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A Pilot Study of Post-Hurricane Katrina Floodwater Pumping on Marsh Infauna

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Key points…

What effect did Hurricane Katrina floodwaters have on benthic invertebrates close to the pumping stations in wetlands near Chalmette and Violet, Louisiana? Did floodwaters pumped on wetlands elevate salinity and contaminants? A pilot sampling study set out to answer these questions. Samples were taken at four pumping stations 3-1/2 months after Hurricane Katrina. Study results suggest that floodwater pumping did indeed affect assemblages of invertebrates. Stations where no pumping occurred had fewer numbers of animals and greater similarity in species composition than actively pumped sites. Study results provide the data needed for statistical power testing and minimum sample size calculations. These results can be used to design alternatives for potential future studies.

PURPOSE: The Interagency Performance Evaluation Taskforce (IPET) is presently evaluating the performance of hurricane protection and damage reduction systems and consequences of structural failures to the New Orleans area following Hurricane Katrina. This evaluation includes determining environmental impacts to habitat and other biological resources. This report presents preliminary data concerning the effects of pumping of floodwaters on assemblages of benthic invertebrates in the immediate vicinity of the pumping stations in wetlands near Chalmette and Violet, Louisiana.

BACKGROUND: On August 29, 2005, Hurricane Katrina struck the coasts of Alabama, Mississippi, and Louisiana, resulting in significant physical damage and loss of life. Levees were breached or overtopped, resulting in massive flooding in the City of New Orleans and adjacent areas. Large portions of Saint Bernard Parish were flooded when levees were overtopped by bay waters from the Mississippi River Gulf Outlet channel and Lake Borgne. Floodwaters were subsequently pumped from affected areas into marshes in the vicinity of Chalmette and Violet, Louisiana. Concerns have been expressed regarding the potential for undesirable environmental impacts on the marsh ecosystem due to elevated salinity and contaminants. To address some of these issues, sampling events were conducted after the storm, including a pilot study to compare benthic invertebrate assemblages of sites in the immediate vicinity of active and inactive pumping stations. Benthic invertebrates are a critical part of estuarine food chains, providing forage for economically and ecologically important finfish and shellfish species and are routinely monitored as part of environmental assessments. The sampling effort reported herein represents a pilot study; that is, an initial effort to discern large-scale patterns in benthic assemblage distributions and determine minimal sample size for potential future studies.

STUDY AREA: Four pumping stations located along the Back Protection Levee were chosen based on their pumping records (Figure 1). Pumps 4 and 6 were in operation through all or most of the emergency whereas Pumps 2 and 3 were selected because they were either not employed or inoperative during this time. Samples were taken in the small basins adjacent to the pumping stations within 50 m of the pumping station outfall (Figures 2 and 3) on December 13-14, 2005, approximately 3-1/2 months after landfall of Hurricane Katrina.

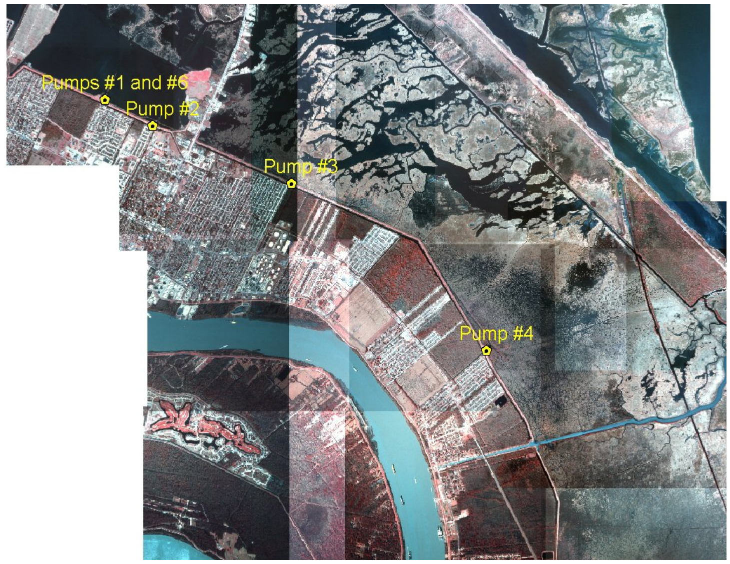

Figure 1. Aerial view of study area

METHODS: Three infaunal samples were taken in waters approximately 1 m in depth at each site (Pumps 2, 3, 4, and 6) using a pole-mounted Eckman dredge (232 cm^2/sample). 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), Vicksburg, MS, where the samples were rinsed with fresh water over a 0.5-mm sieve and material retained on the sieve stored in 70-percent ethanol. Samples were subsequently stained with Rose Bengal and examined under illuminated 3X magnification to facilitate removal from the sediments. All specimens were identified to the lowest practical identification level and counted.

