5.2.3 Invertebrate Measures

Invertebrates were sampled once each season. Three kinds of communities were assayed: the invertebrates living on the marsh surface, those found in the water column, and those living in the benthos under the water column.

All invertebrate data sets were analyzed using Kolmogorov-Smirnov tests initially. Data sets that were not significantly different under this non-parametric test, and found to be normal or log-normal in distribution, were analyzed using Student's t-tests (any log-normal data were transformed prior to analysis). Where significance was not determined under Kolmogorov-Smirnov tests and the data were not normally or log-normally distributed, Mann-Whitney rank-sum tests were used. Significance for all tests was at $p<0.05$. Test data are provided in the Addendum, pp. 229-232, 240-243, 248-250, and 256. More details regarding the statistical tests are provided in Section 5.1, above.

The Before (pre-treatment) data for Area 1 (an Impact or Treatment area) were from 2003-2004. The control Before (pre-treatment) data Area 1 controls were Area 3 and Area 4 2003-2004 data. Post-treatment (After) data for Area 1 was 2005-2007 data, and its Control post-treatment (After) data were Area 3 and Area 4 data for 2005-2007. The Before (pre-treatment) data for Area 2 (also an Impact or Treatment area) were 2003-2005 data sets. The control Before (pre-treatment) data Area 2 controls were Area 3 and Area 4 2003-2005 data. Post-treatment (After) data for Area 2 was 2006-2007 data, and its Control post-treatment (After) data were Area 3 and Area 4 data for 2006-2007.

5.2.3.1 Marsh Surface Invertebrates

In October 2003, the marsh transect stations were stratified in each area by vegetation type (*Phragmites*, low marsh, and high marsh, based on the overall analysis of the dominant vegetation at each station). A subselection of 26 stations was made using random numbers. The selection was represented as such: one station in *Phragmites* and two stations each in the low and high marsh in Areas 2 and 3; two stations in *Phragmites* and three stations each from the low and high marsh in Areas 1 and 4.

The data for this sampling effort is shown as mean values per Class per Area, in Table 50. The data were highly variable, and greatly affected by large numbers of particular organisms often collected at only one or two stations in one particular Area in a year. This led to inconsistent arrays of data, even without considering any effects that may have been caused by the treatments. In terms of overall abundances, and only considering pre-treatment Area 1 and Area 2 and control site data, Area 2 had the lowest (but most consistent) abundances, while abundances in Area 4 tended to be highest, and also were somewhat consistent. Area 1 and Area 3 cycled between high and low abundances. The class Crustacea accounted for approximately 60 percent of the individual specimens. Arachnida accounted for approximately 20 percent and the remaining 20 percent included Gastropoda and Insecta. Crustacea was dominant in each year, as well. The two dominant organisms captured in Crustacea were an isopod from the family Oniscidae and an amphipod from the family Talitridae.

Table 50. Mean Number of Marsh Surface Invertebrates (by Class, per station)

Class	Year	Area 1 (8 stns)	Area 2 (5 stns)	Area 3 (5 stns)	Area 4 (8 stns)
Arachnida	2003	12.0	7.6	11.0	10.9
	2004	6.9	1.1	2.2	7.6
	2005	0.4	1.1	3.6	0.4
	2006	9.0	0	3.0	11.0
	2007	4.4	6.0	10.4	10.3
Crustacea	2003	55.3	15.4	13.2	45.6
	2004	26.1	18.8	67.6	47.3
	2005	10.0	20.4	55.2	27.6
	2006	20.0	0.6	8.2	30.3
	2007	8.1	3.8	23.0	18.9
Insecta	2003	4.0	3.0	3.8	2.4
	2004	6.8	4.8	20.0	9.3
	2005	4.1	8.0	10.0	5.6
	2006	12.3	2.0	9.0	30.8
	2007	3.5	6.0	12.2	3.4
Gastropoda	2003	9.3	2.1	2.0	8.6
	2004	2.3	2.8	6.4	6.5
	2005	3.0	5.6	4.8	12.1
	2006	2.9	1.1	4.6	4.0
	2007	1.8	1.4	6.4	5.4
Oligochaeta	2003	0	0	0	0
	2004	0	0	0	0
	2005	0	0	0	0
	2006	0	0	0	0
	2007	0.1	0	0	0
Total Organisms	2003	80.5	28.2	30.0	67.5
	2004	42.0	27.6	96.2	70.6
	2005	17.5	35.2	73.6	45.8
	2006	44.1	3.8	24.8	76.0
	2007	17.8	17.2	52.0	37.9

