Statistical Analyses on Habitat Alteration, Diversity, Taxa Richness and Density of Benthic Macroinvertebrates:

Terra Ceia Aquatic Preserve Dredging Enforcement Benthic Macroinvertebrate Data for Southwest District

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Major Findings: Unpermitted dredging at Terra Ceia Aquatic Preserve was associated with significant declines in taxa richness and density of benthic macroinvertebrates more than two months after the disturbance as well as a change in the composition of the sediment where benthic macroinvertebrates live. The decline in taxa richness and density of benthic macroinvertebrates and change in sediment composition represents an adverse impact to marine productivity at the site of the dredging.

Background: A channel was dredged through the mangrove fringe and a mudflat in the Terra Ceia Aquatic Preserve in August 2003 without a FDEP permit. The FDEP Biology Section was asked to analyze benthic macroinvertebrate and sediment samples to assess possible effects. Benthic macroinvertebrates include snails, worms, crabs, clams and many other types of marine animals. Benthic macroinvertebrates are major components of soft sediment communities and are fed upon by a wide range of fishes, crabs, snails and other marine life.

Goals: Data were analyzed to assess if the dredging activity adversely affected diversity, marine productivity, the conservation of fish and wildlife including threatened or endangered species or their habitat, fishing and recreational values, or the value of functions provided to fish and wildlife and listed species by wetlands and other surface waters (see Subsection 373.414(1), F.S. and sections 40D-4.301 and 40D-4.302, 62-302.530(11) F.A.C.).

Methods: On 10 October 2003 (more than two months after dredging), petite ponar samples were collected in the dredged channel (dredged sites), in the spoil deposited from the dredging (spoil sites), and in adjacent undisturbed sediments (control sites). Samples were preserved and sent to Biology Section for analysis (n = 27 samples total). Samples were sorted and identified to the lowest practical level. Sediment samples were collected in conjunction with each set of three ponars and analyzed for percent organic content and sediment grain size. Collections, analyses and taxonomic identifications were made following FDEP standard operating procedures (SOPs, http://www.floridadep.org/labs/qa/2002sops.htm).

The number of taxa and number of individuals were tallied from the samples. These data were analyzed to test if there were differences in the distribution and abundance of benthic macroinvertebrates associated with dredging disturbance. Sediment percent organic content and grain size were analyzed to test for habitat alteration associated with

dredging. Shannon-Weaver diversity (H') was calculated on sets of three ponars from each of the transects using collapsed taxa lists and log (2) as the base for calculation (n=3 values from control, dredged and spoil areas). H' data were analyzed for differences among sites, and to test if H' was reduced by 25% or more at dredged or spoil disposal areas as compared with control sites. Statistical tests were chosen based upon standard statistical methods (Sokal and Rohlf 1995); details are provided in Appendix 1.

Community Composition: The benthic macroinvertebrate community in undisturbed shallow, soft sediments at Terra Ceia Aquatic Preserve was composed primarily of polychaetes (~80%) with smaller numbers of bivalves, gastropods, anemones, isopods, amphipods, and a few additional taxa (Appendix 2). The community as a whole was relatively depauperate, with 36 taxa identified from 4,011 macroinvertebrates collected from nine ponar samples. Overall benthic macroinvertebrate density was 18,595 individuals/m^2. Shannon-Weaver diversity at control sites was 2.56 for the samples composited as a whole and ranged from 2.49-2.68 for the three sets of samples from the three control-site transects.

Analytical Results: Ponar samples collected approximately two months after the illegal dredging at Terra Ceia indicated that benthic macroinvertebrates and the sediments they live in remained statistically significantly impacted by dredging and spoil disposal.

Mean number of taxa/sample decreased from 19.7 at control sites to 14.2 at spoil sites to 8.7 in dredged areas (Figure 1). Taxa richness decreased by an average of 28% between control and spoil samples. Differences were even stronger for comparisons between control and dredged areas: there were 56% fewer taxa at dredged sites than in adjacent undisturbed controls.