Figure 2. Pump 4

Figure 3. Pump 4 Basin

Although no samples were taken for sediment grain size analysis, visual examination of the materials during sampling indicated that all were very fine, unconsolidated sediments with substantial amounts of decaying vegetative matter. Later examination of the sieved samples confirmed this observation. Water quality was measured at the surface of the water column using a handheld YSI Model 85. Salinities at the sampling sites ranged between 11 and 12 ppt and temperatures ranged from 12 ^{o}C to 15 ^{o}C. Dissolved oxygen concentrations at the surface were all at or above 100-percent saturation. A distinct petrochemical smell was detected in sediments from Pumps 4 and 6 and an oily sheen was observed at the water surface during sediment sampling at Pump 4.

Both multivariate and univariate statistical techniques were employed to detect potential changes in the benthic assemblages resulting from floodwater pumping. Multivariate techniques test for patterns simultaneously among multiple variables, such as species composition data. Species composition has proven to be a sensitive indicator of assemblage status, particularly in response to disturbance (Clarke and Warwick 2001). The specific multivariate techniques employed include 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 detected 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. All three analyses and the calculation of community diversity values (taxa richness, Shannon-Weiner Diversity ($H'Log_e$), and Pielou's Index (J')) were performed using PRIMER statistical software. Univariate statistics, tests of individual variables, were used to detect differences in abundance and diversity measures. Analysis of Variance (ANOVA) was used to explore potential differences in total abundance among pumped and unpumped sites, followed by Tukey's test to determine which mean values were different. Because of the low numbers of samples inherent in a pilot study, most of the emphasis in univariate statistical analysis was placed on determining statistical power and estimates of minimum sample size. These estimates are used to describe potential designs for future studies. All univariate statistical tests were conducted with JMP statistical software.

RESULTS:

Sample Analysis. The species assemblages were typical of Northern Gulf of Mexico marshes and of low salinity, muddy estuarine sediments in the Gulf of Mexico in general (e.g., Armstrong 1987, Gaston and Nasci 1988, Heard 1982, Horlick and Subrahmanyam 1983, Livingston 1984, La Salle and Rozas 1991).

Differences in species composition were detected both between pumped and unpumped sites and between the two actively pumped stations (4 and 6) by NMDS (Figure 4). A stress value of 0.08 (significant at p value = 0.02) indicates that the data plot provides a good fit to the original distribution of similarity values, i.e., the plot accurately represents the relationships among the samples (Clarke and Warwick 2001). These results were confirmed by ANOSIM (R = 0.616 at a significance level of 2 percent). SIMPER analysis of unpumped and pumped sites indicated an average dissimilarity of 89.37 percent (Table 1).

