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Characterization of Post-Hurricane Katrina Floodwater Pumping on Marsh Infauna

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PURPOSE: The Interagency Performance Evaluation Task Force (IPET) was created to study the performance of hurricane protection and damage reduction systems and consequences of structural failures, including potential impacts on biological resources, following Hurricane Katrina. This technical note describes the results of an IPET study funded to examine the impact of floodwater pumping on benthic invertebrate assemblages near Chalmette and Violet, Louisiana.

Key points…

What impact did Hurricane Katrina have on biological resources in southern Louisiana? This study looks at the effect of floodwater pumping on benthic invertebrates near Chalmette and Violet, Louisiana. Because benthic invertebrates provide forage for finfish and shellfish in the area, they were identified as an important indicator of Hurricane Katrina impact. Water quality was carefully measured and analyzed. There are strong indications that pumping of floodwaters from Hurricane Katrina did indeed affect benthic invertebrate assemblages in the study areas. This was particularly true at sites less than 50 m from the pump outfalls. Information on the Interagency Performance Evaluation Taskforce (IPET) can be found at: *https://ipet.wes.army.mil*

BACKGROUND: When Hurricane Katrina struck the coast of Louisiana, levees were breached or overtopped, resulting in massive flooding in the City of New Orleans and adjacent areas. Saint Bernard Parish, located east of the city, was flooded by water from the Mississippi River Gulf Outlet (MRGO) channel and Lake Borgne. Pumping of these floodwaters into marshes in the vicinity of Chalmette and Violet, Louisiana raised concerns that elevated salinities and potential contaminant loads in the floodwaters could have undesirable impacts on the receiving marshes and their biological resources. Benthic invertebrate assemblages provide forage for economically and ecologically important finfish and shellfish species and were identified as an important indicator of potential effects.

In December 2005 a pilot study was performed to discern large-scale patterns in the distribution of benthic invertebrates and determine adequate sample size for future studies (Ray 2006a). Comparison of sites in the immediate vicinity of active and inactive pumping stations detected differences in species composition between sites. There were also indications that assemblages near active pumps had recently been disturbed. Using this information, quantitative sampling of the sites was conducted 14-15 February 2006.

STUDY AREA: The Violet Marsh covers an area of approximately 81.6 hectares (31.5 sq miles) between the city of Chalmette and Lake Borgne in St. Bernard Parish, Louisiana (Figure 1). Bordered on the east by the back protection levee and on the west by the federal levee, the marsh is connected directly to both the Mississippi River and the MRGO. Most of the

