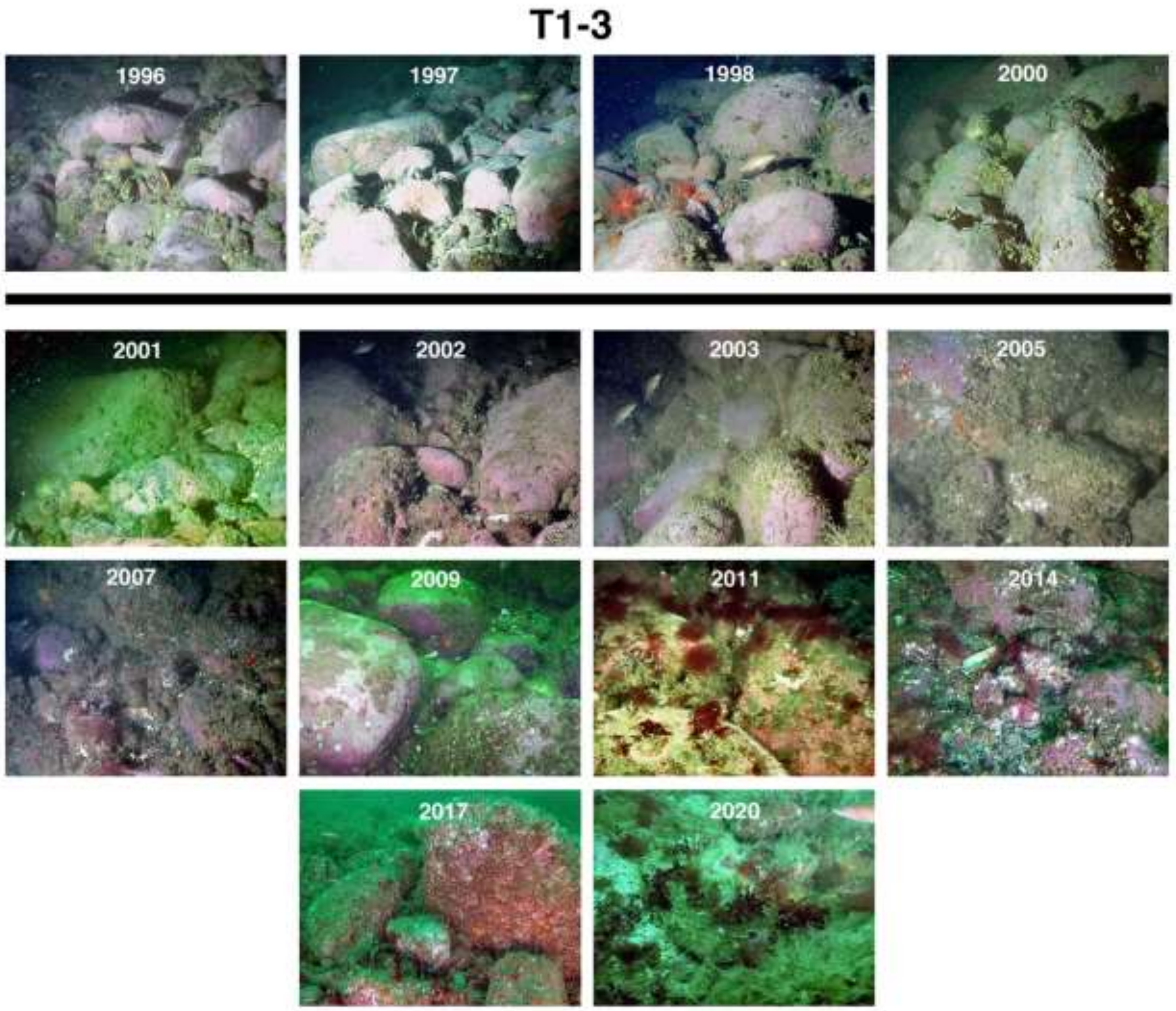

Plate 2. Representative images through time at T1-3 a drumlin top site north of the outfall. The four images above the bold line (1996, 1997, 1998 and 2000) show this site during the pre-diversion years. The benthic community was totally dominated by coralline algae and the rocks had very little drape during this period. The ten 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 started appearing at this site since 2011.