Number of individuals differed significantly between control and dredged areas, with median density dropping by 68% (Figure 2). Median density also dropped in comparisons between the control and spoil sites (-40%) and between dredged and spoil disposal sites (-47%), but these results were not statistically significant due to the low power of the non-parametric analyses and macroinvertebrate recruitment in the two-month interval between dredging and sampling.

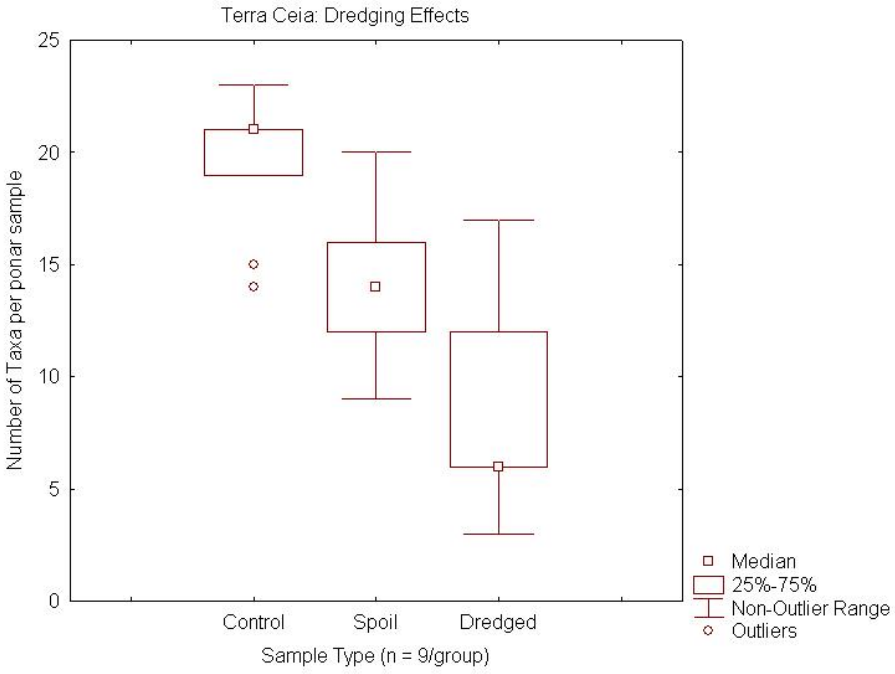


Figure 1. Box plot of number of taxa per ponar sample: Terra Ceia Aquatic Preserve

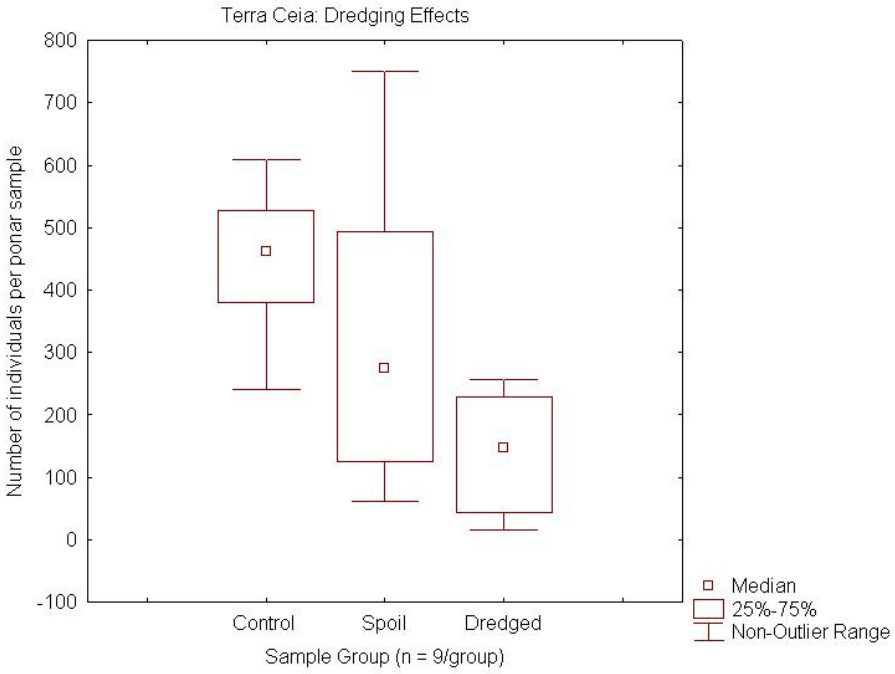


Figure 2. Box plot of number of individuals per ponar sample: Terra Ceia Aquatic Preserve