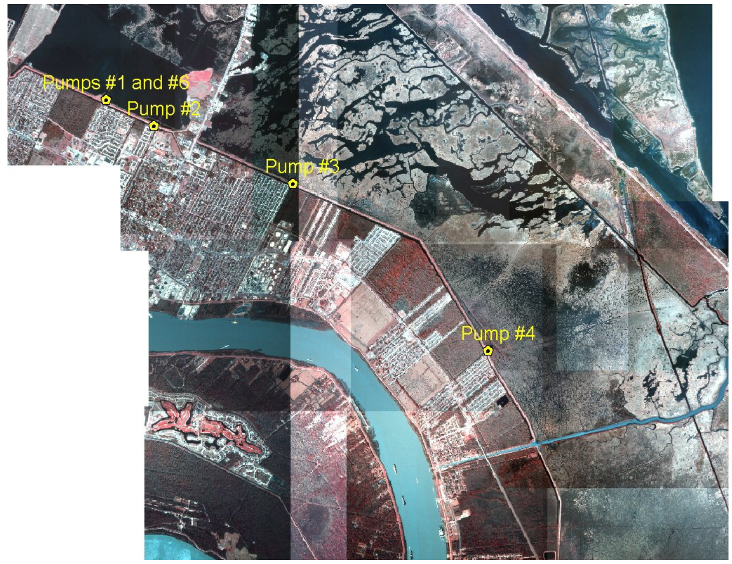

Figure 1. Aerial view of study area

pumps used to remove floodwaters are located along the back protection levee (Figure 1). Sites near four of these pumps were sampled based on their pumping records: Pumps 4 and 6 were active throughout the emergency while Pumps 2 and 3 were inoperative. Pump sites also differ in relation to the surrounding environment. While Pumps 2 and 6 empty into open water, Pumps 3 and 4 are surrounded by marsh and drain into tidal creeks. All four sites and the areas into which the pumps drain were inundated by relatively high salinity waters from Lake Borgne and the MRGO during the early hours of 29 August 2005. The areas from which the floodwaters were pumped (Lower 9th Ward to Violet) were flooded shortly thereafter on the same day.

METHODS: Water quality parameters were measured and samples were collected for infauna and sediment analysis at each of two stations within 50 m and 100 m, respectively, of the pump outfalls. Water quality measures, including salinity, temperature, and dissolved oxygen concentrations, were measured using a handheld YSI Model 85 meter. At each pump station, 10 infaunal samples were taken with a pole-mounted Eckman dredge (232 cm^2/sample). Infaunal samples were rinsed in the field using a sieve bucket with a 0.5-mm mesh screen, placed in labeled cloth bags, and fixed in 4-percent formaldehyde solution. After fixation, the samples were transported to laboratory facilities at the U.S. Army Engineer Research and Development Center (ERDC) in Vicksburg, MS, where the samples were rinsed with fresh water over a 0.5-mm sieve and material retained on the sieve was stored in 70-percent ethanol. Samples were subsequently stained with Rose Bengal and examined under illuminated 3X magnification to facilitate removal of invertebrates from the sediments. All specimens were identified to the lowest practical identification level and counted.

An additional sample was taken at each station for sediment analysis. Sediment samples were placed in plastic bags, immediately stored on ice and later analyzed for both sediment grain size and total organic content. Sediment grain size was analyzed using a combination of wet-sieving and flotation procedures (Folk 1968, Galehouse 1971). Sediment organic content was analyzed by loss upon ignition. Data were analyzed using Gradistat 4.0 (Blott 2000).

Multivariate statistical techniques were used to detect changes in species composition, a sensitive indicator of assemblage responses to disturbance (Clarke and Warwick 2001). Techniques included Nonmetric Dimensional Scaling (NMDS), Analysis of Similarity (ANOSIM), and similarity percentage analysis (SIMPER). NMDS is an ordination technique that compares species composition among sample pairs and is particularly suited for infaunal data (Clarke and Warwick 2001). It was performed using the Bray-Curtis similarity index and logarithmically transformed (log x+1) abundance values to adjust for the influence of very abundant taxa. ANOSIM is a nonparametric technique that compares similarity values between treatments and can be used as a test of the significance of patterns observed in NMDS. SIMPER estimates the contribution of individual taxa to similarity among treatments and is used to determine the extent to which individual species were responsible for the patterns detected by NMDS and ANOSIM.

Total numerical abundance (total numbers of animals) and total numbers of taxa per sample were analyzed by Analysis of Variance (ANOVA) using a nested design. Main effects included pumps (active vs. inactive), sites within pumps (referred to hereafter as sites), and stations within sites within pumps (referred to hereafter as stations). Values were tested for normality and homogeneity of variance prior to analysis and transformed where necessary (Quinn and Keough 2002). Abundance values required a logarithmic transformation ($\log_{10}X+1$) and taxa required a square-root transformation. Where differences were detected among main effects, a Students T test (active vs. inactive pumps) or Tukey's HSD (Honestly Significant Difference) test (sites and stations) was performed to detect differences among means.

RESULTS

Water Quality and Sediments. Conditions at the four sites were somewhat different from those encountered during the pilot study (Ray 2006a). Salinities were lower, ranging from 5 to 7 ppt at Stations 2A, 3A, and 6A and 1.8 ppt at Station 4A (Appendix A). During the previous sampling, salinity averaged 11 to 12 ppt at all stations, a salinity range similar to that found during the same time interval in Lake Borgne (Ray 2006b). Temperatures were similar to the previous December, ranging from 11.6 °C to 15.6 °C. Dissolved oxygen concentrations were all well above saturation level ranging from 9.5 mg/L to 13 mg/L. Sediments at all stations were categorized as coarse silts although visual inspection of the samples revealed that the majority of the sample volume was made up of vegetative matter. This fact is emphasized by the high sediment organic contents (9.68 to 22.49 percent). The highest sediment organic content was found at Pump 2.