Treatments seemed to cause declines in the number of marsh surface invertebrates (see Table 51). The overall decrease in mean numbers of marsh surface invertebrates Area 1 post-treatment was significant in comparison to pre-treatment and controls post-treatment; however, Area 1 had significantly fewer invertebrates pre-treatment compared to the controls. The decrease in the control areas for Area 1 post-treatment compared to pre-treatment was not found to be significant. For individual classes, the decline in Arachnida was significant in Area 1 compared to the controls, but this finding is mitigated because the control Arachnida increased significantly post-treatment compared to pre-treatment conditions. Crustacea declined significantly post-treatment in Area 1 compared to pre-treatment, and were significantly less than controls post-treatment. The control areas also declined significantly relative to the control areas pre-treatment, but there had not been a significant difference between Area 1 and the controls pre-treatment, so that the change for Area 1 was much greater than that experienced by the controls. There were significant differences between Insecta in Area 1 and its controls pre-treatment, and these still existed post-treatment. The mean number of Insecta increased (but not significantly) for the controls post-treatment, but stayed the same for Area 1. Gastropoda decreased significantly post-treatment for Area 1 relative to pre-treatment levels. Therefore, by one measure or another, each of the classes declined for surface invertebrates in Area 1 following the changes to the marsh, and nearly all of the changes were significant in one way or another. However, significance is diminished because of similar variations in the control sites, or due to significant initial conditions prior to the marsh management.

Table 51. Mean Number of Marsh Surface Invertebrates (by Class, per station)

Class		**Area 1**	**Area 1 controls**	**Area 2**	**Area 2 controls**
Arachnida	Pre-treatment	9.4	12.1	6.8	10.5
	Post-treatment	7.2	13.2	4.1	16.2
Crustacea	Pre-treatment	40.7	44.5	18.2	42.4
	Post-treatment	12.7	26.9	2.2	21.2
Insecta	Pre-treatment	3.1	4.6	3.8	6.2
	Post-treatment	3.1	6.9	3.6	5.7
Gastropoda	Pre-treatment	8.0	5.8	1.5	4.4
	Post-treatment	3.7	4.7	0.7	6.3
Oligochaeta	Pre-treatment	0	0	0	0
	Post-treatment	0.0	0	0	0
Total	Pre-treatment	61.2	67.0	30.3	63.5
	Post-treatment	26.4	51.7	10.6	49.3

In Area 2, the total number of organisms decreased significantly post-treatment, both relative to pre-treatment conditions and in comparison to the control sites post-treatment. The impact of this finding is reduced because there was a significant difference between Area 2 and its control sites before the treatment was made. The decline in Arachnida in Area 2 post-treatment was significant compared to pre-treatment and control conditions. The decrease was similarly significant for Crustacea, although there were significant differences between Area 2 and its controls pre-treatment, and the control Crustacea mean values also declined significantly. The small decreases in Insecta were not significant. Area 2 Gastropoda were significantly less post-treatment compared to the controls, but had also been significantly less post-treatment. However, the mean number of Gastropoda per sample increased in the control areas following treatment, and declined in Area 2 post-treatment. So, again, many measures found significant declines post-treatment for Area 2 post-treatment; again, the overall significance of the findings is reduced due to significant changes in the control areas over the same time period, or significant initial conditions between Area 2 and its controls.

5.2.3.2 Water Column Invertebrates

Tables 52 and 53 display the data for water column invertebrate sampling (note seven stations were sampled in each Area). Eight different classes of invertebrates were represented. Three classes, Insecta, Oligochaeta and Crustacea, accounted for 90 percent of the total individuals captured, with Insecta accounting for the greatest number of organisms.

