MCKAY BAY DREDGE HOLE RESTORATION MONITORING

Post-Restoration Benthic Sampling Final Report

By

David J. Karlen, Ph.D., Thomas L. Dix, Ph.D., Barbara K. Goetting,

Sara E. Markham, Kevin W. Campbell, Joette M. Jernigan

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Introduction

Dredge holes are submerged depressions caused by the removal of sediments to provide fill for construction projects or to create navigation channels. These deep borrow pits usually have poor water and sediment quality. They are characterized, by stratification of the water column, bottom hypoxia, and accumulation of silty sediments. These conditions further lead to impoverished benthic communities (Vose et al. 2005; Palmer et al. 2008; Reine et al 2013b; Kotwicki et al. 2015). Some dredge holes may provide bottom relief which can attract fish (Vose et al. 2005; Reine et. al. 2013b). Dredge holes are restored by filling or partially filling with sediments which has been shown to reduce water column stratification, improve bottom dissolved oxygen and increase species richness and abundance of the benthic community (Reine et al. 2013a & 2014). Restored dredge holes can also provide suitable substrate for the growth and recovery of seagrass beds (Dial and Deis 1986).

The Tampa Bay Estuary Program conducted a study evaluating the habitat quality, fisheries use, and restoration potential of 11 dredge holes in Tampa Bay (Tampa Bay Dredged Hole Habitat Assessment Advisory Team, 2005; Grabe et al. 2005). The McKay Bay dredge hole was ranked as the worst in terms of poor water and sediment quality, a degraded benthic community, and low utilization by fish. This study made the recommendation that this dredge hole should be filled to the surrounding depth in order to eliminate hypoxic conditions, cap potentially contaminated sediments, and allow for the establishment of a healthy benthic community. The McKay Bay dredge hole also had a high feasibility for filling due to its location near Port Tampa Bay (Tampa Bay Dredged Hole Habitat Assessment Advisory Team, 2005). Fill material from the dredging of a new berth in Port Tampa Bay and from a mitigation project on the McKay Bay peninsula was made available for the filling of a portion of the McKay Bay dredge hole (Swingle and Brice, 2011).

The Environmental Protection Commission of Hillsborough County was contracted by the Southwest Florida Water Management District to conduct pre- and post- restoration benthic monitoring. This report presents the results of the post-restoration sampling and comparisons with the pre-restoration results.

Materials and Methods

Study Design and Site Selection

This study employs a Before-After-Control-Impact (BACI) study design (Green, 1979) in order to assess the post-restoration recovery of the benthic infaunal community. The advantage of the BACI approach is that it provides both a spatial and temporal control to better detect environmental changes resulting from a disturbance, or in this case, due to the restoration of an impacted site. This is achieved through collecting samples in a control or reference area with similar physical characteristics as the impacted site to provide for a spatial control and both sites are sampled before and after the restoration to control for temporal changes.

A total of 30 locations (sampling sites) were sampled in August 2011 (Table 1, Figure 1). Fifteen sites were within the dredge hole restoration area (impact treatment) and 15 sites were located outside of the dredge hole restoration area (control treatment). Twenty-one of the 30 sites were selected from locations previously sampled between 1999 – 2010 as part of the EPCHC's Hillsborough Independent Monitoring Program (HIMP) or other EPCHC studies that provided baseline monitoring data in McKay Bay (Grabe et al. 2000, 2001, 2004; Karlen et al., 2012). These sites were selected based on their similarity to the expected post-restoration depth of the dredge hole and the sediment composition of the fill material (Swingle and Brice 2011). These 21 sites included all 15 control sites and six of the dredge hole sites. An additional nine sites were added within the restoration area to give a total of 15 dredge hole sites to balance the sampling design. Table 1 shows the 30 sampling sites, their treatment (control or dredge hole), station number, and pre- and post sampling dates and coordinates. The nine added dredge hole sites are designated by their higher site numbers (MCB461 – MCB469).

Table 1. McKay Bay Dredge Hole Pre and Post- Restoration Sampling Stations, Dates and Coordinates.

Treatment	Station	Before/After	Sample Date	Latitude	Longitude
Control	MCB062	Pre	15-Aug-2011	27.94648	-82.42709
		Post	28-May-2014	27.94640	-82.42702
	MCB068	Pre	9-Aug-2011	27.94765	-82.41423
		Post	27-May-2014	27.94743	-82.41434
	MCB076	Pre	15-Aug-2011	27.94419	-82.42662
		Post	28-May-2014	27.94432	-82.42650
	MCB088	Pre	15-Aug-2011	27.94208	-82.43037
		Post	28-May-2014	27.94218	-82.43023
	MCB091	Pre	15-Aug-2011	27.94250	-82.42334
		Post	28-May-2014	27.94248	-82.42338
	MCB102	Pre	15-Aug-2011	27.93892	-82.43106
		Post	28-May-2014	27.93898	-82.43128
	MCB103	Pre	15-Aug-2011	27.94159	-82.42823
		Post	28-May-2014	27.94167	-82.42838
	MCB117	Pre	15-Aug-2011	27.93858	-82.42868
		Post	28-May-2014	27.93857	-82.42868
	MCB129	Pre	15-Aug-2011	27.93684	-82.43283
		Post	28-May-2014	27.93700	-82.43290
	MCB138	Pre	15-Aug-2011	27.93599	-82.41419
		Post	28-May-2014	27.93603	-82.41430
	MCB149	Pre	15-Aug-2011	27.93408	-82.41975
		Post	28-May-2014	27.93412	-82.41973
	MCB161	Pre	15-Aug-2011	27.93109	-82.42379
		Post	28-May-2014	27.93107	-82.42398
	MCB164	Pre	15-Aug-2011	27.93095	-82.41904
		Post	28-May-2014	27.93107	-82.41918
	MCB176	Pre	15-Aug-2011	27.92899	-82.42339
		Post	28-May-2014	27.92888	-82.42355
	MCB178	Pre	15-Aug-2011	27.92955	-82.41776
		Post	28-May-2014	27.92965	-82.41790

Table 1. Continued.

Treatment	Station	Before/After	SampleDate	Latitude	Longitude
Dredge Hole	MCB094	Pre	9-Aug-2011	27.94129	-82.41802
		Post	27-May-2014	27.94137	-82.41808
	MCB095	Pre	9-Aug-2011	27.94264	-82.41501
		Post	27-May-2014	27.94273	-82.41508
	MCB106	Pre	9-Aug-2011	27.94085	-82.42216
		Post	27-May-2014	27.94100	-82.42225
	MCB107	Pre	9-Aug-2011	27.93994	-82.42058
		Post	27-May-2014	27.93985	-82.42042
	MCB108	Pre	9-Aug-2011	27.94012	-82.41896
		Post	27-May-2014	27.94026	-82.41890
	MCB119	Pre	15-Aug-2011	27.93971	-82.42423
		Post	27-May-2014	27.93982	-82.42424
	MCB461	Pre	15-Aug-2011	27.94229	-82.42123
		Post	27-May-2014	27.94244	-82.42125
	MCB462	Pre	9-Aug-2011	27.94252	-82.41735
		Post	27-May-2014	27.94252	-82.41740
	MCB463	Pre	9-Aug-2011	27.94143	-82.41672
		Post	27-May-2014	27.94136	-82.41718
	MCB464	Pre	9-Aug-2011	27.94208	-82.41564
		Post	27-May-2014	27.94194	-82.41562
	MCB465	Pre	9-Aug-2011	27.94224	-82.41391
		Post	27-May-2014	27.94232	-82.41376
	MCB466	Pre	9-Aug-2011	27.93990	-82.42201
		Post	27-May-2014	27.94005	-82.42231
	MCB467	Pre	15-Aug-2011	27.93992	-82.42376
		Post	27-May-2014	27.94002	-82.42384
	MCB468	Pre	9-Aug-2011	27.93885	-82.42354
		Post	27-May-2014	27.93889	-82.42353
	MCB469	Pre	9-Aug-2011	27.93894	-82.42442
		Post	27-May-2014	27.93888	-82.42457

Field Collection

Field and laboratory methods were adopted from the EMAP-E Louisianan Province operations manual (Macauley, 1993) and modified for the Tampa Bay monitoring program (Versar, 1993; Courtney et al. 1995). A hydrographic profile was taken at each site using a Hydrolab® Quanta multi-probe sonde. Measurements were taken from the surface (0.1 meters) and bottom for temperature, salinity, pH, and dissolved oxygen.

Sediment samples for benthic macrofaunal community analysis were taken at each site using a Young-Modified Van Veen grab sampler (Young grab). The grab sample was taken to a sediment depth of 15 cm and covered an area of 0.04 m^2. A 60 cc corer was used to take a subsample for silt+clay analysis. Samples were sieved through a 0.5 mm mesh sieve and the remaining fraction was rinsed into plastic sample jars. The pre-restoration samples were fixed in 10% buffered formalin for a minimum of 72 hours and then transferred into 70% isopropyl alcohol for preservation and storage. The post-restoration samples were fixed and stored in NOTOXhisto™ (Scientific Device Laboratory, Inc.). Rose Bengal was added to the formalin, isopropyl alcohol and NOTOXhisto™ solutions to stain the organisms.

Laboratory Analysis

The silt+clay analysis followed procedures outlined in Versar, 1993. Benthic sediment samples were rough sorted under a dissecting microscope into general taxonomic categories (annelids, mollusks, crustaceans, and miscellaneous taxa). Resorting was done on 10% of the samples completed by each technician for QA/QC. The sorted animals were identified to the lowest practical taxonomic level (species level when possible) and counted. Taxonomic identifications were conducted using available identification keys and primary scientific literature. All identification and count data were recorded on laboratory bench sheets and entered into a Microsoft Access® database maintained by the EPCHC.

Data Analysis

Univariate Statistical Analysis

Statistical analysis was done using SigmaStat ® 3.5 (SYSTAT Software, Inc. 2006a). Data were transformed for normality where needed for the parametric tests. The Two Way Repeated Measures Analysis of Variance (RM ANOVA) with a Holm-Sidak method pair-wise post hoc test was used to test for differences between sampling events and treatments.

Multivariate Statistical Analysis and Benthic Community Indices

PRIMER v6 software (PRIMER-E, Ltd. 2006; Clarke and Gorley 2006) was used for all multivariate statistical analysis and for calculating univariate biological metrics (species richness, abundance, Shannon diversity index and Pielou's evenness index). Species richness (*S*) was defined as the total number of taxa. Abundance (*N*) was expressed as the number of individuals per m^2 (calculated as the raw count x 25) except for colonial organisms which were counted as present/absent. The Shannon diversity index (*H'*) calculations employed the natural logarithm opposed to log base 2 (Clarke and Warwick 2001). The zero-adjusted Bray-Curtis similarity (Clarke et al. 2006) was calculated on square root transformed abundance data and the resulting similarity matrix was used for running Cluster

Analysis, Non-metric Multi-Dimensional Scaling (MDS), Similarity Percentage (SIMPER), and Analysis of Similarity (ANOSIM). The BIO-ENV procedure (Clarke and Ainsworth 1993) was used to find correlations between the environmental parameters and benthic community structure. All environmental parameters were normalized and log transformed prior to analysis. The Tampa Bay Benthic Index (TBBI) was calculated for each site following the methods established in Janicki Environmental (2005) and Malloy et al. (2007). The TBBI threshold scores for “Degraded” (< 73), “Intermediate” (between 73 to 87) and “Healthy” (> 87) benthic habitats were established by Janicki Environmental (2005) and Malloy et al. (2007).