The percent organic content and sediment grain size was significantly different among sites. Mean organic content and percent of total sample composed of <0.125 mm particles were significantly higher at the spoil disposal sites as compared with control and dredged sites (Figure 3a, b, details in Appendix 1). The cause of these changes is uneven settling

of different size particles when spoils are dumped. Finer particles settle more slowly, and thus tend to settle on top of heavier materials. Ponar samplers usually penetrate the top ~5 cm of sediments, and will collect the relatively fine particles from the top layer of spoil disposal sites. Shifts in sediment grain size or organic content in the top layers of sediment change the habitat for benthic macroinvertebrates, because most live in the upper few centimeters of sediment. At Terra Ceia, dredging changed sediment composition, and thus the quality of the habitat for benthic macroinvertebrates, at spoil disposal sites.

Figure 3a.

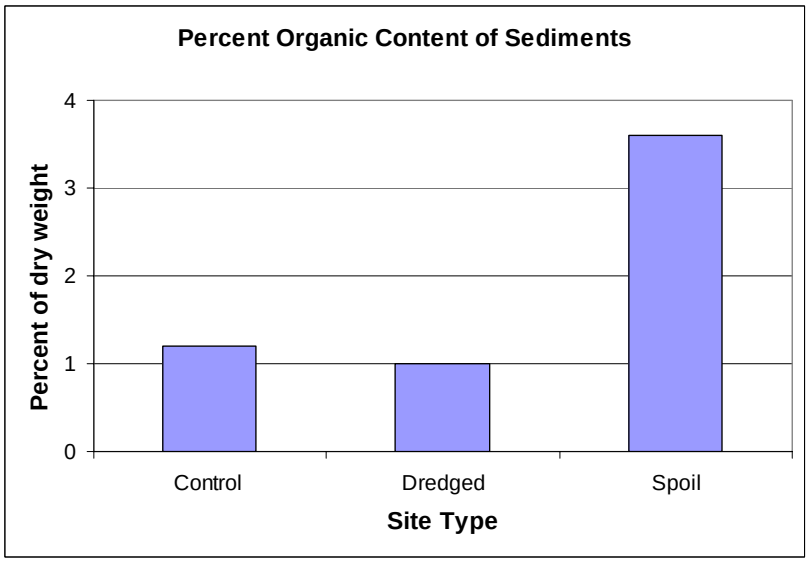


Figure 3b

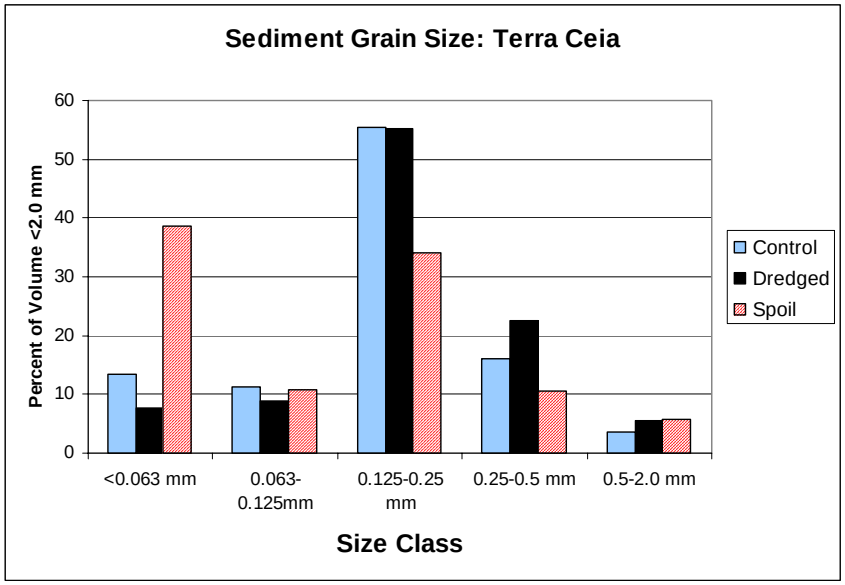


Figure 3. (a) Mean percent organic content of sediments at control, dredged and spoil deposit sites, Terra Ceia Aquatic Preserve. (b) Distribution of mean sediment grain size at control, dredged and spoil disposal sites, Terra Ceia Aquatic Preserve. All data are the mean of three samples from each type of site.