Infaunal Analyses. The species assemblage encountered was nearly identical to that found during the pilot study and was typical of those described elsewhere for low salinity, muddy estuarine sediments and other Northern Gulf of Mexico marshes (e.g., Armstrong 1987, Gaston and Nasci 1988, Heard 1982, Horlick and Subrahmanyam 1983, LaSalle and Rozas 1991, and Livingston 1984). Dominant taxa included the polychaetes *Streblospio benedicti* and *Hobsonia florida*, the naidid oligochaetes *Paranais littoralis* and *Dero digitata*, immature tubificid oligochaetes (without capillary setae), cyclopoid and harpacticoid copepods, cladocera, larvae of the chironomid flies *Chironomus* sp. and *Cryptochironomus* sp. and phantom midge larvae, *Chaoborus* sp. (Appendix B). These 11 taxa accounted for more than 95 percent of all animals collected.

Streblospio benedicti was found in large numbers at all sites except Pump 6, where Nemertea and the capitellid polychaete *Mediomastus* sp. were dominant. The naidid *P. littoralis* was most abundant at Pumps 2 and 4, while *Hobsonia florida* was found almost exclusively at Pumps 2 and 3. Cyclopoid copepods were most abundant at Pump 4, as were *D. digitata*, cladocera, and *Chaoborus* sp. larvae. *Chironomus* sp. was most abundant at Pump 4, but was also found at Pumps 2 and 3. *Cryptochironomus* sp. was found primarily at Pumps 3 and 4.

Differences in species composition were detected by NMDS between active and inactive pump areas; however, the differences were not as distinctive as in the pilot study (Figure 2). Pump 6 stations were clearly different from all the remaining sites while Pump 4 stations were far more similar to the inactive pump stations than in December 2005. There is also an indication that those stations furthest from the pumps at Pumps 2, 3, and 4 were more alike than those close to the pumps (A stations). A stress value of 0.12 (significant at p = 0.1 percent) indicates that the data plot provided a reasonable fit to the original distribution of similarity values, i.e., the plot accurately represents the relationships among the samples (Clarke and Warwick 2001).