Spatial and Graphical Analysis

Graphs were generated using SigmaPlot® 10.0 software (Systat Software, Inc. 2006b). ArcGIS 9.2 was used to generate maps (ESRI 2006).

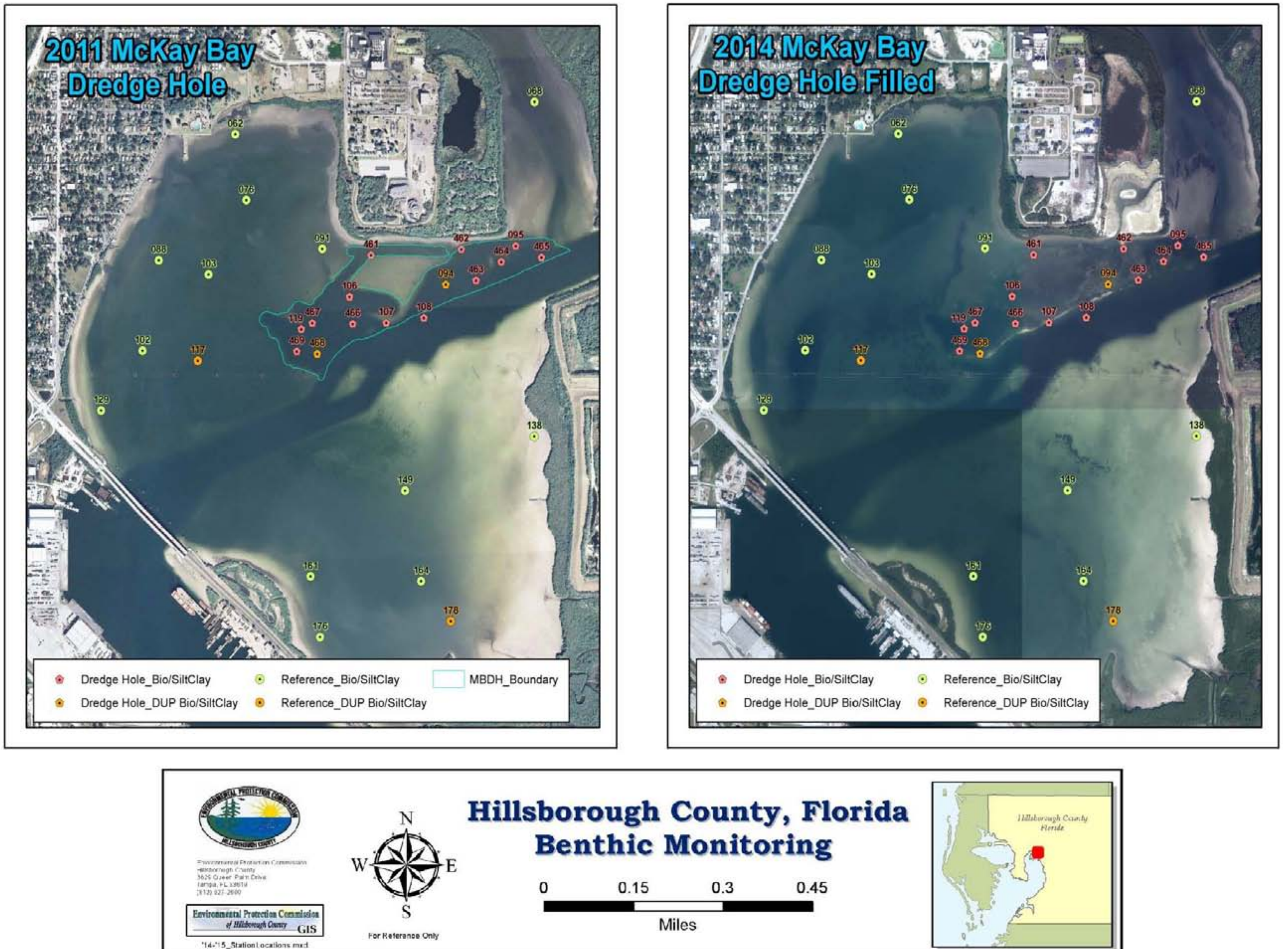


Figure 1. McKay Bay Dredge Hole Pre (2011) and Post (2014) restoration sampling sites.

Results

Physical Parameters

The median, minimum and maximum measured values of physical parameters for each treatment (control, dredge hole) and time period (pre-restoration, post-restoration) are shown in Table 2.

Table 2. Median, minimum and maximum physical parameter measurements for McKay Bay by treatment and sampling period.

	Pre-Restoration Control (n = 15)		Post-Restoration Control (n = 15)		Pre-Restoration Dredge Hole (n = 15)		Post-Restoration Dredge Hole (n = 15)	
Depth (meters)	1.1		1.2		2.6		1.7	
	0.5	1.7	0.7	1.8	1.0	4.2	0.6	3.1
Temperature (°C)	31.6		27.8		31.5		28.0	
	31.1	32.2	26.9	29.2	31.1	31.8	27.6	29.2
Salinity (psu)	22.1		24.4		25.2		25.1	
	18.7	23.5	23.6	25.2	21.0	25.7	24.3	25.8
Dissolved Oxygen (mg/L)	3.6		4.6		1.9		5.2	
	1.5	7.3	2.2	11.1	0.3	3.4	1.8	7.4
Dissolved Oxygen Sat. (%)	56.6		68.3		30.6		77.3	
	22.7	111.2	33.0	165.2	4.1	52.5	25.8	111.2
pH	8.1		7.9		8.0		8.2	
	7.9	8.4	7.7	8.3	7.8	8.2	8.1	8.3
% Silt+Clay	9.9		10.9		26.0		38.9	
	3.2	17.7	5.1	28.5	2.9	72.7	3.1	93.9

Sample depths at the control sites ranged from 0.5 – 1.8 meters and dredge hole sites ranged from 0.6 – 4.2 meters (Table 2). Depths were significantly shallower at the control sites than at the dredge hole sites during the pre-restoration period but there was no significant difference between the control and dredge hole sites during the post-restoration period although the median dredge hole depth was still 0.5 meters deeper than the control sites (Table 2; Figure 2). There was no significant difference in the sample depth among the control sites between the two sampling periods while the pre-restoration dredge hole sites were significantly deeper than the post-restoration dredge sites (Figure 2). The median and maximum depths at the post-restoration dredge hole sites were approximately 1 meter shallower than the pre-restoration period (Table 2).

Bottom water temperatures were significantly higher during the pre-restoration period relative to the post-restoration period for both treatments (Table 2; Figure 3). Median temperatures during the pre-restoration period were around 3.5°C higher than during the post-restoration period (Table 2; Figure3). There were no significant differences in water temperature between the control and dredge hole sites within either sampling period (figure 3).

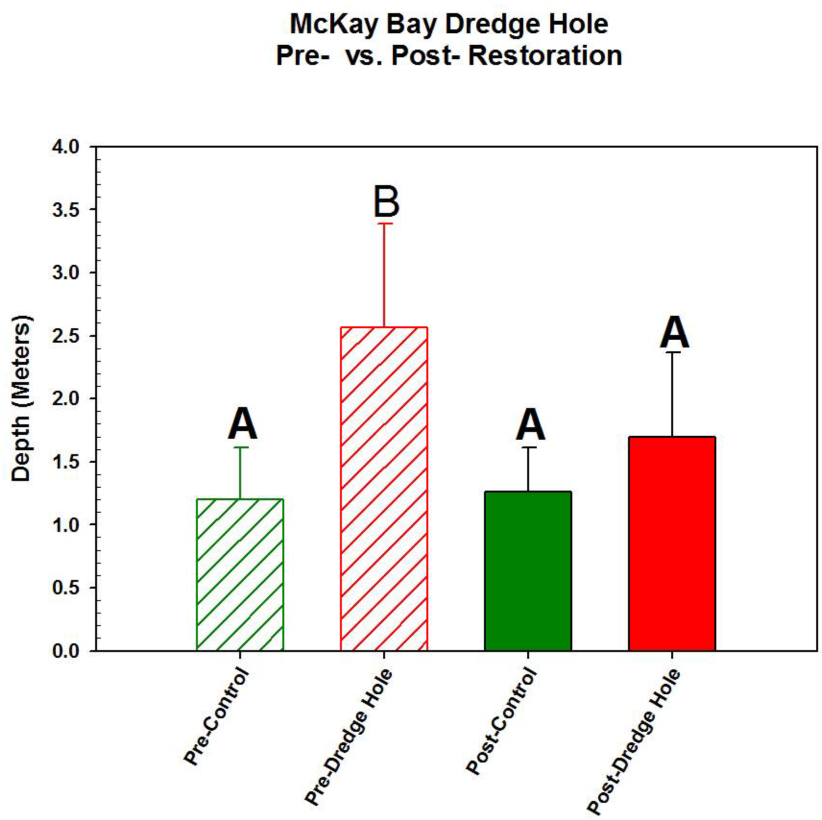


Figure 2. Mean depth by treatment and statistical pair-wise comparisons. Error bars indicate ± 1 s.d. about the mean.

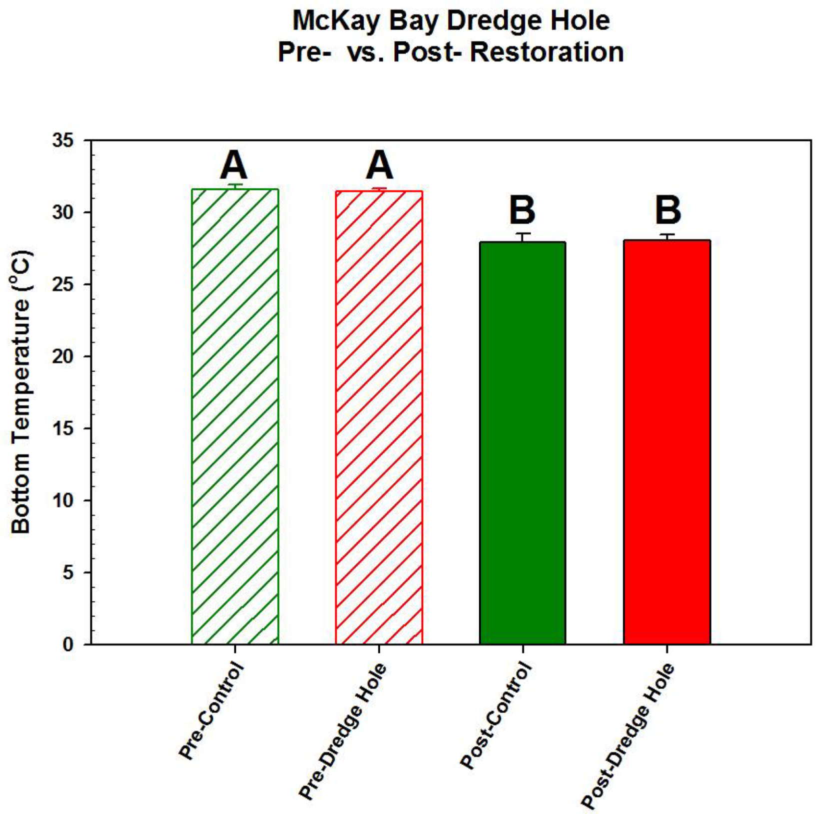


Figure 3. Mean bottom temperature by treatment and statistical pair-wise comparisons. Error bars indicate ± 1 s.d. about the mean.