For evaluation of the Biological Integrity Criterion (62.302-530(11) F.A.C.), all data were composited from each site and H' was calculated on the assemblage data as a whole. At the control sites, H' was 2.56, while at the spoil sites, H' was slightly higher (2.85). At dredged sites, Shannon-Weaver diversity was 14% lower, measuring 2.21.

Analysis of variance was used to compare the three individuals values per site type (control, dredged and spoil disposal). There were no significant differences among sites in Shannon-Weaver diversity (detailed in Appendix 1). We note that this was a statistically weak analysis, due to low sample sizes. There are also questions about the underlying model structure for analysis of H' scores, which makes the form of the correct analysis uncertain (Taylor and Bailey 1997). In addition, the two month delay between dredging and sampling had allowed macroinvertebrate recruitment, weakening the probability of detecting differences in H'.

A major problem with application of the Biological Integrity Criterion is the general weakness of Shannon-Weaver diversity as an indicator of ecological condition. As stated by Taylor and Bailey (1997) in a review of methods for monitoring effects of mine drainages on benthic macroinvertebrates in Canada, "The emerging consensus is that the (Shannon Weaver) diversity index will only reliably detect changes that are so conspicuous that the index is unnecessary anyway" (p.42). The likelihood that a site with a background Shannon-Weaver score of <3.0 will provide evidence of ecological damage is low, unless the disturbance is severe (Taylor and Bailey 1997 and included references). Thus, the lack of a significant change in diversity among locations should not be interpreted as lack of ecological impacts from dredging, given the significant changes in sediment composition, taxa richness and density identified from other analyses.

Conclusions: The illegal dredging activities adversely affected the benthic macroinvertebrate community in the dredged and spoils disposal areas and altered the sediments where benthic macroinvertebrates live. The decrease in both taxa richness and density of organisms and the alteration of their habitat could be interpreted as potential violations of Subsection 373.414(1) of the Florida Statutes and sections 40D-4.301 and 40D-4.302 of the Florida Administrative Code. Data did not indicate violation of the Biological Integrity Criteria (62-302.530(11) F.A.C.), but the analysis was not likely to detect deleterious effects from the dredging. This was due to underlying problems in the applicability of Shannon-Weaver diversity in ecological assessment such as this one.

Appendix 1

Analyses: At three transects across the affected area, sets of three petite ponar samples were collected from the dredged channel, the spoil disposal site and in undisturbed sediments. The number of taxa per sample and the number of individuals per sample were totaled from the data. The data were checked for violations of the assumptions of parametric analysis and analyses selected based upon the results (Sokal and Rohlf 1995). All analyses were performed with Statistica ™ Version 6.0.

Number of taxa/sample was approximately normally distributed and groups had homogenous variances (Hartley F max test, $p=0.365$). Data were analyzed using nested analysis of variance (ANOVA) with control, dredged and spoil (Location) as the main treatments with transect nested within treatment (Location). Significant differences among treatments were analyzed using Tukey post-hoc HSD tests.

Number of individuals was not normally distributed with homogenous variances ($p<0.001$) and data did not meet the assumptions of ANOVA after square root and logarithmic transformations. Data were analyzed using non-parametric Kruskal-Wallis analysis of variance for dredged, spoil and control sample groups. The Kruskal-Wallis ANOVA was followed by z' tests for differences among groups.

Sediment data were summarized by combining the <0.63mm and 0.63-0.125mm categories for an analysis of the sand/silt/clay fraction of the sample. Percent organic content and percent of sample composed of <0.125 mm particles were approximately normally distributed and groups had homogeneous variances (Hartley F max tests, $p>0.05$). Data were analyzed using one way (ANOVA) with location as the grouping factor. Significant differences among treatments were analyzed using Tukey post-hoc HSD tests. Complete data are given in Table A1.