The tables demonstrate there was large variability in these data. For instance, two-thirds of all Oligochaeta were collected in Area 1 in 2004. All stations in Area 1 that year had Oligochaeta captures and the two dominant families were Naididae and Megascolecidae (approximately equivalent in abundances, accounting for 97 percent of the individuals). However, only one of the families was present at each site (i.e., if there was Naididae captured at one site, no Megascolecidae were captured). Over 90 percent of the organisms collected in Area 2 in 2004 were Insecta, and nearly 40 percent of the Insecta came from only one station. Interestingly, Area 3 also had a high proportion of Insecta in 2004 (nearly 75 percent of all water column invertebrates), but these were found more evenly distributed through the stations. Nearly all of the Insecta in Areas 2 and 3 were from the family Corixidae (water boatman) (note that Insecta

number were also elevated in Area 1 in 2004, nearly all being Corixidae, and nearly 75 percent of the individuals found at one station). In 2007, over 400 Crustacea were collected from Area 1 and Area 4, more than were collected at all other sampling events across the marsh. 350 of these organisms were Ostrocoda, collected at one station in Area 3 and two stations in Area 1. Over three-quarters of all polychaetes were captured in Area 2 and 3 in 2003. Thus, several relatively anomalous data points have the potential to control the overall distribution of the data.

The large number of Oligochaeta found in Area 1 make it seem that Area 1 water column invertebrates declined in numbers post-project, but it may be more accurate to state that Area 1 had low abundances generally compared to the other Areas, especially if the 2004 Oligochaeta and 2007 Crustacea are not factored into the analysis. Except for the Insecta outbreak in 2004, overall Area 2 water column invertebrate abundances did not seem to change much over time, although they were certainly even lower in 2006 and 2007 (post-project).

Table 52. Water Column Invertebrates (Number, by Class)

Class	Year	Area 1	Area 2	Area 3	Area 4
Crustacea	2003	12	17	17	12
	2004	14	25	35	17
	2005	12	7	70	75
	2006	18	1	10	1
	2007	147	15	266	31
Insecta	2003	14	7	20	24
	2004	76	258	99	55
	2005	10	72	46	57
	2006	27	25	71	35
	2007	35	8	97	94
Polychaeta	2003	6	48	66	8
	2004	0	1	4	4
	2005	0	0	0	1
	2006	3	1	0	0
	2007	2	1	0	3
Oligochaeta	2003	8	5	48	1
	2004	480	0	1	1
	2005	0	3	1	0
	2006	20	0	0	0
	2007	0	0	37	95
Anthozoa	2003	0	0	3	5
	2004	0	0	0	0
	2005	0	0	0	0
	2006	0	0	0	0
	2007	0	0	0	0
Gastropoda	2003	0	0	1	1
	2004	4	2	0	0
	2005	0	0	0	0
	2006	0	0	0	1
	2007	3	0	4	2
Entognatha	2003	0	0	0	1
	2004	0	0	0	0
	2005	0	0	0	0
	2006	0	0	0	0
	2007	0	0	0	0
Arachnida	2003	1	2	3	0
	2004	6	1	1	3
	2005	0	4	2	15
	2006	1	3	1	3
	2007	1	1	0	0
Total Organisms	2003	41	79	158	52
	2004	580	287	140	80
	2005	22	86	119	148
	2006	59	30	82	40
	2007	188	25	404	225

Table 53. Mean Number of Water Column Invertebrates (by Class, per station)

Class		**Area 1**	**Area 1 controls**	**Area 2**	**Area 2 controls**
Crustacea	Pre-treatment	1.9	2.9	2.3	5.4
	Post-treatment	8.0	11.0	1.1	11.4
Insecta	Pre-treatment	6.4	7.1	16.0	7.2
	Post-treatment	3.4	9.8	2.4	11.0
Polychaeta	Pre-treatment	0.4	2.9	2.3	2.0
	Post-treatment	0.2	0.1	0.1	0.1
Oligochaeta	Pre-treatment	34.9	1.8	0.4	1.2
	Post-treatment	1.0	3.2	0	4.9
Anthozoa	Pre-treatment	0	0.3	0	0.2
	Post-treatment	0	0	0	0
Gastropoda	Pre-treatment	0.3	0.1	0.1	0.0
	Post-treatment	0.1	0.2	0	0.3
Entognatha	Pre-treatment	0	0.0	0	0.0
	Post-treatment	0	0	0	0
Arachnida	Pre-treatment	0.5	0.3	0.3	0.6
	Post-treatment	0.1	0.5	0.3	0.1
Total	Pre-treatment	44.4	15.4	21.5	16.6
	Post-treatment	12.8	24.8	3.9	27.8

