APPENDIX E – BIOLOGICAL MONITORING

US ARMY CORPS OF ENGINEERS

US DEPARTMENT OF INTERIOR
NATIONAL PARK SERVICE

CAPE HATTERAS NATIONAL SEASHORE
NORTH CAROLINA

ENVIRONMENTAL ASSESSMENT

BEACH RESTORATION TO PROTECT NC HIGHWAY 12
CLEAN WATER ACT 404 AND NPS SPECIAL USE PERMITS
AT BUXTON, DARE COUNTY, NORTH CAROLINA

SEPTEMBER 2015

Nags Head Beach 2011 Nourishment Project

Biological Monitoring Post-Year 2 and Final Report

Prepared for:

Town of Nags Head, Dare County, NC

Prepared by:

CZR Incorporated
Wilmington, NC

and

Coastal Science & Engineering, Inc.
Columbia, SC

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Cover Photos: NHB Station 6 view to the north pre-spring 2010 on top and NHB Station 6 view to the north summer post-Y2 2013 on bottom.

TABLE OF CONTENTS

POST-YEAR 2 AND FINAL EXECUTIVE SUMMARY vi
1.0 INTRODUCTION 1
2.0 METHODOLOGY 1
2.1 Offshore Sample Stations 1
2.2 Beach Sample Stations 2
2.2.1 Relocation of Cape Hatteras National Seashore Southern Control Beach Stations (NSS01-NSS05) 2
2.3 QA/QC Benthic Sorting and Identification 2
2.4 Sediment Sampling 3
2.4.1 Percent Calcium Carbonate Substituted for Percent Organic 3
2.5 Pre- and Post-nourishment Comparative Statistical Analysis 3
3.0 RESULTS 4
3.1 Offshore Control Benthos and Sediment 4
3.1.1 Offshore Control Benthos Pre-nourishment and Post-Y2 4
3.1.2 Offshore Control Sediment Pre-nourishment and Post-Y2 8
3.2 Offshore Borrow Benthos and Sediment 8
3.2.1 Offshore Borrow Benthos Pre-nourishment and Post-Y2 8
3.2.2 Offshore Borrow Sediment Pre-nourishment and Post-Y2 9
3.3 Graphic and Statistical Comparisons for Offshore Stations 9
3.3.1 Offshore Abundance 9
3.3.2 Offshore Taxa Richness and Diversity 21
3.3.3 Offshore Sediment Grain Size 21
3.4 Control Beach Benthos and Sediment 22
3.4.1 Control Beach Benthos and Sediment Pre-nourishment and Post-Y2 22
3.4.1.1 Control Beach Zone A and Zone B Benthos Pre-nourishment and Post-Y2 23
3.4.1.2 Control Beach Zone A and Zone B Sediment Pre-nourishment and Post-Y2 23
3.5 Nourished Beach (Nags Head Beach or NHB) Benthos and Sediment 24
3.5.1 NHB Benthos and Sediment Pre-nourishment and Post-Y2 24
3.5.1.1 NHB Zone A and Zone B Benthos Pre-nourishment and Post-Y2 24
3.5.1.2 NHB Zone A and Zone B Sediments Pre-nourishment and Post-Y2 25
3.6 Graphic and Statistical Comparisons for Beach Stations 25
3.6.1 Beach Abundance. 25
3.6.2 Beach Taxa Richness and Diversity 37

3.6.3. Beach Grain Size 37
4.0 CONCLUSIONS 38
REFERENCES 39
LIST OF PREPARERS 40

LIST OF FIGURES

Figure 1. Benthic and sediment sampling stations for beach and offshore locations with north and easting coordinates for Town of Nags Head beach nourishment project vii

Figure 2. Pie charts of pre-nourishment and post-Y1 and -Y2 abundance by season, group, and percent in offshore control stations ix

Figure 3. Pie charts of pre-nourishment and post-Y1 and -Y2 abundance by season, group, and percent in offshore borrow stations x

Figure 4. Pie charts of offshore borrow percent abundance by group compared to offshore control percent abundance by group on seasonal event basis and on all seasons combined annual basis xi

Figure 5. Pie charts of pre-nourishment and post-Y1 and post-Y2 control beach abundance by season, group, and percent for all stations combined xiii

Figure 6. Pie charts of pre-nourishment and post-Y1 and post-Y2 nourished beach abundance by season, group, and percent for all stations combined xiv