Shannon Weaver diversity was analyzed using H' values calculated from each set of three ponars (n = 9 H' values). Data met the assumptions of homogeneity of variances (Hartley F max test, $p>0.05$) and a oneway ANOVA was performed.

Results:

Number of Taxa: The number of taxa differed significantly among locations and among transects within locations (Table A2). A box plot of the number of taxa/group is shown in Figure 1. The overall results show that there was a significant drop in the number of taxa from control to spoil to dredged samples. Mean number of taxa/sample decreased from 19.7 (standard error ± 1.04) at control sites to 14.2 (± 1.2) at spoil sites to 8.7 (± 1.7) in dredged areas.

The presence of significant variation among transects indicates that one transect had less difference in number of taxa with location than the other two transects. The effect of location was then tested over the transect (Location) effect. The effect of location (control, dredged, or spoil) was highly significant, regardless of heterogeneity among

transects. In summary, there was an overall, highly significant effect of loss of taxa with dredging disturbance.

Number of Individuals: The number of individuals/sample differed significantly among locations (Kruskal-Wallis test, H=11.9610, p=0.0025). Data are summarized in a box plot (Figure 2). Median density dropped from 461 (range 241-609) at control sites to 275 (61-750) at spoil sites and 147 (16-256) at dredged sites.

Differences among control, dredged and spoil sites were tested using z' multiple comparisons. Significantly more individuals/ponar were collected at control sites than at dredged sites ($p<0.002$). There were no significant differences between control and spoil groups or between dredged and spoil groups ($p >0.05$, each test). Although these two comparisons were not significant, high variability and relatively low number of samples made the statistical power of the tests low. In addition, the two-month lag between the dredging and the ponar sampling had allowed some recruitment of benthic macroinvertebrates to the impacted sediments.

Sediment percent organic content and grain size: Percent organic content of sediments differed significantly among control, dredged and spoils disposal sites ($p = 0.0011$, Table A3). In post-hoc pairwise tests, sediments at spoils disposal sites had significantly higher percent organic content than sediments from control or dredged sites ($p<0.003$ or smaller). Control and dredged sites did not differ in sediment organic content ($p=0.83$).

The percent of sample composed of particles <0.0125mm in size differed significantly among control, dredged and spoils disposal sites ($p=0.011$, Table A4). As for percent organic content, in post-hoc pairwise tests, sediments at spoils disposal sites had significantly higher percent of sample composed of <0.125mm grain size than sediments from control or dredged sites ($p<0.025$ or smaller). Control and dredged sites did not differ in percent of sample composed of <0.125mm grain size ($p=0.82$).

Shannon-Weaver Diversity: Shannon-Weaver diversity did not differ among control, dredged and spoils disposal areas in oneway ANOVA ($p=0.45$, Table A5).

References:

Sokal, F. J. and R. R. Rohlf. 1995. Biometry. Freeman and Sons, New York.

Taylor, B. R. and R. C. Bailey. 1997. Technical evaluation on methods for benthic invertebrate data analysis and interpretation: Final Report. Canada Centre for Mineral and Energy Technology, Ottawa, Canada, 108 pp. http://www.nrcan.gc.ca/mms/canmet-mtb/mmsl-lmsm/enviro/reports/2.1.3final-aete.pdf

Additional Information: Please contact David Whiting, Environmental Administrator, Biology Section, Bureau of Laboratories, FDEP with questions or requests for additional information (850-245-8191 or david.d.whiting@dep.state.fl.us).