Statistical analyses were only made for Crustacea, Insecta, and the total number of organisms. The decrease in the total number of water column invertebrates in Area 1 was significant, both with respect to pre-treatment conditions and controls areas. Pre-treatment, Area 1 had more water column invertebrates per station than the control areas did. After the alterations, there were fewer water column invertebrates in Area 1 than in the control areas. The numbers of invertebrates per sample increased for the control areas, but decreased over the same time period for Area 1. The changes measured for Crustacea (an increase relative to pre-treatment conditions) and Insecta (a decrease relative to pre-treatment conditions) were not significant.

The same general pattern was found for water column invertebrates in Area 2. Post-treatment, there was a significant decrease in total invertebrates relative to pre-treatment conditions, and Area 2 post-treatment water column invertebrate numbers per station were significantly less than the control areas. However, prior to the alterations, there were more invertebrates in Area 2 per station than had been found in the control areas. Significantly fewer Crustacea and Insecta were found in Area 2 post-treatment compared to the control areas (all other changes in those populations were not statistically significant).

In sum, water column invertebrate sampling were greatly affected by a few samples that contained many more organisms than other samples did. These outlier samples meant that it was

difficult to find statistical significance, even when seemingly large differences in arithmetic mean measures were found. However, it is fairly clear that there was a change in water column invertebrate numbers after the project. Nearly all classes decreased in number in Area 1 and Area 2 post-treatment, but many of the control populations increased over the same time period.

5.2.3.3 Benthic Invertebrates

Benthic invertebrate data are shown in Tables 54 and 55 (again, please note seven stations were sampled per Area, except in Area 2 in 2003, 2004, and 2005 when only 6 stations were sampled). Three cores were taken at each station; the data for each core have been combined to generate a "station" result. Seven classes of organisms were found, although only two Arachnids and Gastropods and only one organism from Anthozoa were found in five years of sampling.

Although Oligochaeta were the most numerous Class sampled from 2003-2006, none were captured in 2007. The Oligochaete data are strongly affected by results from Area 1 in 2004 (204 individuals) and Area 3 in 2006 (284 individuals) (those data account for 75 percent of all the Oligochaete organisms). The Area 1 organisms were from family Naididae, with 50 percent taken from one station (D9). The Area 3 organisms were primarily family Megascolecidae, and 80 percent were all from Station D3. This means that more than half of all the Oligochaeta were from only two samples.

Insecta data were also skewed towards only a few data points. For instance, Chironomidae larvae (midges) were most of the individuals captured in Area 1 in 2005 and 2006. Fully 50 percent of the 2005 captures were from Station D1. In 2006, 80 percent were from Stations D1 and D9. In 2007, nearly all the Insecta captured in Area 3 and Area 4 were Tabanidae larvae – horse flies. Thus, most of the detected Insecta were from three "hatches" of two different insects. This suggests minor changes in sampling timing might have produced very different results without any changes in the underlying ecology.

Overall, all Areas increased in benthic organisms over the time frame following the changes to Area 1 and Area 2. The increases in total organisms were proportional. Thus, the increases in organisms in Area 1 from pre-treatment to post-treatment was nearly two-fold, and a similar increase was found across Areas 3 and 4 over the same time period (2005-2007). For Area 2, the

number of benthic invertebrates per station increased four-fold after the treatments (post 2006), which is exactly what occurred for the Area 3 and Area 4 control stations. This suggests that the changes to the marsh had little effect on the benthic invertebrate community. It is difficult to be too precise, given the patchiness of the data, but polychaetes appeared to be reduced in number generally post-treatment in Areas 1 and 2, without a similar decline occurring in all of the control Areas.