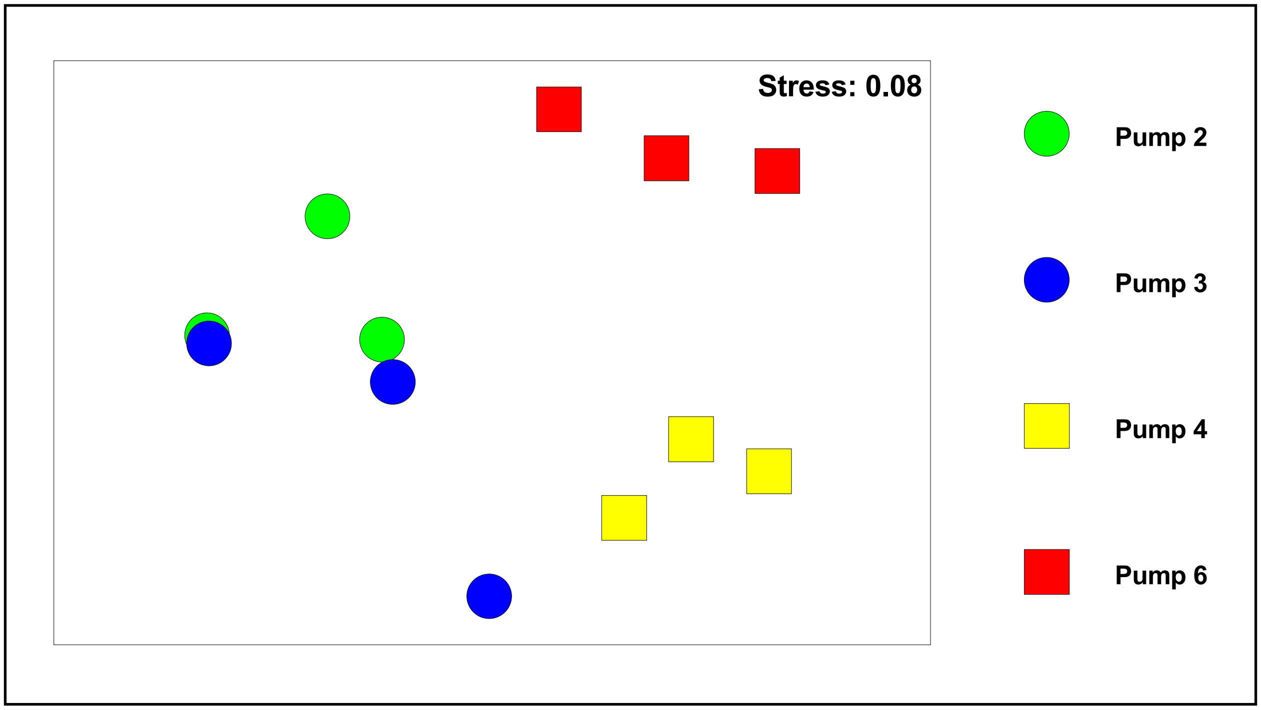

Figure 4. Nonmetric dimensional scaling results for Violet Marsh infauna (circles represent unpumped stations and squares represent pumped stations)

Table 1
Test Results for Pumped and Unpumped Sites[1]

Species	Average Abundance	Average Similarity	Contribution (%)	Cumulative (%)
	Unpumped			
	(Average similarity = 50.27)			
Streblospio benedicti	11	44.85	89.23	89.23
Harpacticoida	1.33	3.94	7.84	97.07
	Pumped			
Species	**Average Abundance**	**Average Similarity**	**Contribution (%)**	**Cumulative (%)**
	(Average similarity = 22.40)			
Harpacticoida	31.5	11.13	49.68	49.68
Streblospio benedicti	155.5	6.99	31.22	80.9
Cyclopodia	111.83	2.3	10.25	91.15
	Unpumped vs. Pumped			
Species	**Average Abundance**	**Average Similarity**	**Contribution (%)**	**Cumulative (%)**
	(Average dissimilarity = 89.37)			
Streblospio benedicti	11	155.5	37.08	37.08
Harpacticoida	1.33	31.5	28.77	65.85
Cyclopodia	0	111.83	18.66	84.5
Nemertea	0	1.5	2.84	87.35
Tubificidae	0.17	2.17	2.1	89.45
Hobsonia florida	2.33	0	1.94	91.39

[1] Av. = Average, Abund = Abundance, Sim = Similarity, Contrib. = Contribution, Cum = Cumulative.

Benthic assemblages of both pumped and unpumped stations were dominated by the polychaete *Streblospio benedicti*; however, densities of this species were far greater at the pumped sites. Harpacticoid copepods were also dominant at all sites and were also most abundant at pumped sites. Cyclopoid copepods and nemerteans were abundant only at pumped sites, while the polychaete *Hobsonia florida* was collected exclusively at Pump Station 3 (unpumped).

A subsequent SIMPER analysis based on individual stations detected the least degree of dissimilarity (greatest similarity) among unpumped sites (Table 2). The greatest degree of dissimilarity was found between Pump Stations 4 and 6. Station 4 was dominated (in order of abundance) by *S. benedicti* and cyclopoid copepods, whereas Station 6 was dominated by harpacticoids and *S. benedicti.*

Table 2
Pairwise SIMPER Results for Pump Sites

Pairwise Comparison	Average Dissimilarity
Pumps 2 & 3	50.74
Pumps 2 & 4	95.08
Pumps 3 & 4	89.19
Pumps 2 & 6	85.31
Pumps 3 & 6	87.90
Pumps 4 & 6	93.02

Overall community metrics (Abundance, Number of Taxa, Shannon-Weiner Diversity, and Pielou's Evenness) were also calculated (Table 3). Abundances (animals per sample) averaged 10 to 11 per sample at the unpumped stations, 21 per sample at Station 4, and 268 per sample at Station 6. The average number of taxa present was 2.5 to 3.5 per sample at the unpumped stations and 5 to 6 per sample at the pumped stations (Table 3). Diversity values ranged from 0.820 to 0.886 at all stations except 3 where H' was 0.525. Evenness ranged from 0.706 to 0.786 at all stations except 6, where it was 0.566.

Analysis of Variance (ANOVA) of abundance values yielded a significant difference at a power of 83 percent (effect size = 25 percent of mean) after logarithmic transformation to correct for non-normality. Tukey's least significant difference test indicated that these differences were statistically significant ($p < 0.05$). Statistical testing of the remaining community metrics was precluded by very low statistical power, generally less than 30 percent for detection of a change equivalent to 25 percent of the mean. As a result, interpretation of these values is tentative.