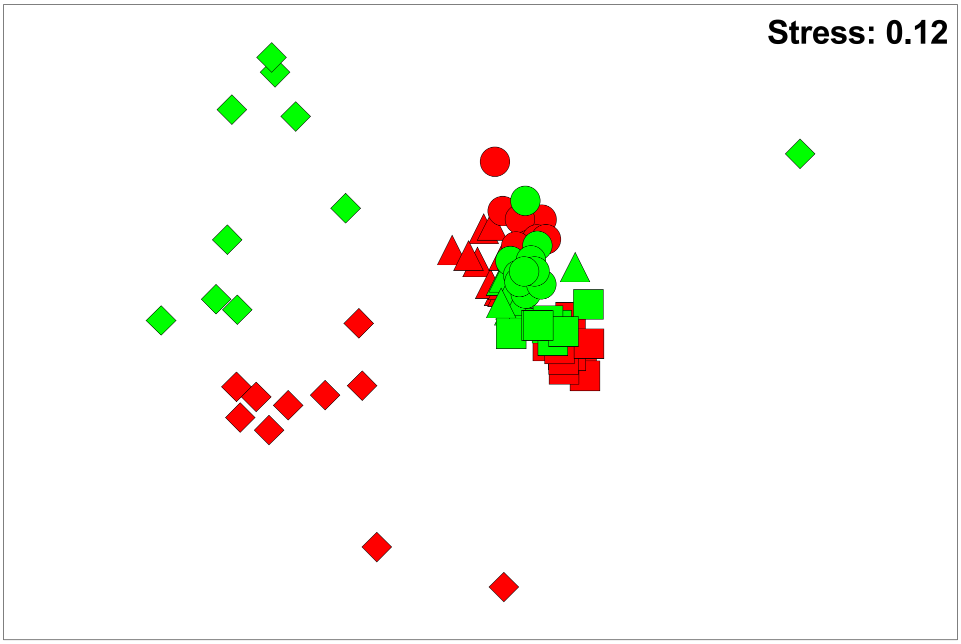

Figure 2. Nonmetric dimensional scaling results for Violet Marsh infauna. Triangles = Pump 2, Circles = Pump 3, Squares = Pump 4, Diamonds = Pump 6, Red = A (50 m) Stations, Green = B (100 m) Stations.

Results from ANOSIM confirmed there were differences between active and inactive pump assemblages (Table 1). However, significant differences ($p < 0.5$ percent) were also detected between all combinations of sites and stations and R values for these tests were generally higher than those between active and inactive pumps, suggesting the former were of a greater magnitude. Within the tests for differences among sites and stations, the lowest R values were associated with comparisons of inactive sites (Pump 2 versus 3) suggesting assemblages at these sites were most alike. Pairwise comparisons of individual stations had uniformly higher R values for those tests where one of the pair was the station closest to an active pump (Table A3).

SIMPER results support these findings. The lowest degree of similarity was found among replicate samples at active pump sites, especially at Pump 6 (Table 2). Pairwise comparisons of the sites detected the greatest dissimilarity among combinations including Site 6, a clear indication that species composition at this site was different from the remaining sites. This pattern is repeated in pairwise comparisons of the individual stations (Table A3). The greatest dissimilarity values were found in comparisons of active versus inactive pump stations, especially Stations 6A and 6B.

Table 1. ANOSIM results.

Global Tests	R	p (%)
Active vs. Inactive Pumps	0.339	0.1%
Sites	0.592	0.1%
Stations	0.646	0.1%
Pairwise Tests		
Stations 2, 3	0.572	0.1%
Stations 2, 4	0.811	0.1%
Stations 2, 6	0.578	0.1%
Stations 3, 4	0.799	0.2%
Stations 3, 6	0.614	0.1%
Stations 4, 6	0.625	0.1%

Table 2. SIMPER results for pumps and sites.

Global Tests	Similarity
Active	16.48
Inactive	40.90
Site 2	46.98
Site 3	48.84
Site 4	45.06
Site 6	18.15
Pairwise Comparisons	Dissimilarity
Active vs. Inactive	83.38
Site 2 & 3	65.77
Site 2 & 4	69.02
Site 3 & 4	71.51
Site 2 & 6	95.85
Site 3 & 6	97.12
Site 4 & 6	97.89

The principal difference in species composition among stations with inactive pumps (2 and 3) was the relatively high abundance of *Hobsonia florida*. Differences among the active pump stations are related to the very low overall abundances at Pump 6 and the low densities of *S. benedicti* and *P. littoralis*. Inactive pump stations also differed from Pump 6 in that they had higher abundances particularly of *S. benedicti* (both stations), *P. littoralis* and *H. florida*. Differences between the inactive pump sites and Pump 4 can be traced to the presence of large numbers of cyclopoid copepods and low numbers of *H. florida*.

Analysis of variance detected significant differences ($p < 0.05$) among all three levels of the test for both total numbers of taxa/sample and total numbers of animals/sample (Table 3). Student's t tests of means for active and inactive pumps were significant ($p < 0.05$) for both taxa and abundance, and in each case inactive pumps had the highest values. Tukey's HSD tests among sites (within pumps) were also significant ($p < 0.05$) for both parameters and produced the same pattern of differences: Site 4 > Site 2, Site 3 > Site 6. The only difference in the test results was that there was no significant difference ($p>.0.05$) between Sites 4 and 2 or between Sites 2 and 3 for total taxa and there was a difference between Sites 4 and 3. Results from Tukey's HSD test were also significant ($p < 0.05$) for stations and are plotted in Figures 3 and 4 for taxa and abundance, respectively.