Table A1. Sediment characteristics at control, dredged and spoil sites								
	Sample	Percent Organic	Sediment Particle Size, Percent of Volume <2.0 mm					
Site	ID	% dry weight	<0.063 mm	0.063-0.125mm	0.125-0.25 mm	0.25-0.5 mm	0.5-2.0 mm	% dry weight >2.0 mm
Control	29279	1.6	18.7	11.1	47.8	15.4	7.0	<1
	29283	<1	11.2	11.9	59.7	15.6	1.5	<1
	29287	1.1	10.2	11.0	59.0	17.5	2.3	<1
	Mean	1.2	13.4	11.3	55.5	16.2	3.6	<1
Dredged	29284	<1	2.8	7.1	55.7	28.1	6.3	<1
	29280	<1	7.2	8.9	53.9	22.2	7.9	<1
	29288	<1	13.3	10.7	56.0	17.4	2.6	<1
	Mean	<1	7.7	8.9	55.2	22.6	5.6	<1
Spoil	29281	4.2	53.5	9.9	23.2	8.2	5.3	<1
	29285	3.8	41.8	9.0	30.7	12.6	6.0	<1
	29289	2.7	20.9	13.4	48.4	11.0	6.3	<1
	Mean	3.6	38.7	10.8	34.1	10.6	5.8	<1

Note: Samples given as "<1" were reported as "1 K " (true value known to be less than value given) in the original LIMS data.

Table A2. Nested ANOVA for number of taxa/sample, Terra Ceia Dredging Enforcement					
Effect	Sum of Squares	Degrees of freedom	Mean square	F	Probability
Location	544.519	2	272.259	41.067	<0.0001
Transect(Location)	260.222	6	43.370	6.5419	0.0009
Error	119.333	18	6.630		

Table A3. Oneway ANOVA for percent organic content of sediments, Terra Ceia Dredging Enforcement					
Effect	Sum of Squares	Degrees of freedom	Mean square	F	Probability
Location	12.08667	2	6.04333	25.6557	0.0011
Error	1.41333	6	0.23556		
Total	13.5	8			

Table A4. Oneway ANOVA for percent <0.125mm particle size in sediments, Terra Ceia Dredging Enforcement					
Effect	Sum of Squares	Degrees of freedom	Mean square	F	Probability
Location	1891.602	2	945.801	10.68072	0.011
Error	531.313	6	88.552		
Total	2422.916	8			

Table A5. Oneway ANOVA for Shannon-Weaver diversity, Terra Ceia Dredging Enforcement					
Effect	Sum of Squares	Degrees of freedom	Mean square	F	Probability
Location	0.62349	2	0.31174	0.9190	0.4485
Error	2.03540	6	0.33923		
Total	2.65889	8			

Appendix 2

A. Benthic macroinvertebrate data summed from all ponar samples, Terra Ceia Aquatic Preserve. Taxa collapsed following FDEP SOP LT 7100 sect. 4.2.1. Data given in number per m^2.

			Control	Spoils Disposal	Dredged
Annelida					
Oligochaeta					
	Tubificidae	Tubificidae	148	181	167
Polychaeta					
	Ampharetidae	Ampharetidae	0	0	9
		Hobsonia florida	408	232	79
	Capitellidae	*Capitella capitata* complex	658	376	362
		Heteromastus filiformis	23	9	0
	Cirratulidae	Cirratulidae	0	0	5
	Goniadidae	*Glycinde* sp.	0	5	0
	Hesionidae	Hesionidae	0	5	0
	Nereididae	*Laeonereis culveri*	6,231	5,443	1,103
		Nereis succinea	93	32	28
		Stenoninereis martini	0	0	125
	Pectinariidae	*Pectinaria gouldi*	65	19	32
		Pectinariidae	0	5	0
	Phyllodocidae	*Eteone heteropoda*	42	9	5
	Spionidae	*Paraprionospio pinnata*	5	5	14
		Polydora cornuta	65	102	5
		Streblospio sp.	7,339	3,310	3,097
Arthropoda					
Crustacea					
	Ampeliscidae	*Ampelisca abdita*	32	0	5
	Anthuridae	*Cyathura polita*	5	0	0
		Xenanthura brevitelson	42	37	0
	Aoridae	Aoridae	42	46	0
		Grandidierella bonnieroides	320	301	5
	Corophiidae	*Americorophium ellisi*	807	797	56
	Hyalellidae	*Hyalella azteca*	5	0	0
	Idoteidae	*Edotea triloba*	148	70	5
	Leptocheliidae	*Hargeria rapax*	65	283	0
	Mysidae	*Americamysis* sp.	14	9	0
		Mysidae	0	0	5
	Nannastacidae	*Almyracuma proximoculi*	60	32	0
	Parapseudidae	Parapseudidae	0	5	0
Insecta					
	Chironomidae	*Tanypus clavatus*	9	0	121
Cnidaria					
Anthozoa					
	Actiniaria	Actiniaria	598	788	23
Mollusca					
Bivalvia					
	Bivalvia	Bivalvia	0	0	23
	Mactridae	*Mactra fragilis*	37	23	0
	Mytilidae(mollusca)	*Amygdalum papyrium*	46	42	0
	Psammobiidae	*Tagelus plebeius*	487	510	56
	Veneridae	*Anomalocardia auberiana*	9	5	0
		Parastarte triquetra	37	144	0
Gastropoda					
	Acteonidae	Acteonidae	9	0	0
		Rictaxis punctostriatus	9	0	0
	Hydrobiidae	Hydrobiidae	709	932	153
	Pyramidellidae	*Odostomia* sp.	5	0	0
		Pyramidellidae	5	0	0
Nemertea					
Nemertea	Nemertea	Nemertea	9	0	5
Platyhelminthes					
Turbellaria					
	Polycladida	Polycladida	0	5	0
	Turbellaria	Turbellaria	9	0	0