Bottom salinities tended to be within the polyhaline range (18 – 30 psu) across all samples (Table 2). The bottom salinities were higher at the dredge hole sites during the pre-restoration period but there was no significant difference between the control and dredge hole sites during the post-restoration period while bottom salinities at the control sites were significantly higher during the post-restoration period (Figure 4). Median values were lower by about 2.3 psu during the 2011 pre-restoration sampling period relative to the 2014 post-restoration control samples (Table 2; Figure 4). The salinity also exhibited a wider range during the pre-restoration sampling period (4.7 – 4.8 psu) than during the post-restoration sampling period (1.5-1.6 psu) at both the control and dredge hole sites (Table 2).

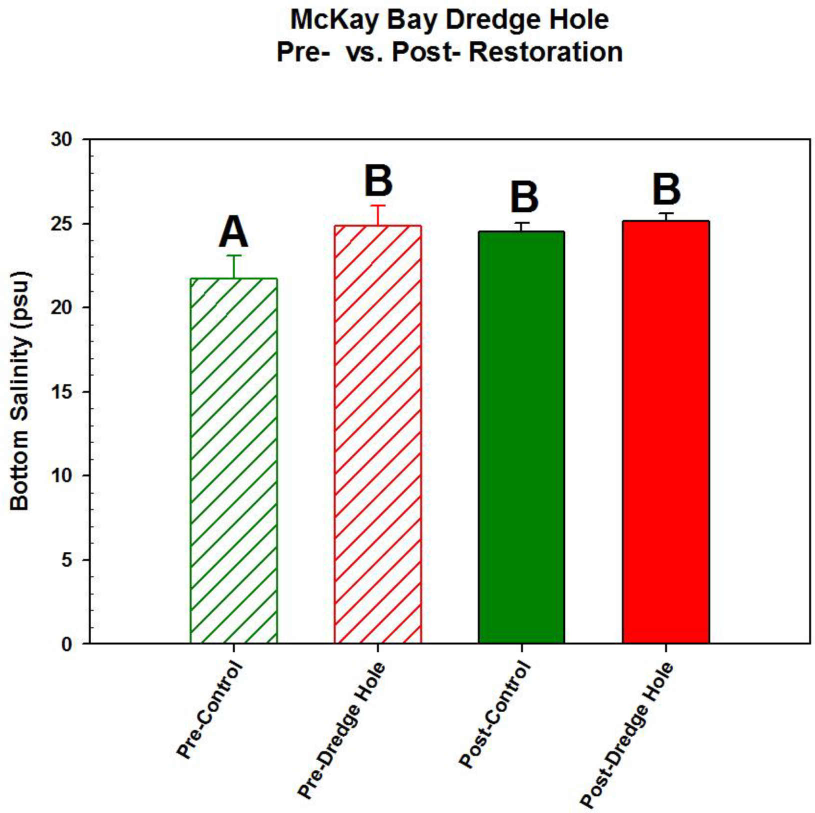


Figure 4. Mean bottom salinity by treatment and statistical pair-wise comparisons. Error bars indicate ± 1 s.d. about the mean. Dashed line = 18 psu threshold for polyhaline salinity level.

The bottom dissolved oxygen was significantly lower at the dredge hole sites compared to the control sites during the pre-restoration period, with the median value falling below the 2 mg/L and 42% saturation thresholds for hypoxia (Table 2; Figures 5 & 6). Bottom dissolved oxygen values at the control sites during the pre-restoration period were higher but still below the 4mg/L threshold for normoxic conditions, but above the criteria for percent saturation (Table 2; Figures 5 & 6). The post-restoration bottom dissolved oxygen concentrations were significantly higher relative to the pre-restoration period for both treatments (Figures 5 & 6). There was no significant difference between the control and dredge hole sites during the post-restoration sampling period (Figures 5 & 6).

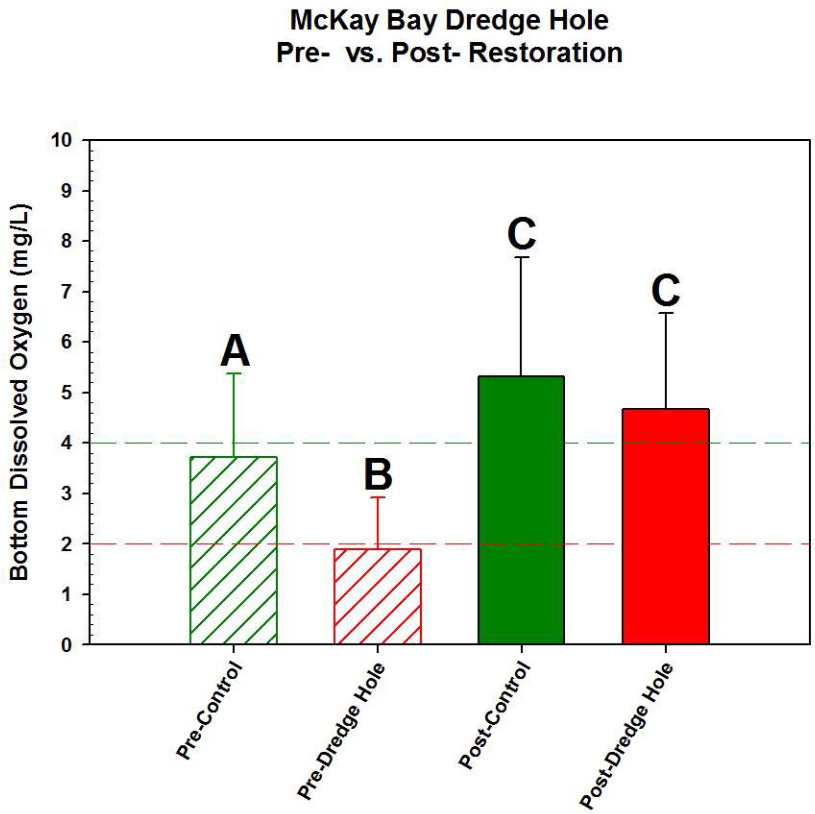


Figure 5. Mean bottom dissolved oxygen by treatment and statistical pair-wise comparisons. Error bars indicate ± 1 s.d. about the mean. Dashed lines indicate threshold levels for hypoxic conditions (lower line = 2 mg/L) and normoxic conditions (upper line = 4 mg/L).

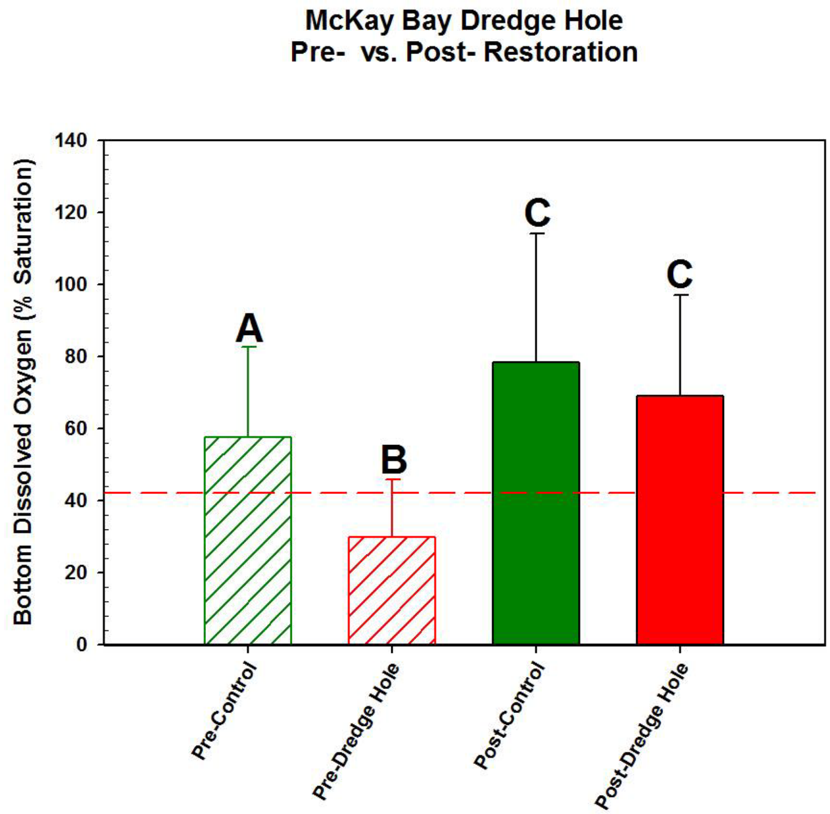


Figure 6. Mean bottom dissolved oxygen saturation by treatment and statistical pair-wise comparisons. Error bars indicate ± 1 s.d. about the mean. Dashed line indicates minimum allowable daily dissolved oxygen condition criterion (42 % saturation) for Class II and III marine waters (FDEP 2013).

The bottom pH was significantly lower at the dredge hole sites relative to the control sites during the pre-restoration period, while the opposite trend was apparent during the post-restoration period (Figure 7). The median bottom pH at the control sites was 0.2 units lower during the post-restoration period compared to the pre-restoration samples (Table 2). The median bottom pH at the dredge hole sites increased by 0.2 units during the post-restoration period (Table 2).

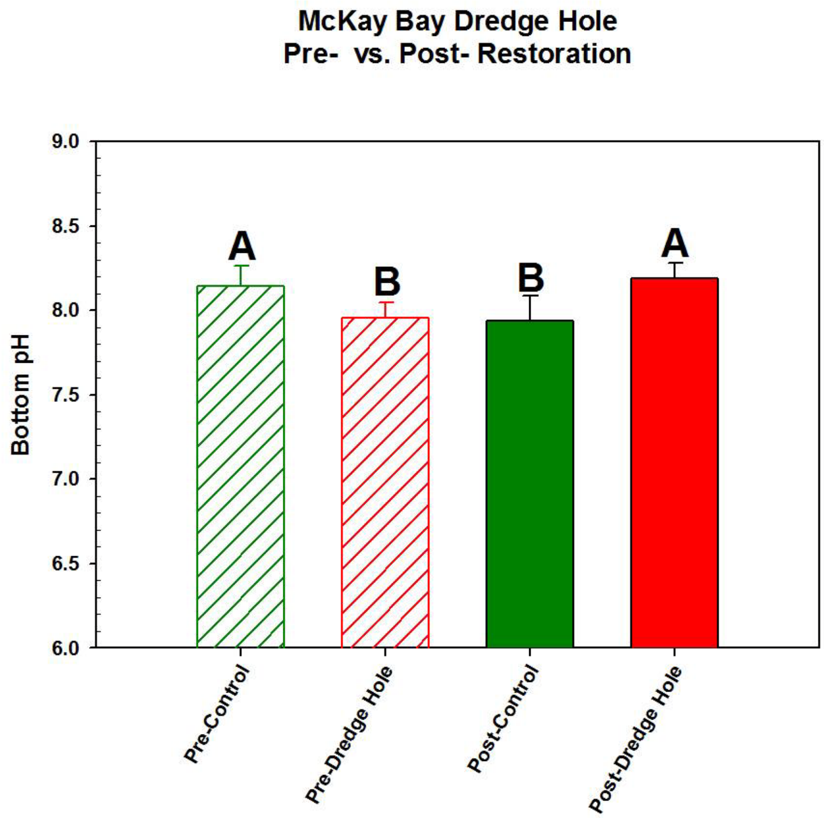


Figure 7. Mean bottom pH by treatment and statistical pair-wise comparisons. Error bars indicate ± 1 s.d. about the mean.