Table 54. Mean Number of Benthic Invertebrates (by Class, per Station)

Class	Year	Area 1	Area 2	Area 3	Area 4
Crustacea	2003	3.7	0.6	0.3	2.8
	2004	0.6	0	3.6	1.3
	2005	0	0	0	3.3
	2006	8.1	0.4	2.6	4.3
	2007	5.0	7.6	20.0	11.3
Insecta	2003	2.1	0.8	0.7	4.4
	2004	6.9	1.0	2.3	4.1
	2005	25.0	0.2	0	0
	2006	33.1	0.3	0.3	9.4
	2007	9.7	7.7	28.5	27.9
Polychaeta	2003	10.9	1.3	9.3	15.1
	2004	1.9	0	0.7	3.0
	2005	1.7	0	0.1	5.0
	2006	24.7	1.1	2.3	9.0
	2007	2.9	0.9	2.4	0.1
Oligochaeta	2003	4.6	0.8	1.3	5.9
	2004	29.6	0	5.6	0.6
	2005	0.6	0.3	0.4	0.6
	2006	0	0	40.6	4.7
	2007	0	0	0	0
Anthozoa	2003	0	0	0	0.1
	2004	0	0	0	0
	2005	0	0	0	0
	2006	0	0	0	0
	2007	0	0	0	0
Arachnida	2003	0	0	0	0
	2004	0	0	0.1	0
	2005	0	0	0	0
	2006	0	0	0	0
	2007	0	0	0	0.1
Gastropoda	2003	0	0	0	0
	2004	0	0	0	0
	2005	0	0	0	0
	2006	0	0	0	0
	2007	0.1	0	0	0
Total Organisms	2003	21.3	3.7	11.7	28.0
	2004	38.9	0.9	12.3	9.0
	2005	27.3	0.5	0.6	8.9
	2006	66.0	1.9	45.7	27.4
	2007	17.7	16.1	51.1	39.4

Table 55. Mean Number of Benthic Invertebrates (by Class, per station)

Class		Area 1	Area 1 controls	Area 2	Area 2 controls
Crustacea	Pre-treatment	2.1	2.0	0.2	1.9
	Post-treatment	4.4	6.9	4.0	9.5
Insecta	Pre-treatment	4.5	2.9	0.7	1.9
	Post-treatment	22.6	11.0	4.0	16.5
Polychaeta	Pre-treatment	6.4	7.0	0.4	5.5
	Post-treatment	9.8	3.2	1.0	3.5
Oligochaeta	Pre-treatment	17.1	3.4	0.4	2.4
	Post-treatment	0.2	7.7	0	11.3
Anthozoa	Pre-treatment	0	0.0	0	0.0
	Post-treatment	0	0	0	0
Arachnida	Pre-treatment	0	0.0	0	0.0
	Post-treatment	0	0.0	0	0.0
Gastropoda	Pre-treatment	0	0	0	0
	Post-treatment	0.0	0.0	0	0.0
Total	Pre-treatment	30.1	15.4	1.7	11.7
	Post-treatment	55.6	28.9	9.0	40.9

In terms of statistical significance, the greater numbers of benthic invertebrates in Area 1 compared to the controls prior to treatment was significant, and so was the greater number in Area 1 compared to controls post-treatment. The increases in average numbers of invertebrates after treatment were not significant. The smaller number of Crustacea post-treatment in Area 1 compared to the controls was significant. The larger number of Insecta in Area 1 post-treatment compared to the controls was significant. The increase in Polychaeta in Area 1 following the treatment, the larger number of Polychaeta per sample compared to the control areas post-treatment, and that there were fewer Polychaeta in Area 1 compared to the control areas were all significant. That there had been a decline in Oligochaeta numbers following the treatment in Area 1, that there were fewer Oligochaeta in Area 1 compared to the control areas post-treatment, that prior to treatment there were more Oligiochaeta in Area 1 than in the control areas, and that following treatment there were more Oligochaeta in the control areas were all significant relations. Therefore, this suggests that although benthic invertebrate numbers increased post-treatment in Area 1, it may not be due to the marsh management project. The project probably increased Polychaeta, may have increased Insecta, probably reduced Oligochaeta, and may have reduced Crustacae in Area 1.