Figure 7. Pie charts of nourished beach percent abundance by group compared to control beach percent abundance by group on seasonal event basis and on all seasons combined annual basis xv

Figure 8. Bar graphs of pre-nourishment and post-Y2 offshore abundance by macroinvertebrate group in borrow stations compared to control stations. 11

Figure 9. Bar graph of pre- nourishment and post-Y2 combined abundance by season for offshore borrow stations compared to control stations 12

Figure 10. Box plots of pre-nourishment and post-Y2 abundance for offshore stations combined by season and by station type. 12

Figure 11. Box plots of pre-nourishment and post-Y2 offshore abundance compared annually by station type 13

Figure 12. Box plots of seasonal mean differences (XpostY2-Xpre) for offshore abundance by station type and for all seasons combined by station type 14

Figure 13. Bar graph of pre-nourishment and post-Y2 offshore total taxa richness combined by season for borrow stations compared to control stations 15

Figure 14. Box plots of pre-nourishment and post-Y2 taxa richness for offshore stations combined by season and by station type.. 15

Figure 15. Box plots of pre-nourishment and post-Y2 offshore taxa richness in all borrow and all control stations 16

Figure 16. Box plots of seasonal mean differences (XpostY2-Xpre) for offshore taxa richness by station type and for all seasons combined by station type 17

Figure 17. Bar graph of pre-nourishment and post-Y2 offshore Shannon diversity indices combined by season for borrow stations compared to control stations 18

Figure 18. Bar graph of average grain size of offshore stations combined by season compared by station type for the pre-nourishment year and post-Y2 18

Figure 19. Box plots of pre-nourishment and post-Y2 grain size (mm) for offshore stations combined by season and by station type 19

Figure 20. Box plots of pre-nourishment and post-Y2 grain size (mm) for offshore stations combined annually by station type 19

Figure 21. Box plots of seasonal mean differences (XpostY2-Xpre) for offshore grain size by station type and for all seasons combined by station type 20

Figure 22. Bar graphs of pre-nourishment and post-Y2 total abundance by station type and macroinvertebrate group, combined nourished beach stations compared to combined control beach stations 27

Figure 23. Bar graph comparison of pre-nourishment and post-Y2 beach total abundance by season between combined nourished and combined control stations 28

Figure 24. Box plots of pre-nourishment and post-Y2 abundance for beach stations by season and by type 28

Figure 25. Box plots of pre-nourishment and post-Y2 beach abundance for nourished and control beach stations combined by type and by each control beach 29

Figure 26. Box plots of seasonal mean differences (XpostY2-Xpre) for Nags Head beach abundance by station type and for all seasons combined by station type 30

Figure 27. Bar graph comparison of pre-nourishment and post-Y2 beach total taxa richness by season between the combined nourished and combined control stations 31

Figure 28. Box plots of pre-nourishment and post-Y2 beach taxa richness combined by season and by station type 31

Figure 29. Box plots of beach taxa richness for pre- nourishment and post-Y2 combined by season and by station type 32

Figure 30. Box plots of seasonal mean differences (XpostY2-Xpre) for Nags Head beach taxa richness by station type and for all seasons combined by station type 33

Figure 31. Bar graph comparison of beach Shannon diversity index values by season between the combined nourished and combined control stations 34

Figure 32. Bar graph of pre-nourishment and post- nourishment year 2 beach grain size by season and station type 34

Figure 33. Box plots of pre-nourishment and post-Y2 beach grain size (mm) grouped by season and by station type 35

Figure 34. Box plots of beach grain size for pre-nourishment and post-nourishment combined by station type and location 35

Figure 35. Box plots of seasonal mean differences (XpostY2-Xpre) for Nags Head beach grains size by station type and for all seasons combined by station type 36

LIST OF TABLES

Table 1 Dates of the 2011 Nags Head Beach Nourishment Project sample events (four pre-nourishment, four post-Y1 (Y1), and four post-Y2 (Y2) seasonal events, E1-E12) vi

Table 2 Seasonal tally of abundance and taxa richness for 2011 Nags Head Beach Nourishment Project events 1 – 12 and by combined annual totals xvii

Table 3 Statistically significant results of all One-Way ANOVAs and t-tests performed on all seasonal pre-nourishment to post-Y1 and to post-Y2 comparisons and all seasons combined comparisons for each station type (offshore borrow, offshore control, nourished beach, control beach) xix