The percent silt+clay content was significantly higher at the dredge hole sites relative to the control sites during both sampling periods, while there was no significant difference between sampling periods for either the control or dredge hole treatments (Figure 8). The dredge hole sediments were generally classified as muds (% silt +clay > 25.95%) and the control sites were predominantly fine to very fine sandy sediments (Figure 8). The median silt+clay content at the dredge hole site was approximately 13% higher in the post-restoration samples relative to the pre-restoration period , while there was a slight increase also at the control sites between periods (Table 2).

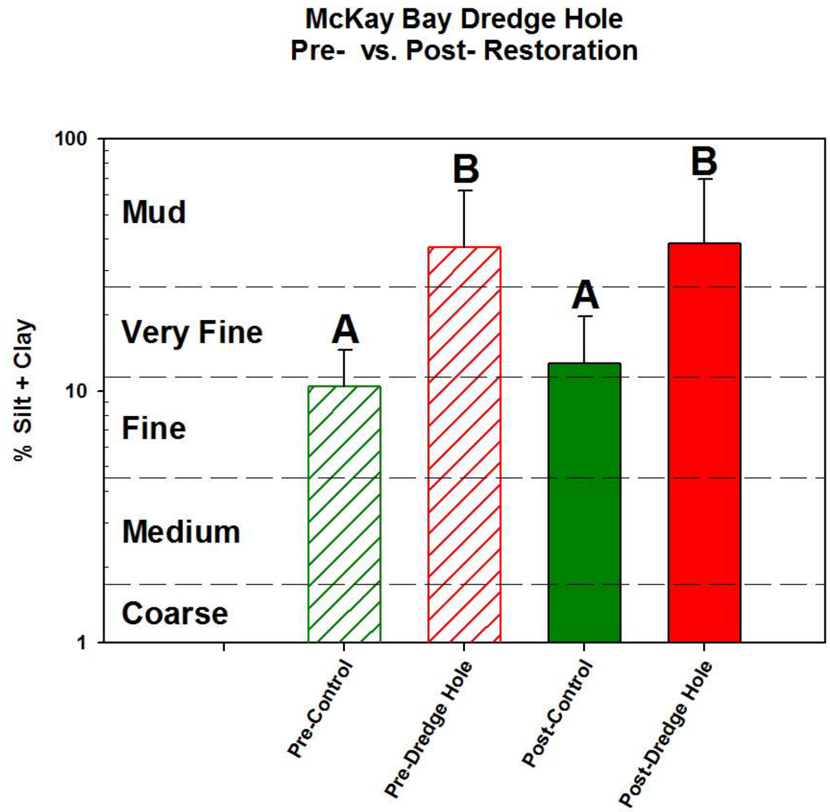


Figure 8. Mean sediment composition by treatment and statistical pair-wise comparisons. Error bars indicate ± 1 s.d. about the mean. Dashed lines demarcate calculated sediment grain-size categories as indicated.

Principal component analysis (PCA) is a multivariate ordination method used to group samples based on the resemblance of their physical parameters. Samples in PCA are plotted along multidimensional vectors representing the physical parameters. The plotted samples are projected onto orthogonal axes in 2-dimentional space referred to as principal components (PCs). The eigenvalue represents the amount of variation among the data accounted for by the PC axis. The eigenvalues are ranked in descending order so that the 1st principle component axes (PC1) explains the largest percentage of the variation. The eigenvectors represent the contribution or “weight” of each parameter vector to the PC axis.

The PCA of the physical parameters is shown in Figure 9. The first principal component axis (PC1) explains 44.5% of the variability in the data (Table 3). The sites group along PC1 by treatment (control vs. dredge hole), particularly for the pre-restoration samples, with the higher depth and percent silt/clay dredge hole sites towards the positive (right) direction and the higher dissolved oxygen and pH control sites on the negative (left) side of PC1 (Table 4; Figure 9). The second principal component axis

(PC2) accounted for 26.2% of the variation and was weighted primarily by the bottom temperature and salinity (Tables 3 & 4). The sites group along this axis according to sampling period, with the pre-restoration samples towards the positive (upper) direction and the post-restoration samples towards the negative (lower) end of the axis (Figure 9).

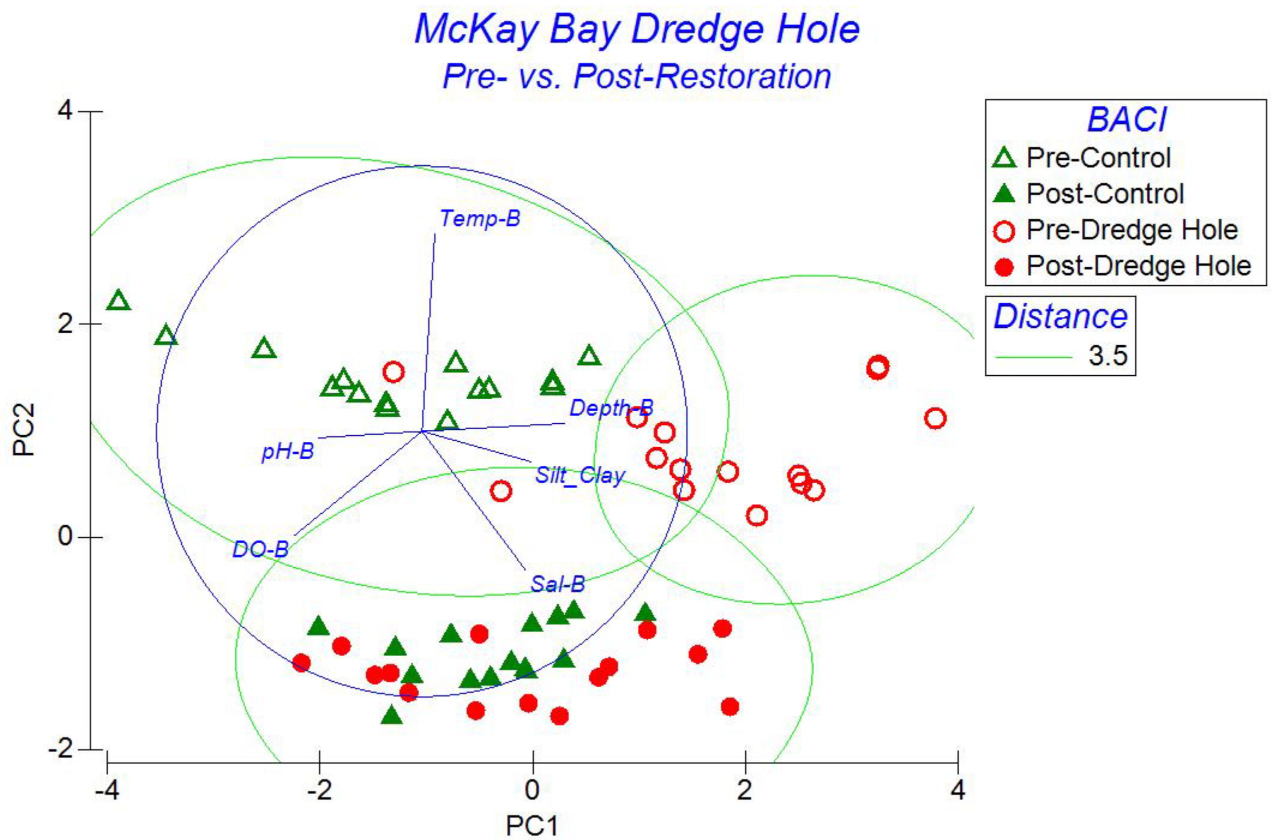


Figure 9. Principal Components Analysis of McKay Bay physical parameters.

Table 3. Principal Components Analysis Eigenvalues and percent variation explained.

PC Axis	Eigenvalues	%Variation	Cumulative %Variation
1	2.67	44.5	44.5
2	1.57	26.2	70.7
3	0.971	16.2	86.8
4	0.477	8.0	94.8
5	0.164	2.7	97.5

Table 4. Principal Components Analysis Eigenvectors

Variable	PC1	PC2	PC3	PC4	PC5
Depth	0.539	0.030	0.250	-0.444	0.381
Temperature	0.048	0.745	0.172	-0.312	0.173
Salinity	0.391	-0.524	-0.033	-0.468	-0.280
Dissolved Oxygen (mg/L)	-0.483	-0.394	0.172	-0.166	0.714
pH	-0.390	-0.024	0.733	-0.257	-0.466
%Silt+Clay	0.410	-0.115	0.584	0.627	0.145

Benthic Community

The median, minimum and maximum values for five benthic community metrics for each sampling period and treatment are presented in Table 5.

Table 5. Median, minimum and maximum benthic community indices for McKay Bay by treatment and time period.

	Pre-Restoration Control (n = 15)		Post-Restoration Control (n = 15)		Pre-Restoration Dredge Hole (n = 15)		Post-Restoration Dredge Hole (n = 15)	
Species Richness (*S*) # of taxa	**35**		**42**		**2**		**28**	
	24	**41**	**21**	**65**	**0**	**26**	**5**	**56**
Abundance (*N*) # organisms/m^2	**8750**		**14875**		**100**		**4325**	
	4000	**32650**	**1600**	**32075**	**0**	**5300**	**275**	**38125**
Shannon Diversity Index (*H'*)	**2.3**		**2.6**		**0.6**		**2.3**	
	1.8	**2.8**	**2.2**	**3.0**	**0.0**	**2.7**	**1.1**	**3.0**
Pielou's Evenness Index (*J'*)	**0.7**		**0.7**		**0.8**		**0.7**	
	0.5	**0.8**	**0.6**	**0.9**	**0.6**	**0.9**	**0.4**	**0.9**
Tampa Bay Benthic Index (TBBI)	**86.9**		**91.7**		**64.5**		**80.4**	
	70.7	**90.4**	**80.5**	**95.0**	**0.0**	**83.9**	**71.7**	**94.2**

Species Richness (*S*) refers to the number of unique species or taxa present at a site. Past samples collected by EPCHC from 1999-2010 recorded a total 384 taxa in McKay Bay with a median of 28 taxa per site and ranging from 0 – 67 (Karlen et al. 2012). A total of 108 taxa were identified from the 2011 pre-restoration control sites with a median of 35 taxa per site (Table 5). The pre-restoration dredge hole sites had significantly lower species richness with only 64 taxa total and median of 2 taxa per site (Table 5; Figure 10). The post-restoration control sites had a total of 161 taxa with a median of 42 taxa per site and the post-restoration dredge hole sites had a total of 133 taxa and a median of 28 taxa per site (Table 5). Species richness was significantly higher at the control sites than at the dredge hole site during both the pre- and post-restoration periods and was significantly higher in the post-restoration period for both treatments (Figure 10). The species richness in the post-restoration dredge hole samples was comparable to the pre-restoration control samples (Figure 10).