Sample Size Estimation. The primary purpose of most environmental sampling efforts is to determine if a difference exists between two or more sites or conditions (e.g., pumped vs. unpumped) (Underwood 1997). In order to make this comparison it is necessary to know the variability of the parameters being measured, a basic objective of pilot studies such as described here. It is then necessary to define the effect size, i.e., the degree of difference that is considered to be important, and the statistical power or degree of confidence in the test to be performed (Schmitt and Osenberg 1996, Quinn and Keough 2002).

There are no strict guidelines in defining either effect size or statistical power; however, both directly affect the minimum number of samples necessary to achieve a valid test. For the purpose of this work it will be assumed that a statistical power of 90 percent is required. This means that there will be a 10-percent probability that a finding of no significant difference was erroneous. Estimates of minimal sample size for different effect sizes (expressed as a percentage of the mean) calculated from the pilot study data are listed in Table 4. The present study design of 12 samples represents an effect size between 30 and 40 percent of mean abundance (after log

Table 3
Species Composition and Community Structure Data

Taxa	Pump 2	Pump 3	Pump 4	Pump 6
Streblospio benedicti	17	49	927	6
Cyclopodia	0	0	671	0
Harpacticoida	4	4	93	96
Chaoborus sp.	0	0	7	0
Tubificidae	0	1	6	7
Polydora sp.	2	2	3	1
Chironomus sp.	0	0	3	0
Nematoda	0	1	2	0
Hobsonia florida	1	13	0	0
Bivalvia	1	0	0	0
Hypereteone heteropoda	1	0	0	0
Syllidae	1	0	0	0
Naididae	0	2	0	0
Cryptochironomus sp.	0	1	0	1
Grandidierella bonneroides	0	2	0	0
Gammaridae	0	1	0	0
Capitella sp.	0	1	0	1
Nereis succinea	0	0	0	1
Nemertea	0	0	0	9
Heteromastus filiformis	0	0	0	3
Stenoninereis martini	0	0	0	5
Mediomastus sp.	0	0	0	5
Total Taxa	7	11	8	11
Total Abundance	27	77	1712	135
Average Taxa	3.5	2.5	5.0	6.0
Average Abundance (Animals/Sample)	11.0	10.0	21.3	268.3
Shannon Weiner Diversity (H'(loge))	0.864	0.525	0.886	0.820
Pileou's Evenness Index (J')	0.786	0.757	0.706	0.566

Table 4
Minimal Sample Sizes

% Mean	No. Samples	
	Taxa	Log Abundance
10%	264	105
20%	70	30
30%	32	15
40%	20	10
50%	13	7

transformation to correct for a non-normal distribution). To detect a 10-percent difference between mean abundances would require 105 samples, while 264 samples are needed to detect the same difference in mean numbers of taxa. A minimum of 80 samples would detect a difference of less than 20 percent between both mean abundances and mean numbers of taxa and accommodate several potential versions of the design. For instance, number of samples could be increased to 20 per site and sampled during a single effort (20 samples × 4 sites = 80). Likewise, potential seasonal variation at the sites could be assessed by sampling on a quarterly basis (5 samples × 4 sites × 4 sampling efforts = 80 samples). Another alternative would be to incorporate additional sampling locations at each pump site, but at greater distances from the outfall to determine the spatial extent of potential impacts. This design could be accomplished within a single sampling effort (5 samples × 4 sampling stations × 4 sites = 80). Any of these designs should provide satisfactory statistical results on a cost-effective basis.

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, Livingston 1984, La Salle and Rozas 1991). In the absence of data from these or nearby sites prior to Hurricane Katrina it is impossible to say if they resemble those present immediately prior to overtopping of the levees; however, the study results do suggest that floodwater pumping affected these assemblages. Stations where no pumping occurred had fewer numbers of animals and a greater similarity in species composition than actively pumped sites. The heavy dominance of the Pump 4 (pumped) assemblage by the polychaete *Streblospio benedicti* and the presence of large numbers of harpacticoid copepods may indicate a history of disturbance. *Streblospio benedicti* is well-known as an early colonizer of recently disturbed sediments. Gaston and Nasci (1988) and Carman et al. (1997) report that although most harpacticoid species are sensitive to hydrocarbon pollution, a few such as *Cletocamptus deitersi* are relatively insensitive and may occur in large numbers in recently contaminated sediments.

The study results also provide the data necessary for statistical power testing and minimum sample size calculations. These results have been used to suggest several alternative designs for potential future studies. These include a single sampling event limited to the original four sites with more comprehensive sampling, a single sampling event with greater spatial coverage, and a multiple sampling event design incorporating seasonal variability.

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> Ray, G. L. (2006). "A pilot study of Post-Hurricane Katrina floodwater pumping on marsh infauna," Environmental Laboratory Technical Notes (ERDC/EL TN-06-2). U.S. Army Engineer Research and Development Center, Vicksburg, MS. *http://el.erdc.usace.army.mil/.*

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