Table 3. ANOVA results.

Taxa	DF	Sum of Squares	F Ratio	Prob > F
Active vs. Inactive Pump	1	4.21	24.04	<.0001
Site (A vs. I)	2	32.49	92.70	<.0001
Station (Site (A vs. I))	4	6.48	9.25	<.0001
Error	72	12.62	0.18	
Abundance	**DF**	**Sum of Squares**	**F Ratio**	**Prob > F**
Active vs. Inactive Pump	1	4.22	37.00	<.0001
Site (A vs. I)	2	27.54	120.70	<.0001
Station (Site (A vs. I))	4	3.26	7.14	<.0001
Error	72	8.21	0.11	

Total numbers of taxa/sample were highest at Station 4A and lowest at the two Pump 6 stations (Figure 3). Values at the remaining stations were similar with the exception of Station 3A, which was not significantly different ($p > 0.05$) from Station 6A. Abundance values were also highest at Station 4A and lowest at the two Pump 6 stations (Figure 4). All of the remaining stations had similar abundance values.

DISCUSSION: Benthic assemblages in the study area are typical of low salinity, muddy environments in the Northern Gulf of Mexico (e.g., Armstrong 1987, Gaston and Nasci 1988, Heard 1982, Horlick and Subrahmanyam 1983, La Salle and Rozas 1991, and Livingston 1984) and are similar to those encountered in the pilot study (Ray 2006a). Although the absence of data from these sites prior to Hurricane Katrina makes it impossible to assess pre-storm conditions, the study results do strongly suggest that floodwater pumping affected the assemblages. The low abundance, low numbers of taxa, low Shannon-Weiner diversity index values, and high degree of variability at Pump 6 in particular, are highly indicative of disturbed conditions. The heavy dominance of Station 4A by the polychaete *Streblospio benedicti* and the presence of large numbers of harpacticoid copepods also indicate recent disturbance. *Streblospio benedicti* is well-known as an early colonizer of recently disturbed sediments (Gaston and Nasci 1988) and has been identified as being tolerant of moderately high metal and organic pollution (Rakocinski et al. 1997). Carman et al. (1997) report that although most harpacticoid copepod species are

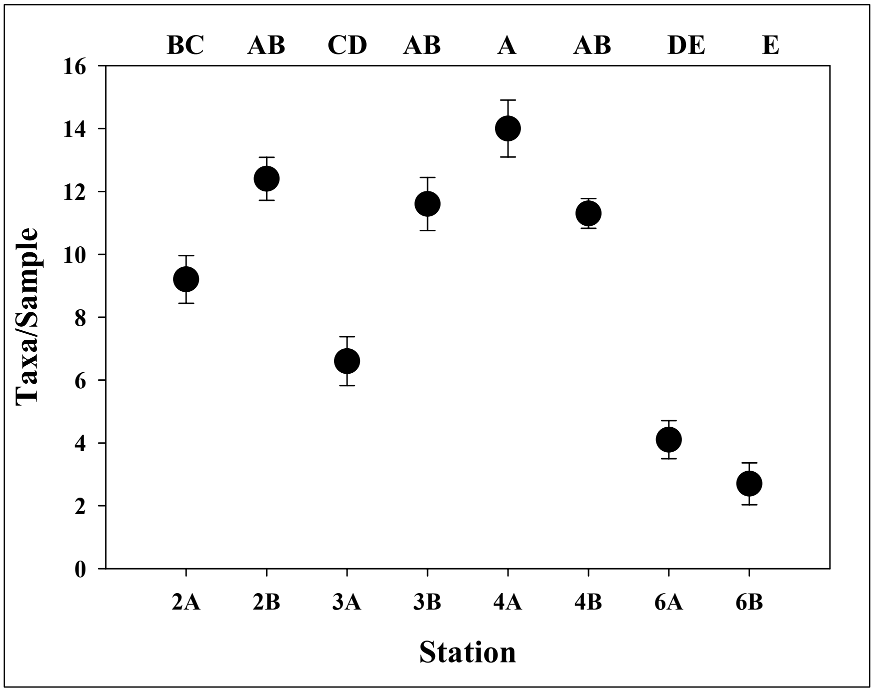

Figure 3. Taxa (Mean ± SE) for stations. Stations with the same letters (above graph) are not significantly different (p>0/.05) by Tukey's HSD test.