Abundance (*N*) is the number of individual animals counted at a site. This index is usually standardized by sampling area and expressed as the number of organisms per square meter (m^2). Past EPCHC samples from McKay Bay (1999-2010) had a median of 6,200 organisms/m^2 and ranged from 0 – 63,225 organisms /m^2 (Karlen et al. 2012). The abundance of benthic organisms was significantly lower at the dredge hole sites compared to the control sites during the pre-restoration period but there was no significant difference between treatments during the post-restoration period (Figure 11). The control sites had no significant difference in the abundance between the two sampling periods while it was significantly higher at the dredge hole sites during the post-restoration period(Figure 11). Two pre-restoration dredge hole sites had abundances of 0 organisms/m^2 while the minimum abundance in the post-restoration dredge hole samples was 275 organisms/m^2 (Table 5).

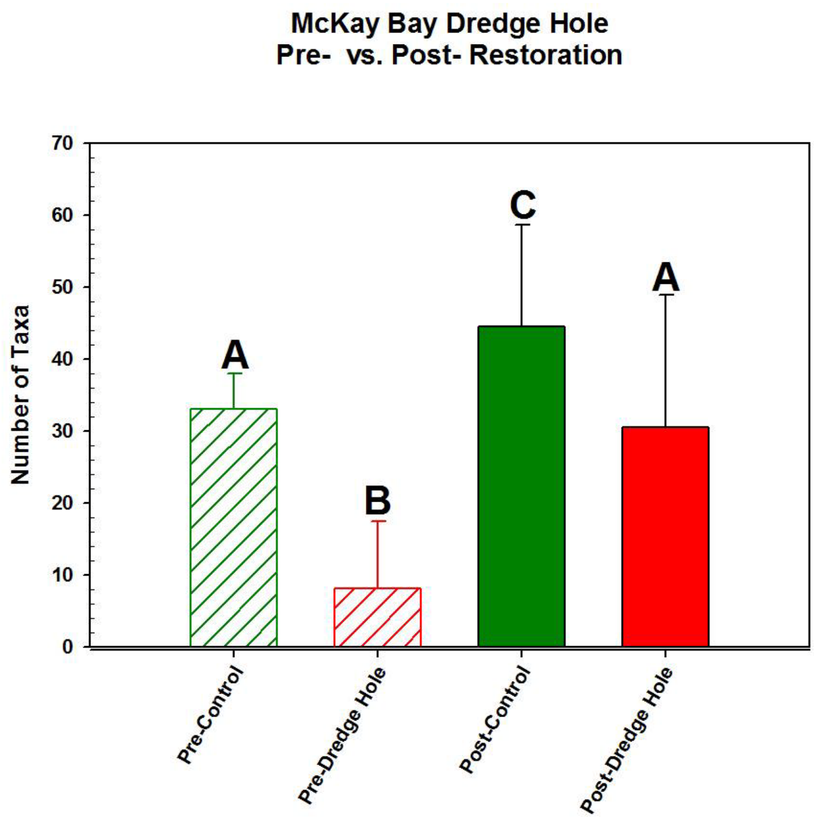


Figure 10. Mean benthic species richness by treatment and statistical pair-wise comparisons. Error bars indicate ± 1 s.d. about the mean.

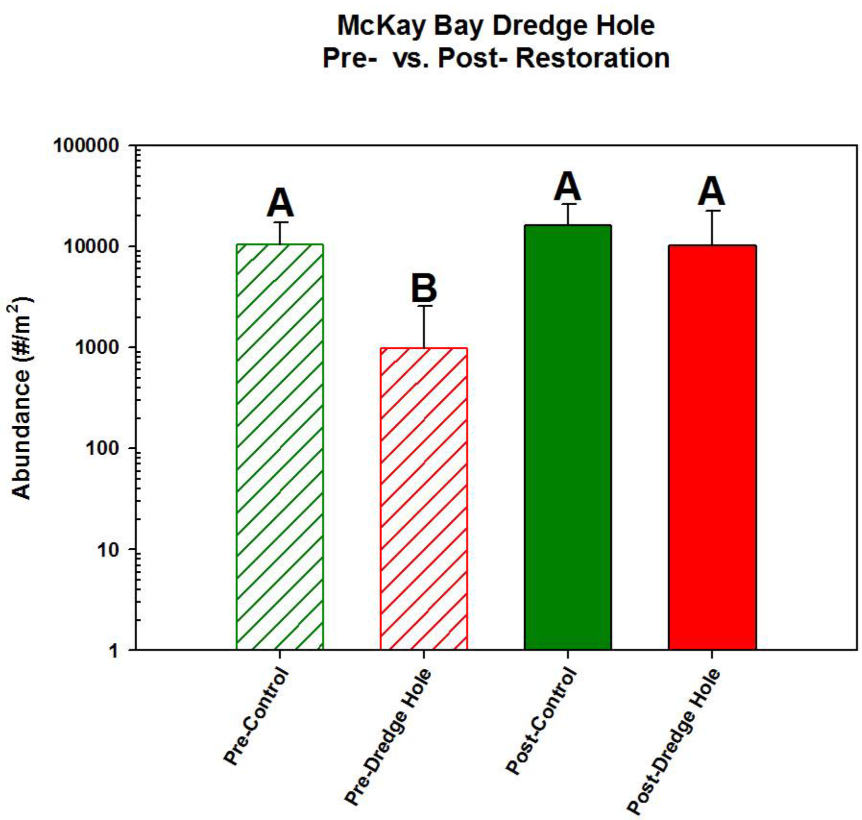


Figure 11. Mean benthic abundance by treatment and statistical pair-wise comparisons. Error bars indicate ± 1 s.d. about the mean.

Diversity indices are measures which account for the species richness and the proportion of the abundance represented by each species (referred to as evenness). The Shannon diversity index (*H'*) is the most commonly used index in ecological studies. Past McKay Bay samples had a median *H'* of 2.33 and ranged from 0 – 3.49 (Karlen et al. 2012). Shannon diversity index *(H')* showed a similar pattern in this study as the species richness and abundance with higher values at the control sites and lower values at the dredge hole sites (Table 5; Figure 12). The pre-restoration period mean diversity was significantly lower at the dredge hole sites, but there was no statistically significant difference between the dredge hole and control sites during the post-restoration period (Figure 12). There was a significant increase in diversity at the dredge hole sites between the pre-restoration and post restoration periods while diversity at the control sites remained consistent between periods (Table 5; Figure 12).

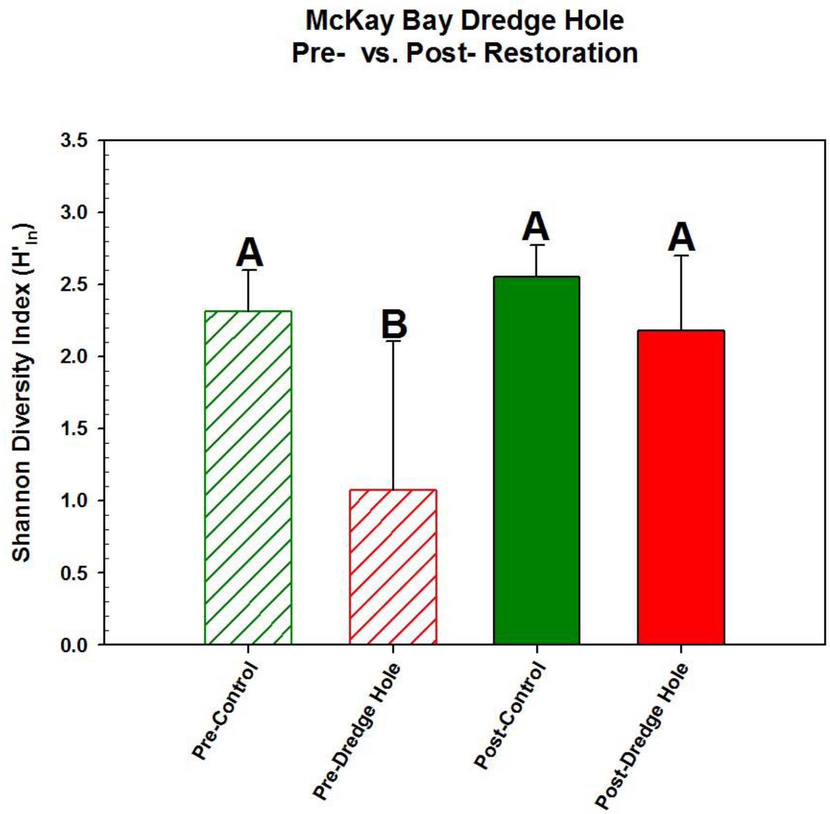


Figure 12. Mean benthic Shannon diversity by treatment and statistical pair-wise comparisons. Error bars indicate ± 1 s.d. about the mean.

Evenness refers to the distribution of the abundance among the species at a site. Pielou's evenness index (*J'*) is the most common measure used to express this metric. Lower evenness values indicate the dominance of a single or a few species in a sample. The maximum value for *J'* is 1 when all species at a site have an equal abundance. A higher *J'* generally indicates a more diverse site, however sites with a low species richness and abundance can often result in high J' values. Previous samples collected in McKay Bay (1999-2010) had a median *J'* of 0.73 (Karlen et al. 2012). The evenness during the pre-restoration period was significantly higher at the dredge hole sites compared to the control sites and the post-restoration dredge hole samples (Figure 13). This was due mainly to the fact that there were few taxa and low abundances in the pre-restoration dredge hole samples. There were no significant differences between the two sampling periods for the control sites (Figure 13).

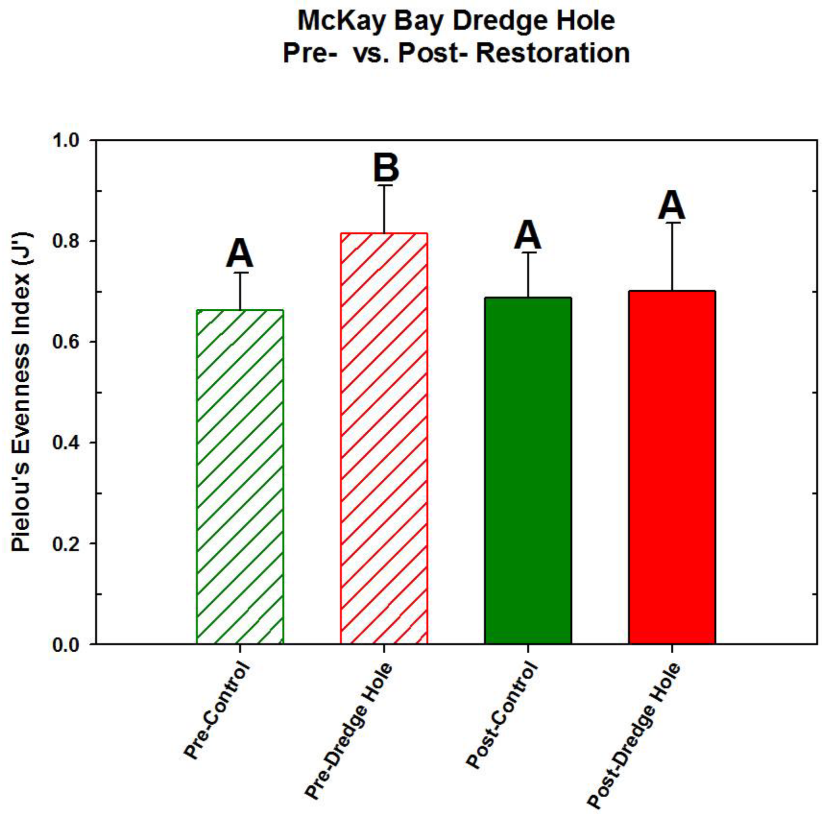


Figure 13. Mean benthic evenness by treatment and statistical pair-wise comparisons. Error bars indicate ± 1 s.d. about the mean.