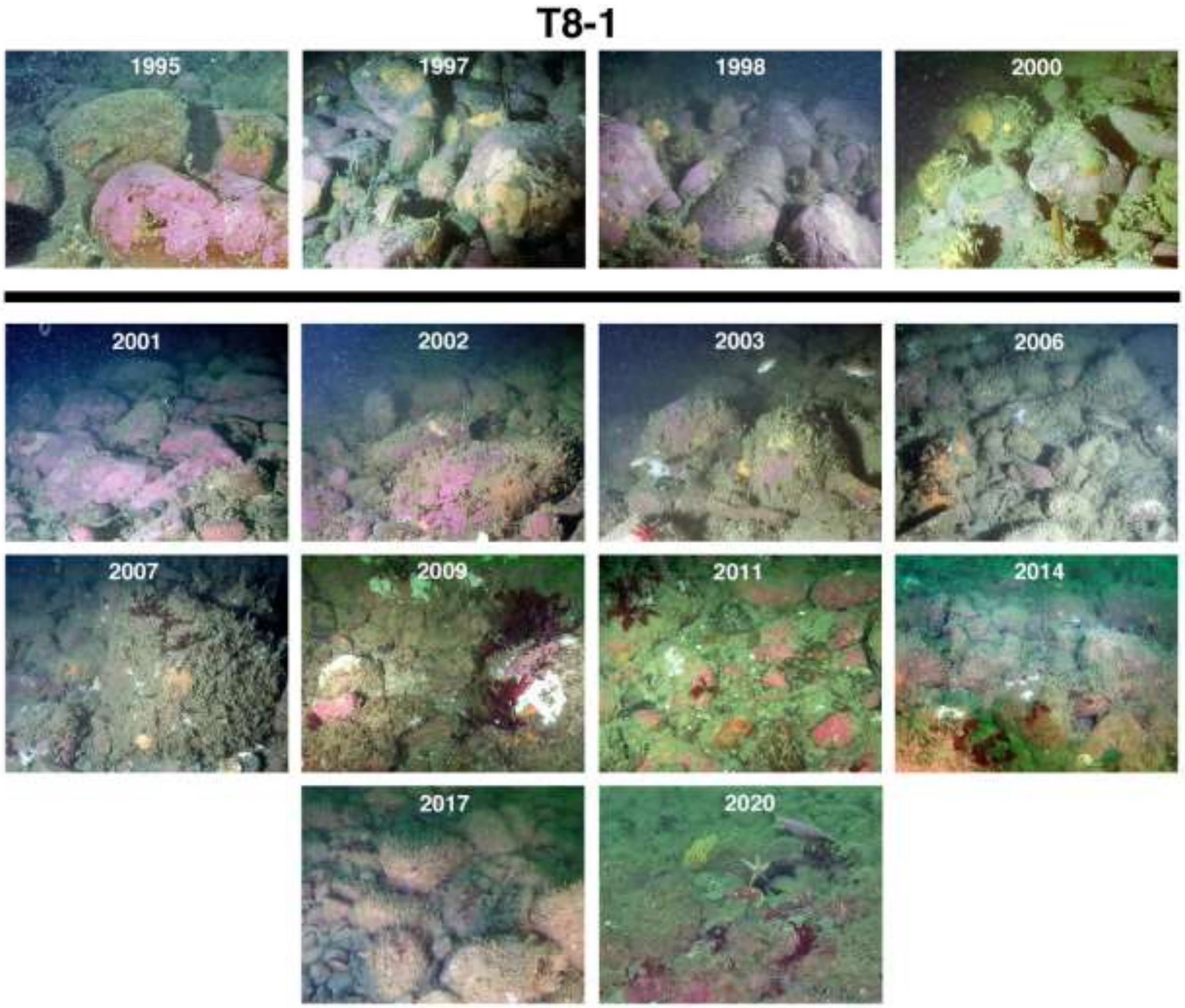

Plate 3. Representative images through time at T8-1 one of the southern reference sites. The four images above the bold line (1995, 1997, 1998 and 2000) show this site during the pre-diversion years. The benthic community was dominated by coralline algae during this period. The ten images below the bold 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*) have been seen at this site since 2007.

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