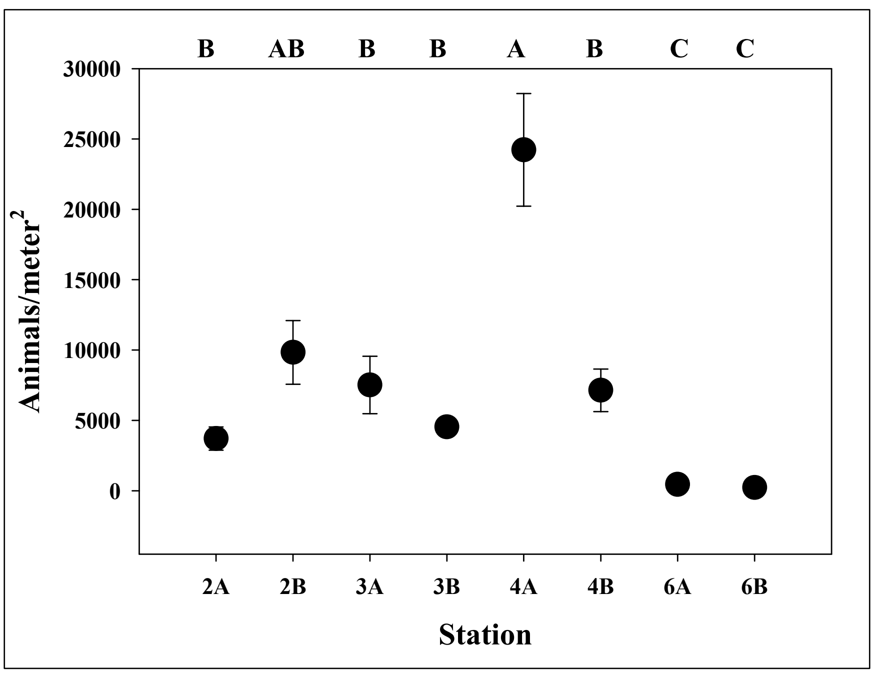

Figure 4. Abundance (Mean + SE) for stations. Stations with the same letters (above graph) are not significantly different (p>0/.05) by Tukey's HSD test.

sensitive to hydrocarbon pollution, a few are relatively insensitive and may occur in large numbers in recently contaminated sediments. The presence of relatively large numbers of oligochaetes at the active pumps also indicates that they may have been subjected to organic enrichment, although Pump 2 (the site with the highest sediment organic content) also had high oligochaete abundances (Pearson and Rosenberg 1978). The very low abundance of *Hobsonia florida* at active pump sites may also be an indication of disturbance. This species has been reported to be sensitive to both pulp mill effluents (Harrel et al. 1976) and petroleum contamination (Hyland et al. 1985).

These conclusions are at odds, however, with the presence of large numbers of species and relatively high diversity values at Pump 4, characteristics generally associated with low stress conditions. The seeming inconsistency between these results may be due to a number of possible influences. First, there was a 3.5-month interval between the storm event and sampling associated with the pilot study (December 2005) and an additional two months before the sampling reported herein. During these intervals, not only was there time for the benthic assemblages to begin recovering, but there was also time for site-specific changes. For instance, the relatively low salinities measured at Pump 4 in February may reflect localized flushing by rain events, thereby countering the initial disturbance. Since the pumps drained different physical areas, there is a strong possibility that the contaminant load of the pumped waters differed both qualitatively and quantitatively among pumped areas. Preliminary analyses of sediment contamination conducted as part of the pilot study detected elevated levels of petroleum-based hydrocarbons at Pump 4 and arsenic and zinc at Pump 6 (Suedel et al. 2006). This pattern may explain much of the difference in the responses of assemblages associated with the active pumps. High concentrations of metals such as arsenic and zinc that persist in sediments result in toxicity over relatively long time periods. Petroleum hydrocarbons, particularly low molecular weight fractions, can be readily mobilized resulting in significant initial toxicity, but relatively less long-term toxicity. Hyland et al. (1985) have reported that after initial defaunation, oil-treated sediments were rapidly recolonized by benthic invertebrates.