The Tampa Bay Benthic Index values were significantly lower for the dredge hole sites compared to the control sites during the pre-restoration period, but there was no significant difference between the control or dredge hole treatments during the post-restoration period (Figure 14). The post-restoration dredge hole sites had a significantly higher TBBI value than the pre-restoration dredge hole sites (Table 5; Figure 14). The control sites generally rated as "Intermediate" to "Healthy" while the dredge hole sites were rated as "Degraded" to "Intermediate". The pre-restoration control sites had 47% of the sites rated as "Healthy", 47% rated as "Intermediate" and 6% (one site) rated as "Degraded". The pre-restoration dredge hole had 40% of sites rated as "Intermediate" and 60% as "Degraded" (two sites being completely depauperate) and no sites rated as "Healthy". The post-restoration control sites had 80% rated as "Healthy" and 20% rated as "Intermediate". The post-restoration dredge hole had 33% of the sites rated as "Healthy", 60% rated as "Intermediate" and only one site rated as "Degraded" with no depauperate sites .

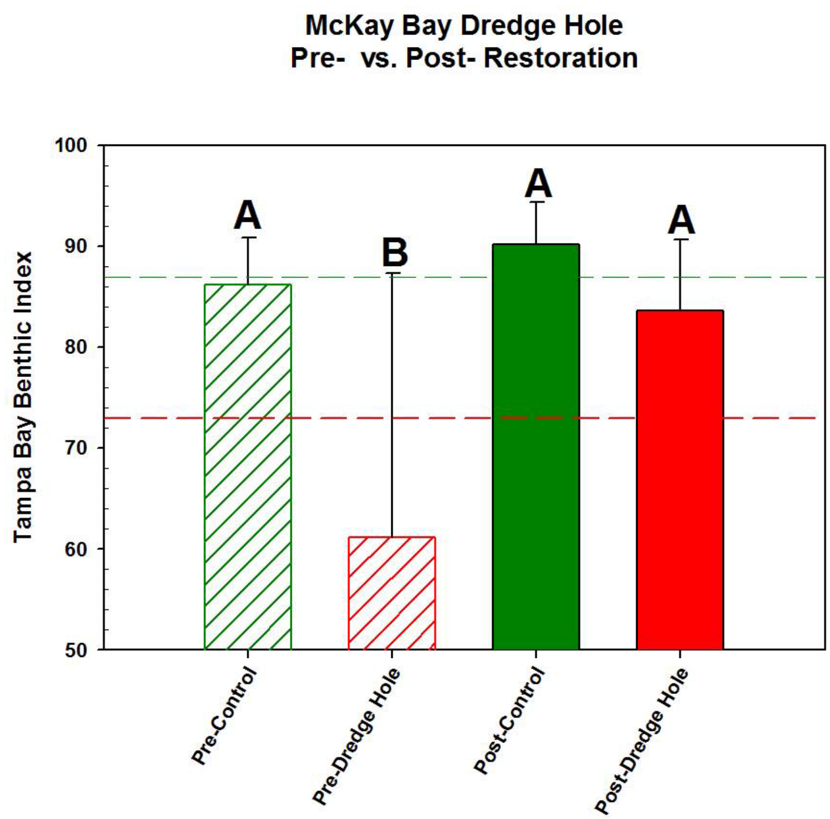
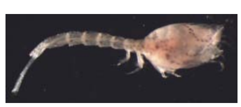
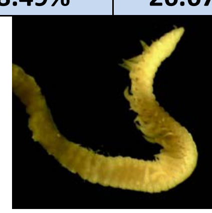


Figure 14. Mean Tampa Bay Benthic Index scores by treatment and statistical pair-wise comparisons. Error bars indicate ± 1 s.d. about the mean.

The top five dominate taxa for each sampling period and treatment based on their relative abundance and frequency of occurrence among the sites are presented in Table 6. The top five ranked taxa cumulatively accounted for >50% of the total abundance within their treatment x period grouping. The amphipod *Ampelisca abdita* was among the top two dominant taxa at the control and dredge hole sites during both the pre- and post-restoration periods and was the most abundant species at the post-restoration dredge hole sites. The dominant species during the 2011 pre-restoration sampling period was the polychaete *Monticellina* cf. *dorsobranchialis* in both the control and dredge hole sites, followed by *Ampelisca abdita*. The polychaete *Aricidea taylori* was the most abundant species at the control sites during the post-restoration period. The amphipod *Ampelisca abdita* dominated the dredge hole sites during the post-restoration period. Three of the dominant taxa for the pre-restoration control treatment were found at all 15 sites: *Monticellina* cf. *dorsobranchialis, Ampelisca abdita* and the polychaete *Paraprionospio pinnata* while *Ampelisca abdita* was the only species found at 100% of the control sites during the post-restoration period.

Table 6. Top five dominant benthic taxa for each treatment and time period. Dominance calculated as the geometric mean of the relative abundance (left value) and frequency of occurrence (right value). Rankings weighted by frequency of occurrence.

Pre-Restoration Control (n = 15)		Post-Restoration Control (n = 15)		Pre-Restoration Dredge Hole (n = 15)		Post-Restoration Dredge Hole (n = 15)	
 ***Monticellina cf. dorsobranchialis***		 ***Aricidea (Acmira) taylori***		 ***Monticellina cf. dorsobranchialis***		 ***Ampelisca abdita***	
23.18%	**100.00%**	**18.37%**	**93.33%**	**25.30%**	**40.00%**	**34.61%**	**60.00%**
 ***Ampelisca abdita***		 ***Ampelisca abdita***		 ***Ampelisca abdita***		 **Tubificinae**	
17.25%	**100.00%**	**13.82%**	**100.00%**	**13.07%**	**40.00%**	**8.72%**	**53.33%**
 ***Aricidea (Acmira) taylori***		 ***Monticellina cf. dorsobranchialis***		 ***Sabaco elongatus***		 ***Tubificoides brownae***	
15.69%	**100.00%**	**8.33%**	**93.33%**	**6.28%**	**60.00%**	**5.68%**	**60.00%**
 ***Paraprionospio pinnata***		 ***Xenanthura brevitelson***		 ***Paraprionospio pinnata***		 ***Xenanthura brevitelson***	
5.62%	**100.00%**	**7.65%**	**86.67%**	**8.49%**	**26.67%**	**4.19%**	**60.00%**
 ***Xenanthura brevitelson***		 ***Cyclaspis varians***		 ***Aricidea (Acmira) taylori***		 ***Grandidierella bonnieroides***	
4.22%	**93.33%**	**3.70%**	**86.67%**	**5.09%**	**33.33%**	**3.33%**	**73.33%**

Four taxa were among the top five dominants in both the pre- and post-restoration control sites: *Monticellina cf. dorsobranchialis*, *Ampelisca abdita*, *Aricidea taylor*i and the isopod *Xenanthura brevitelson.* No taxa were present at 100% of the dredge hole sites in either the pre- or post- restoration periods and *Ampelisca abdita* was the only species occurring among the top five dominant taxa at the dredge hole sites in both periods.

Annelid worms (polychaetes and oligochaetes) were the largest component of the benthic community during the pre-restoration period at both the control and dredge hole sites comprising approximately 40% of the species richness and 58.5% of the abundance at the control sites and 45% of the species richness and 59% of the abundance at the dredge hole sites. Annelids accounted for 37% of the species richness and 44% of the abundance at the post-restoration control sites and 36% of the species richness and 29% of the abundance at the post-restoration dredge hole sites.

Crustaceans comprised over 19% of the species richness and 28% of the abundance at the pre-restoration control sites and 17% of the species richness and 25% of the abundance at the pre-restoration dredge hole sites. Crustaceans were a larger component of the benthic community during the post restoration period accounting for 25.5% of the species richness and 42% of the abundance at the control sites and 25% of the species richness and 54% of the abundance at the dredge hole sites.

The pre-restoration dredge hole was the least similar to the other period x treatment groups with a Bray-Curtis (BC) similarity of 39.9 with the pre-restoration control and 27.7 and 31.9 with the post – restoration control and dredge hole respectively (Figure 15). The pre-restoration control had higher similarities to the post-restoration control (BC = 59.6) and post-restoration dredge hole (BC = 57.6) than to the pre-restoration dredge hole (Figure 15). The post-restoration control and dredge hole grouped together with a Bray-Curtis similarity of 69.8 (Figure 15). The similarity profile test (SIMPROF) indicated that the post-restoration community structure at the control and dredge hole were not significantly different from each other which is indicated by the red lines in Figure 15.

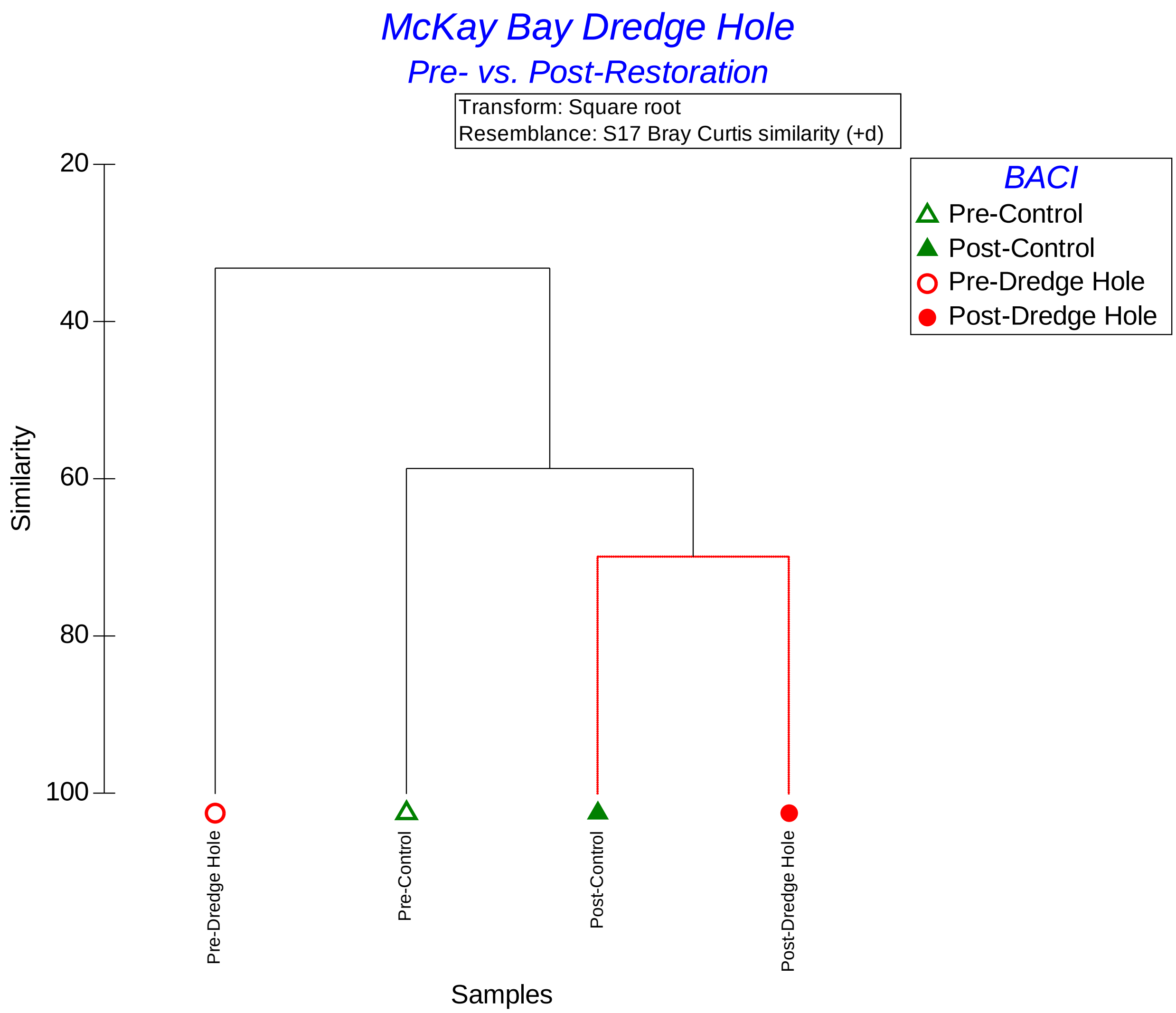


Figure 15. Cluster analysis of benthic community structure averaged by period and treatment.