Table 4 Summary of benthic and sediment parameters across four seasonal survey events in the pre-nourishment year, four each in post-Y1 and -Y2, and all four seasons combined for each year 5

LIST OF APPENDICES

Appendix A Taxa Enumerated From Each Pre-, Post-Y1 and -Y2 Benthos Sampling Event by Station Type (Offshore Control, Offshore Borrow, Control Beach, and Nourished Beach)

Appendix B Sediment Analyses Results for Nags Head Beach 2011 Nourishment Project Post-Y2, Pre-nourishment, and Post-Y1 (Performed by Coastal Science & Engineering, Inc.)

Nags Head Beach 2011 Nourishment Project

Post-Year 2 and Final Report

POST-YEAR 2 AND FINAL REPORT EXECUTIVE SUMMARY

As required by North Carolina Department of Environment and Natural Resources (NCDENR)/North Carolina Department of Coastal Management (NCDCM) Permit 45-10 Beach Nourishment Town of Nags Head, four pre-nourishment and eight post-nourishment (four in post-Year 1 [post-Y1] and four in post-Year 2 [post-Y2]) seasonal benthic and sediment sampling events occurred in the following areas shown on Figure 1:

- Nourished beach – 10 stations at Nags Head
- Control beach- five stations at Kitty Hawk and five stations at Cape Hatteras National Seashore
- Offshore borrow- 10 stations in the permitted borrow areas "2" and "3" within US Army Corps of Engineers (USACE) area S1, and
- Offshore control -10 separate stations in the S1 polygon outside of the designated borrow areas

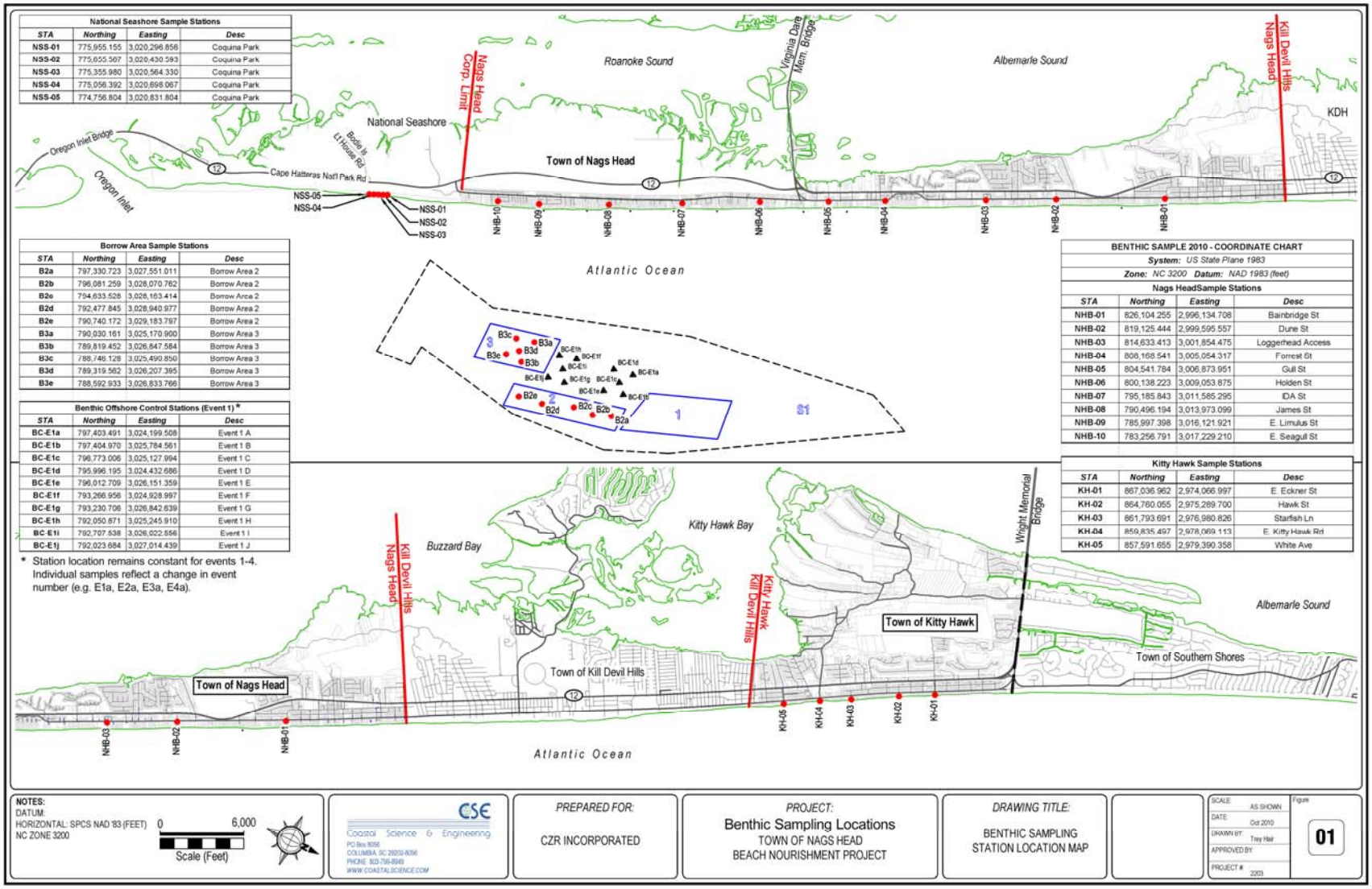
The Nags Head nourished beach (NHB) spans approximately 10 miles. The Kitty Hawk control beach (KH) is located between Kill Devil Hills to the south and Southern Shores to the north and spans approximately 2 miles. The National Seashore control beach (NSS) is located on Bodie Island directly adjacent to the ramp at the Coquina Beach recreation area. The middle NSS sample station is directly adjacent to the Coquina Beach ramp and NSS sampling stations span 0.25-mile.