The greater number of benthic invertebrates post-treatment in Area 2 was significant, but so was the increase found post-treatment in the control areas. The increase in Crustacae numbers in Area 2 following treatment was found to be significant. That there were fewer Polychaetes after

treatment in Area 2 compared to the control sites was significant. And that there were fewer Oligochaetes in Area 2 compared to the control sites pre- and post-treatment was significant. Thus, the increased numbers of invertebrates In Area 2 was probably not due to the marsh management project. The project may have increased Crustacae numbers, but also may have decreased Polychaetes.

In general, the large variation in the data and many "outlier" values made determinations of significance difficult, even when there were clear changes in arithmetic means for many of these parameters. Generally, however, benthic invertebrates appeared to increase across the site in the time periods that followed the changes to the marsh.

5.2.3.4 Invertebrate Summary

The material above suggests that marsh surface and water column invertebrate numbers declined in the treatment areas after the project. Although benthic invertebrates increased in the treatment areas post-project, similar increases occurred in the control areas, suggesting an environmental cause for the changes. For the classes of marsh surface invertebrates, the statistical evidence regarding declines were all ambiguous. Water column Crustacea and Insecta appeared to have declined in Area 2 post-treatment, relative to the control sites. Benthic Polychaeta seemed to have increased post-treatment in Area 1, but decreased in Area 2; benthic Crustacea may have increased post-treatment in Area 2, but probably decreased in Area 1; and the treatments in Area 1 may have increased Insecta in Area 1, but decreased Oligochaeta.

The following three tables (Tables 56-58) project the total number of invertebrates present on the marsh at the time sampling occurred. These projections necessarily include a great deal of uncertainty, both based on the variability of the sampling data, and the projection to marsh-wide values from small sampling areas. However, they provide a site-wide context for the data presented above. The data suggest that at least part of the decline in marsh surface invertebrates has to do with environmental conditions (approximately 40 percent of the decrease in total numbers occurred in the control areas, according to the mean values compiled over 2006-2007), although at least some of the decline is probably attributable to changes in conditions in Areas 1 and 2. The total number of water column invertebrates increased after construction. It is clear that water column invertebrate numbers across Area 1 and Area 2 are not responding in a similar

fashion to the similar changes that occurred there. Finally, the number of benthic invertebrates has increased across the marsh post-project. At least part of this appears due to environmental factors, as seen in the increases for Areas 3 and 4 over 2006-2007; but a great deal of the effect is due to the increases in the total number of organisms associated with Area 1. The water column and benthic data are greatly affected by the doubling of available aquatic habitat in Areas 1 and 2 (an overall increase across all four areas of approximately two-thirds) that was associated with the project. Conversely, the change in marsh surface habitat is relatively small (a decrease of 1.3%), and is not important in these calculations given the overall data variability.

Table 56. Total number of marsh surface invertebrates (in millions) (10^6) (based on 30 cm sampling ring diameter)

	2003	2004	2005	2006	2007	2003-2005 Mean	2006-2007 Mean
Area 1	180	90	40	100	40	100	70
Area 2	70	70	70	10	40	80	30
Area 3	40	130	100	30	70	90	50
Area 4	190	200	130	220	110	180	160
Total	490	500	360	360	270	450	310

Table 57. Total number of water column invertebrates (in thousands) (10^3) (based on 1-m sq. area sweep)

	2003	2004	2005	2006	2007	2003-2005 Mean	2006-2007 Mean
Area 1	15	207	22	58	185	81	122
Area 2	41	148	44	31	26	78	29
Area 3	56	50	43	29	144	49	87
Area 4	27	41	76	21	116	48	68
Total	140	450	190	140	470	256	305

Table 58. Total number of benthic invertebrates (in millions) (10^6) (based on 6-cm diameter sampling cone)

	2003	2004	2005	2006	2007	2003-2005 Mean	2006-2007 Mean
Area 1	4	7	15	35	9	9	22
Area 2	1	0.2	0.1	1	9	0.4	5
Area 3	2	2	0.1	9	10	2	9
Area 4	8	2	2	8	11	4	9
Total	15	13	17	53	39	15	46