The cluster analysis based on the species composition for all samples aggregated the sites into five cluster groups designated as “A”, “B”, “C”, “D” and “E” (Figure 16).

Group “A” consisted of 12 of the 15 pre-restoration dredge hole sites. These represented the deepest sites (mean = 2.87 m) characterized by hypoxic conditions (mean dissolved oxygen = 1.72 mg/L; 27.18% saturation) and high silt+clay content (mean = 43.68%). The cluster “A” sites had an impoverished benthic community with low species richness (mean = 4.25 taxa/site and included two depauperate sites), abundance (mean = 316.67 organisms /m2), Shannon diversity (mean = 0.73) and had “Degraded” or “Empty” TBBI scores (mean = 56.37). SIMPER analysis showed the average Bray-Curtis similarity among the Cluster “A” sites was 15.8 and taxa contributing to the similarity among sites included the polychaete *Sabaco elongate*, Hemichordates (Enteropneusta) and pea crabs *Pinnixa* spp.

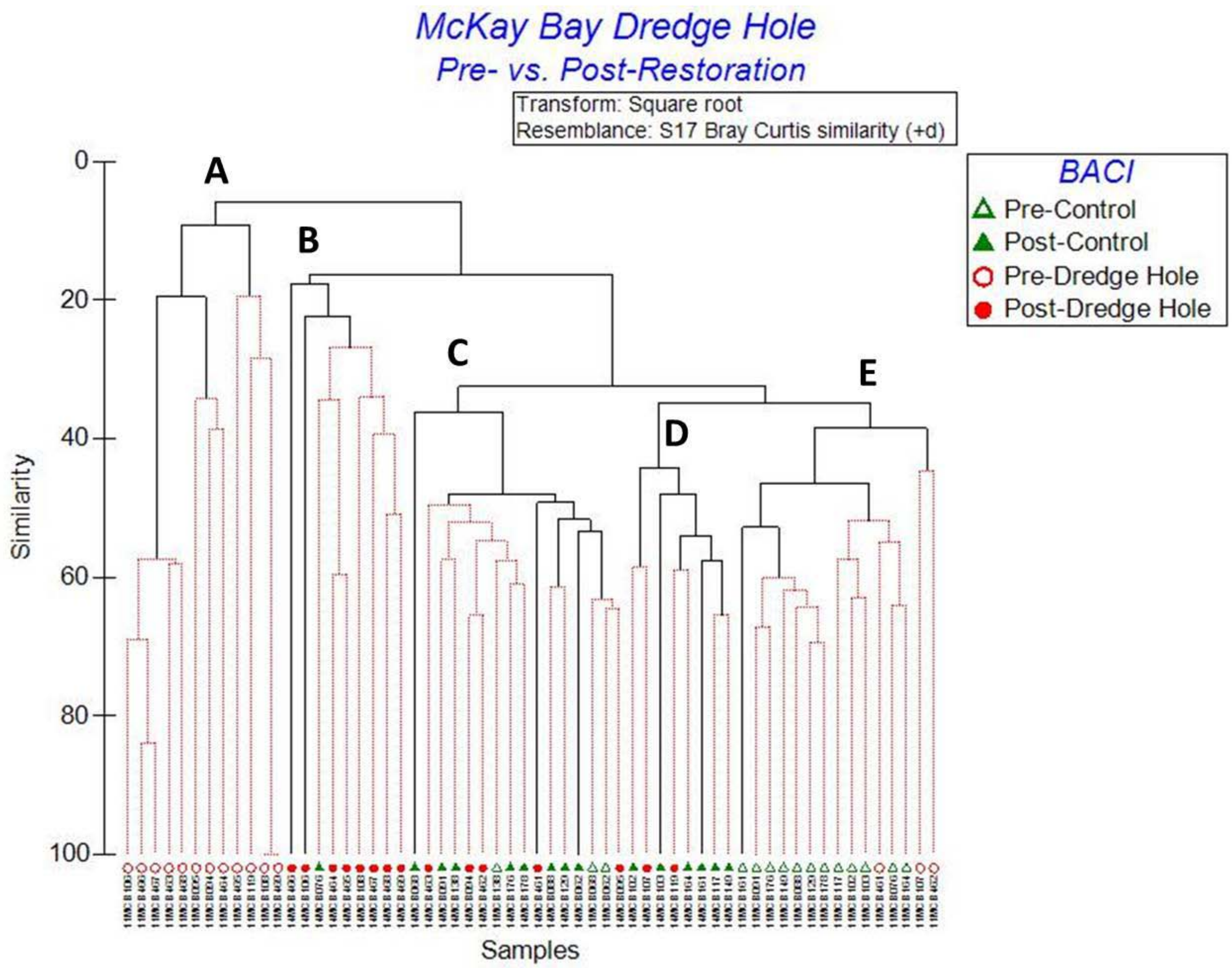


Figure 16. Cluster analysis of benthic community structure on all sites.

Group "B" consisted of eight of the 15 post-restoration dredge hole sites and one post –restoration control site. These sites were relatively deep with a mean depth of 1.96m and were characterized by suboptimal dissolved oxygen (mean = 3.81 mg/L; 56.26% saturation) and high silt+clay content (58.66%). The benthic community metrics were higher than at the Group "A" sites, but lower than at the other site with a mean species richness of 15.89 taxa/site; mean abundance of 1,611 organisms /m^2, mean Shannon diversity of 2.11 and an "Intermediate" TBBI of 78.67. SIMPER analysis indicated the average Bray-Curtis similarity among the Group "B" sites was 26.65 with Hemichordates (Enteropneusta) and the polychaetes *Sigambra tentaculata* and *Paramphinome* sp. B contributing to the similarity among the sites.

Group "C" consisted of a mixture of Post-restoration control and dredge hole sites and a few pre-restoration control sites. These sites where generally shallower (mean = 0.96m) with high dissolved oxygen (mean = 5.95 mg/L; 88.6% saturation) and very fine grained sediments (mean silt+clay = 12.5%).

The benthic community at these sites was “Healthy” with a mean species richness of 41.69 taxa/site, a mean abundance of 19,076 organisms /m^2, a mean Shannon diversity of 2.3 and a mean TBBI score of 88.26, above the “Healthy” threshold. SIMPER analysis indicated that the average similarity among the Group “C” sites was 48.69 with several crustaceans (*Ampelisca abdita*, *Cyathura polita*, *Xenanthura brevitelson*, *Grandidierella bonnieroides*) and the polychaetes *Aricidea taylori* and *Streblospio* spp. contributing to the similarity among the sites.

Group “D” was composed of post-restoration control and dredge hole sites. These sites had a mean depth of 1.71m, relatively high dissolved oxygen (mean = 4.0 mg/L; 58.94% saturation) and fine grained sediments with a mean silt+clay content of 8.91%. The Group “D” sites overall had the healthiest benthic community with the highest mean species richness (51.63 taxa/site), high abundance (mean = 16,065 organisms /m^2), a mean Shannon diversity of 2.72 and a mean TBBI score of 91.46, indicative of a “Healthy” benthic habitat. The average Bray-Curtis similarity among the Group “D” sites was 49.73 with a diverse assemblage of primarily crustaceans (*Xenanthura brevitelson*, *Cyclaspis varians*, *Ampelisca abdita*, *Listriella barnardi*, *Deutella incerta*), polychaetes (*Aricidea taylori*, *Monticellina cf. dorsobranchialis*), Enteropneusta and the bivalve *Mysella planulata* contributing to the similarity.

Group “E” consisted primarily of the pre-restoration control sites and a few of the pre-restoration dredge hole sites. These sites were relatively shallow (mean depth = 1.33 m) and had slightly low dissolved oxygen levels (mean = 3.45 mg/L; 53.43% saturation) and fine grained sediments (mean silt+clay = 10.53%). The benthic community was relatively healthy with a mean species richness of 31.20 taxa/sample, a mean abundance of 7,785 organisms /m^2 and Shannon diversity of 2.37. The TBBI score was just below the “Healthy” threshold (mean = 86.01). The mean Bray-Curtis similarity among the Group “E” sites was 48.19 and taxa contributing to the similarity included the polychaetes *Monticellina cf. dorsobranchialis*, *Aricidea taylori* and *Paraprionospio pinnata* and the amphipod *Ampelisca abdita*.

The non-metric multidimensional scaling analysis (Figure 17) further illustrates the shift in the benthic community structure from the pre-restoration to the post-restoration periods. Most of the pre-restoration dredge hole sites separate out from the other sites due largely to low numbers of taxa and abundances (Figure 17). The control sites for both the pre- and post-restoration periods group together along with most of the post-restoration dredge hole sites at a Bray Curtis similarity of 20. Within this grouping there is some separation between the pre- and post-restoration control samples, while there is more overlap among the post-restoration control and dredge hole sites indicating a greater similarity in their benthic community composition relative to the pre-restoration period.