The physical disturbance created by floodwater pumping also differed between pump sites with the waters being more constrained by the marshes surrounding Pump 4. This may partially explain why the 100-m station at Pump 6 was similar to the 50-m station, whereas at Pump 4 this was not the case. At Pump 6 the stations fell along a straight line with no intervening structure that could dissipate the force of discharged pump water reaching both stations. At Pump 4, the 100-m station lies in a more protected position. It is in a marsh creek, at a 90-deg angle from the outfall and much less likely to have been impacted by the force of the pump discharge.

In conclusion, benthic assemblages in close proximity (50 m) to active pumps showed evidence of having been impacted by pumping of Hurricane Katrina floodwaters. The impacts varied between the two active pumps presumably due to differences in locale, the nature of contaminants present in the floodwaters, the length of time after disturbance, and possibly pre-existing sediment contamination. The response of assemblages further away from the pumps (100 m) differed for the same reasons, but may also reflect differences in the degree to which they were exposed to the physical force of the pumped waters. Assemblages near inactive pumps were similar to one another regardless of distance from the outfall.

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> Ray, G. L. 2006. *Characterization of Post-Hurricane Katrina floodwater pumping on marsh infauna*. Environmental Laboratory Technical Notes (ERDC/EL TN-06-4). Vicksburg, MS: U.S. Army Engineer Research and Development Center. *http://el.erdc.usace.army.mil/.*

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APPENDIX A: DATA SUMMARIES

Table A1. Water quality and sediment data.

Water Quality Data	2A	2B	3A	3B	4A	4B	6A	6B
Temperature (°C)	11.6	ND	15.6	ND	13.6	ND	12.0	ND
Salinity (ppt)	7.0	ND	5.1	ND	1.8	ND	5.1	ND
Dissolved Oxygen (mg/L)	13	ND	14.5	ND	11.3	ND	9.52	ND
Depth (cm)	100	100	100	100	120	100	100	100
Sediment Data	Coarse Silt	Coarse Silt	Coarse Silt	Coarse Silt	Coarse Silt	Coarse Silt	Coarse Silt	Coarse Silt
Organic Content (%)	22.49	21.02	9.68	15.83	14.45	13.24	21.61	15.65
Mean Grain Size (um)	31.22	29.52	38.06	31.74	39.6	47.48	31.23	34.39
Sorting Coefficient	57.6	25.58	104.5	53.48	110.7	178.1	53.19	69.89
Sediment Fractions								
% Gravel	0.0%	0.0%	0.3%	0.0%	0.2%	0.6%	0.1%	0.1%
% Very Coarse Sand	0.0%	0.0%	0.1%	0.0%	0.1%	0.3%	0.0%	0.1%
% Coarse Sand	0.0%	0.0%	0.2%	0.0%	0.3%	0.4%	0.0%	0.1%
% Medium Sand	0.0%	0.0%	0.1%	0.0%	0.3%	0.2%	0.0%	0.2%
% Fine Sand	0.2%	0.1%	0.3%	0.1%	0.7%	0.5%	0.1%	0.1%
% Very Fine Sand	13.4%	12.9%	15.5%	14.1%	15.1%	14.8%	13.5%	14.9%
% Silt	85.9%	86.6%	83.1%	85.4%	82.8%	82.8%	85.7%	84.2%
% Clay	0.4%	0.4%	0.3%	0.4%	0.4%	0.4%	0.4%	0.4%
ND = No Data.								

Table A2. Dominant species abundance and community structure data.