B. Benthic macroinvertebrate data summed from all ponar samples, Terra Ceia Aquatic Preserve. Taxa as counted. Sum of counts from 9 ponar samples.

			Control	Spoil Disposal	Dredged
Annelida					
	Oligochaeta				
		Tubificidae	32	39	36
	Polychaeta				
		Ampharetidae	49	15	8
		Hobsonia florida	39	35	11
		Capitella capitata complex	142	79	78
		Capitellidae	0	2	0
		Heteromastus filiformis	5	2	0
		Cirratulidae	0	0	1
		Glycinde sp.	0	1	0
		Hesionidae	0	1	0
		Laeonereis culveri	275	321	113
		Nereididae	1,085	858	142
		Nereis succinea	4	2	3
		Stenoninereis martini	0	0	13
		Pectinaria sp.	7	2	0
		Pectinaria gouldi	7	2	7
		Pectinariidae	0	1	0
		Eteone heteropoda	9	2	1
		Paraprionospio pinnata	1	1	3
		Polydora sp.	0	1	0
		Polydora cornuta	14	20	1
		Spionidae	64	33	0
		Streblospio sp.	1,519	682	668
Arthropoda					
	Crustacea				
		Ampelisca sp.	2	0	0
		Ampelisca abdita	5	0	1
		Aoridae	9	10	0
		Grandidierella bonnieroides	65	60	1
		Americorophium ellisi	156	152	10
		Corophiidae	22	25	2
		Hyalella azteca	1	0	0
		Almyracuma proximoculi	13	7	0
		Cyathura polita	1	0	0
		Xenanthura brevitelson	9	8	0
		Edotea triloba	32	15	1
		Americamysis sp.	3	2	0
		Mysidae	0	0	1
		Hargeria rapax	14	61	0
		Parapseudidae	0	1	0
	Insecta				
		Chironomidae	0	0	1
		Tanypus clavatus	2	0	25
Cnidaria					
	Anthozoa				
		Actiniaria	129	170	5
Mollusca					
	Bivalvia				
		Amygdalum papyrium	10	8	0
		Bivalvia	5	17	13
		Mactra fragilis	6	4	0
		Mactridae	2	1	0
		Tagelus plebeius	100	100	4
		Anomalocardia auberiana	2	1	0
		Parastarte triquetra	7	25	0
		Veneridae	1	0	0
	Gastropoda				
		Acteonidae	3	0	0
		Rictaxis punctostriatus	1	0	0
		Gastropoda	0	2	0
		Hydrobiidae	153	199	33
		Odostomia sp.	1	0	0
		Pyramidellidae	1	0	0
Nemertea					
	Nemertea				
		Nemertea	2	0	1
Platyhelminthes					
	Turbellaria				
		Polycladida	0	1	0