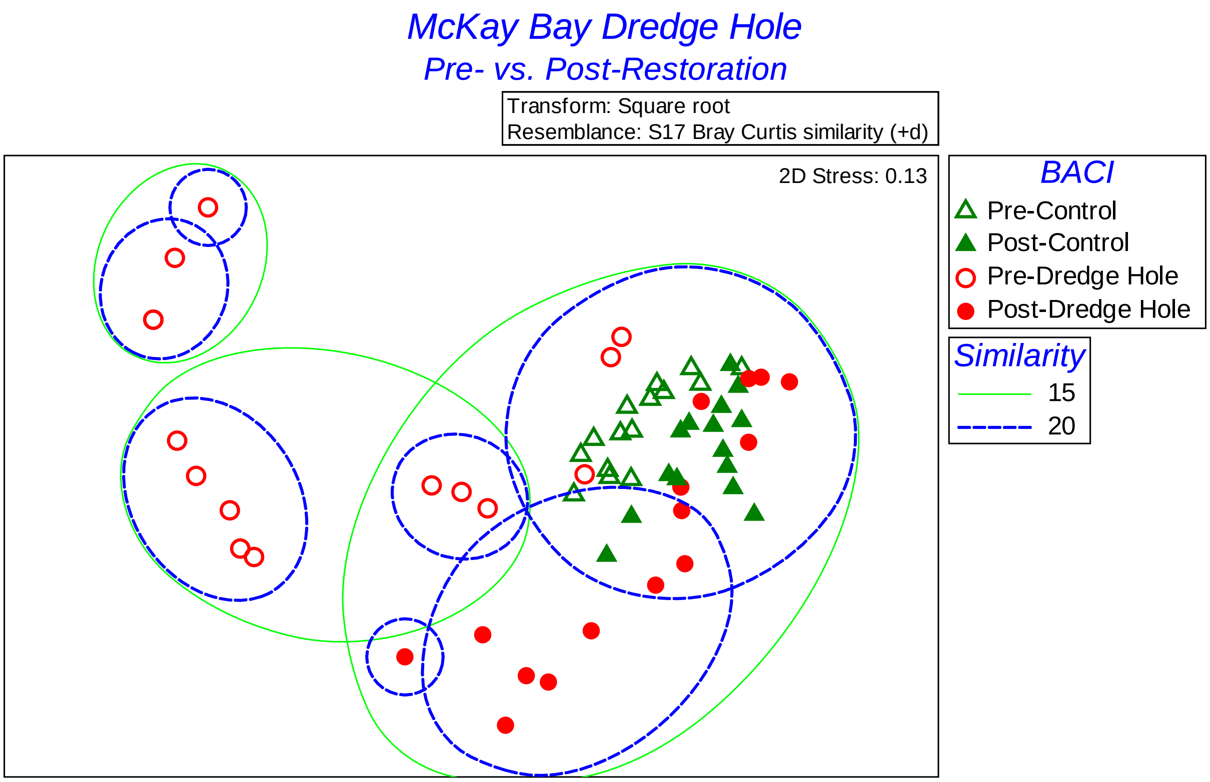


Figure 17. Non-metric multidimensional scaling (MDS) plot of benthic species similarity among McKay Bay sampling sites.

The BIO-ENV analysis found the strongest correlation between the benthic community structure and the physical parameters was with the combination of depth, bottom dissolved oxygen and the % silt+clay with a Spearman correlation coefficient of 0.704 (Table 7). Individually, depth and the % silt/clay had the highest correlations of 0.567 and 0.546 respectively with the community structure while bottom dissolved oxygen had a relatively weaker correlation of 0.338 (Table 7).

Table 7. BIO-ENV correlations between the benthic community structure and physical parameters.

Parameters	Correlation
Depth +D.O.+ Silt/Clay	**0.704**
Depth +Silt/Clay	0.688
Depth + Temp.+D.O. + Silt/Clay	0.683
Depth	**0.567**
Silt/Clay	**0.546**
D.O.	0.338
Temperature	0.102
pH	0.026
Salinity	-0.091

Discussion and Conclusions

The post-restoration sampling was conducted earlier in the summer than the pre-restoration sampling (late-May vs. early-August) due to scheduling and delays in the filling operations at the McKay Bay dredge hole. The majority of the restoration was complete in May 2014, a small portion of the dredge hole had not been filled and work was scheduled to resume later that summer. It was decided to proceed with the post-restoration sampling approximately six-weeks early during a break in the filling activities in order to avoid conflicting with the filling operations and not have to extend the monitoring contract. There were some concerns that moving up the sampling schedule could introduce seasonal effects which may complicate the interpretation of the post-restoration results. The BACI monitoring design used in this study is useful in discriminating between seasonal effects and changes attributable to the restoration efforts. A parameter such as bottom temperature (Figure 3) that exhibited a significant change between the pre and post-restoration periods at both the control and dredge hole treatments would be due to seasonal effects. Parameters which showed a significant change in the dredge hole treatment but not at in the control treatment (such as depth; Figure 2) can be attributed to the restoration. Some parameters may show a combined effect of both season and the restoration. The magnitude of change at the control sites is indicative of seasonal effects. Comparing the change at the dredge hole sites vs. the change at the control sites can be used to estimate the proportion of the observed change attributable to the restoration or to seasonal effects.

Seasonal effects were evident in the significantly lower water temperatures and higher bottom salinity observed during the post-restoration period. The magnitude of the drop in mean bottom temperatures between the pre- and post- restoration periods was the same at both the control and dredges holes sites (12% and 11% respectively) which indicates that the observed change was due to seasonal effects and not influenced by the restoration. The higher bottom salinity recorded at the control sites during the post-restoration period also indicate a seasonal effect. The dredge hole sites did not differ significantly in bottom salinity between periods. This most likely was a result in the change in overall depth after the restoration. Higher salinity water with a greater density would sink and accumulate at the deeper dredge hole sites, during the pre-restoration period. Bottom salinities were not significantly different than at the control sites during the post-restoration sampling, with the elimination of these deeper areas.

The physical parameters which showed the greatest response to the restoration were depth and bottom dissolved oxygen. The filling of the dredge hole decreased the mean depth within the dredge hole area by 34% and while the mean depth was still slightly deeper than the surrounding control areas, it was not significant. Concurrent with the decrease in depth was an increase in the bottom dissolved oxygen within the dredge hole. Part of this increase was most likely seasonal since the control sites also exhibited a 42.5% increase in bottom DO concentration and a 36.2% increase in % saturation between the pre- and post-restoration periods. The Tampa Bay Dredged Hole Habitat Assessment Project also noted an increase in bottom DO at the McKay Bay dredge hole during the spring sampling period (Tampa Bay Dredged Hole Habitat Assessment Advisory Team, 2005; Grabe et al. 2005). The increase in the bottom DO at the post-restoration dredge hole sites however was much greater than the observed increase at the control sites (146% increase in DO concentration and 131% increase in % Saturation) which implies that improvements were attributable to the dredge hole restoration.

The trend in the bottom pH had opposite trends between the sampling periods with the control sites decreasing and dredge hole sites increasing (Figure 7). The shift in pH at the control sites may be a seasonal effect reflecting lower productivity during the post-restoration sampling. This does not account for the significantly higher pH at the post-restoration dredge hole sites.

The % silt+clay had no change at the dredge hole sites. It was assumed based on sediment analysis (percent fines) of the fill material from the Port Tampa Bay dredging of Berth 222 that the sediment composition within the dredge hole area would be improved with a lower % silt+clay content (Swingle and Brice, 2011). Most of the fill material used in the restoration came from soils excavated from the adjacent McKay Bay Mitigation site which were tested for sediment contaminants (metals) but not for percent fines (Swingle and Brice, 2011). The fill from this site may have had a higher % silt+clay content than the material from the Berth 222 site and may have been more similar to the ambient dredge hole sediments. A second possibility is that the fill material was denser than the ambient sediments and subsequently displaced the finer sediments towards the surface after being deposited.

The benthic community measures were higher during the post-restoration period at both the control and dredge hole sites which implies that these increases were in part due to seasonal effects. The earlier dredge hole assessment study reported higher species richness and abundance during the spring sampling at most of the dredge holes studied (Grabe et al. 2005). The increases at the dredge hole sites however was much greater than at the control sites indicating that the restoration project did have a positive impact on the benthic community. The mean species richness increased by 34.5% at the control sites and by 279% at the dredge hole sites indicating that the restoration had a greater effect than seasonality. The post-restoration increase the species richness was still significantly lower than at the control sites. This suggests that the benthic community within the dredge hole restoration area has not fully recovered or this may be a factor of the higher silt+clay content at the restoration site.

The abundance of benthic infauna increased by 941% and Shannon Diversity increased by 103.6% at the dredge hole sites vs. 53.3% and 10.3% respectively at the control sites. These metrics were significantly different from the control sites during the post-restoration period which indicated that the benthic community was recovering within the restored area. The Pielou's Evenness Index (J') did not show a seasonal effect since there was no change at the control sites between sampling periods. There was a significant decrease in J' at the dredge hole which was due to the relatively few species and low abundances during the pre-restoration period and the dominance of *Ampelisca abdita* in the post-restoration dredge hole samples.

The post-restoration dredge hole sites had a significantly higher Tampa Bay Benthic Index score than the pre-restoration dredge hole sites, with a 36.6% increase in the mean TBBI score. The pre-restoration dredge hole had 60% of the sites rated as "Degraded" (with two sites being depauperate) and no sites were rated as "Healthy". The post-restoration dredge hole had 33% of the sites rated as "Healthy", 60% rated as "Intermediate" and only one site rated as "Degraded" with no depauperate sites. The post-restoration TBBI scores were not significantly different between the control and dredge hole sites or between the pre- and post-restoration control sites. This indicates the improvements seen at the dredge hole sites were due to the restoration and not influenced by seasonality.

The dominant taxa at the control sites were similar during both the pre- and post-restoration periods with four of the same species occurring among the top five dominant taxa. The dredge hole sites had a greater change in dominant taxa with only the amphipod *Ampelisca abdita* being among the top five dominant taxa during both periods. The dredge hole sites had an overall shift from a polychaete dominated community to a largely crustacean dominated community. *Ampelisca abdita* was also the dominant amphipod in dredge holes in Lake Worth on the east coast of Florida (Vose et al, 2005) and *Ampelisca* spp. (which included *A. abdita* +*A. vadorum*) were the most abundant taxa in a dredge hole study in Barnegat Bay, New Jersey (Reine et al. 2013a). Oligochaetes (*Tubificoides brownae* + unidentified Tubificinae) comprised a large proportion of the abundance which is probably a reflection of the higher silt+clay composition in the post-restoration dredge hole sediments. The polychaete *Paraprionospio pinnata* was noticeably absent among the dominant taxa during the post-restoration period. This species was abundant at both the control and dredge hole sites during the pre-restoration period and was present at all of the control sites. Palmer et al. (2008) also found *P. pinnata* in their study of a dredge hole off of Louisiana, where it was the dominant species at their dredge hole sites and ranked second overall in their study. Vose et al. (2005) also found *P. pinnata* at 8 out of 10 dredge holes they surveyed in Lake Worth, Florida. The drop in abundance observed in the post-restoration samples may have been a seasonal phenomenon. Mayfield (1988) in his study on the life history of *Paraprionospio pinnata* populations in Galveston Bay, Texas recorded a drop in abundance from May to June which was attributed to post-spawning mortality of adult worms. It is possible that our post-restoration sampling corresponded to a similar life history cycle in the local population of *P. pinnata*.

The average species composition was more similar between the control and dredge hole sites during the post-restoration period than during the pre-restoration period (mean Bray-Curtis Similarity = 69.8 vs. 39.9 respectively) which indicated the benthic community within the restoration area has improved after the dredge hole was filled.

The benthic community structure was largely influenced by depth and the sediment composition. This is consistent with an earlier analysis of the EPCHC McKay Bay benthic data which found that the spatial trends in the benthic community structure were driven by the sediment composition (% silt+clay), while temporal trends were primarily influenced by changes in salinity (Karlen et al. 2012). Depth and silt/clay content also had the strongest correlation with the benthic community structure in a dredge hole off of Louisiana (Palmer et al. 2008).

The filling of the McKay Bay dredge hole was successful in reducing the depth and improving the bottom dissolved oxygen concentrations, however, the composition of the sediments has not changed. The benthic community within the restoration area indicated recovery as reflected by the increases in the biological metrics and the increase in the similarity to the control sites. The restoration area, however, has not reached the same level of species richness as the surrounding control sites. It remains to be seen if the benthic community will continue to recruit more species for long term recovery. One recommendation would be to revisit the monitoring sites periodically in future years to assess the long-term recovery of a stable benthic community at the former dredge hole site.

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