Taxa	2A	2B	3A	3B	4A	4B	6A	6B	Total	%
Streblospio benedicti	188	382	835	397	1743	496	2	2	4045	30.16
Paranais littoralis	398	800	13	56	1135	367	0	1	2770	20.66
Harpacticoida	98	651	80	58	424	122	9	0	1442	10.75
Cyclopodia	2	96	5	23	821	272	8	1	1228	9.16
Hobsonia florida	83	171	714	156	0	3	1	2	1130	8.43
Chironomus sp.	28	56	35	53	693	94	4	0	963	7.18
Cryptochironomus sp.	2	3	36	221	82	84	1	0	429	3.20
Dero digitata	0	0	0	0	221	48	3	0	272	2.03
Immature Tubificid w/cap. setae	5	8	7	24	56	85	5	3	193	1.44
Cladocera	0	2	0	0	175	8	0	0	185	1.38
Chaoborus sp.	0	1	0	4	79	18	9	1	112	0.84
Ceratopogonidae	0	0	4	14	55	33	0	0	106	0.79
Mediomastus sp.	16	23	2	15	0	1	0	21	78	0.58
Nemertea	5	3	4	1	0	0	52	12	77	0.57
Immature Tubificid w/cap. setae	1	0	0	0	51	1	0	0	53	0.40
Total Animals	863	2287	1749	1057	5635	1661	106	53		
Average Animals/m2	3711	9834	7521	4545	24231	7142	456	228		
Total Taxa	23	25	17	23	24	21	15	13		
Average Taxa/ 232 cm^2	9.2	12.4	6.6	11.6	14	11.3	4.1	2.7		
H'	1.542	1.680	1.050	1.742	1.800	1.847	1.049	0.658		
J'	0.715	0.676	0.583	0.718	0.688	0.765	0.791	0.605		

Table A3. ANOSIM results – comparisons of stations.

Stations	R	p
2A, 4A	0.985	0.2
4A, 3B	0.975	0.1
2A, 4B	0.970	0.1
3A, 4A	0.966	0.1
4A, 2B	0.956	0.1
3A, 4B	0.915	0.1
2B, 4B	0.857	0.1
3A, 6A	0.813	0.1
4A, 6A	0.810	0.1
2B, 3B	0.804	0.1
6A, 2B	0.796	0.2
2A, 6A	0.791	0.1
3B, 4B	0.790	0.1
6A, 3B	0.788	0.1
3A, 2B	0.787	0.1
2A, 3B	0.781	0.1
6A, 4B	0.775	0.1
4A, 6B	0.760	0.1
3A, 6B	0.745	0.1
4B, 6B	0.732	0.1
3B, 6B	0.674	0.1
2B, 6B	0.672	0.1
2A, 3A	0.652	0.1
2A, 6B	0.639	0.1
4A, 4B	0.519	0.1
6A, 6B	0.418	0.1
2A, 2B	0.410	0.1
3A, 3B	0.405	0.1

Table A4. SIMPER results – Pairwise station comparisons.

Station	Average Similarity
2A	50.77
2B	50.64
3B	62.90
3A	47.43
4A	56.41
4B	52.16
6A	31.27
6B	19.81
Pairwise Comparison	Average Dissimilarity
4A & 6B	99.72
3A & 6B	98.76
4B & 6B	98.57
4A & 6A	98.48
2B & 6B	97.89
3A & 6A	97.38
3B & 6B	97.15
6A & 2B	96.63
6A & 3B	95.18
6A & 4B	94.79
2A & 6B	94.58
2A & 6A	94.32
6A & 6B	88.50
2A & 4A	80.00
4A & 3B	77.39
3A & 4A	76.54
3A & 4B	72.18
2A & 3A	71.33
3A & 2B	69.95
4A & 2B	67.84
2A & 4B	67.55
4A & 4B	63.24
2B & 3B	61.38
2B & 4B	60.69
2A & 3B	60.41
3B & 4B	59.95
3A & 3B	56.85
2A & 2B	56.37