Each seasonal beach sampling event occurred over a two-day period, during a two-hour window either side of low tide, for a maximum of four hours of possible sample collection. Each beach sample station consisted of an upper-beach swash Zone A and a lower-beach subtidal Zone B. Offshore sample collection was completed in one day with one or two divers deployed from a boat. The weather-dependent nature of safe survey conditions did not always allow for offshore and beach collections to co-occur and the lunar progression of tides did not always allow the eight post-nourishment collection events to occur during the same calendar week as the pre-nourishment events (Table 1).

Table 1. Dates of the 2011 Nags Head Beach Nourishment Project sample events (four pre-nourishment, four post-Y1 (Y1), and four post-Y2 (Y2) seasonal events, E1-E12).

	Spring	Summer	Fall	Winter
Pre-nourishment Events 1 - 4	8-9 June 2010 (E1)	19-20 August 2010 (E2)	17-18 November 2010 (E3)	14-15 April 2011 (E4)
Post-Y1 Events 5 - 8	13-14 & 19 June 2012 (E7)	28-30 August 2012 (E8)	15 December 2011 & 21-22 January 2012 (E5)	6-7 March 2012 (E6)
Post-Y2 Events 9 - 12	4-5 & 12 June 2013 (E11)	20-21 & 22 August 2013 (E12)	27 November & 11-12 December 2012 (E9)	9 April & 26-27 March 2013 (E10)

Figure 1. Benthic and sediment sampling stations for beach and offshore locations with north and easting coordinates for Town of Nags Head beach nourishment project.



GROUP ABUNDANCE

The pie charts of Figure 2 – Figure 7 show the percentage of major taxonomic groups in each event by season and location type (offshore control vs offshore borrow and nourished beach vs control beach) and all seasons combined on an annual basis. Figures 4 and 7 show the pie charts rearranged to compare impact areas (nourished beach and offshore borrow) to their designated controls on a seasonal basis.

OFFSHORE ABUNDANCE

Figure 2 depicts seasonal variability across the offshore control stations as well as variability from before nourishment to post-Y2; however, for most seasons and years, Polychaeta was the dominant group, the exceptions being the first two spring events when Mollusca was dominant. Similar to the offshore control stations, the offshore borrow stations showed a large degree of seasonal variability (Figure 3). Among the offshore borrow stations, post-Y2 spring appears to be the most different from its pre-nourishment counterpart among all post-seasons; at least somewhat due to the large number of razor clams found in the pre-nourishment sample which increased the percent of mollusks for that event. Figure 4 shows a large degree of similarity of dominant groups when the offshore borrow events are compared to offshore controls with a few exceptions: winter pre- (control had no Mollusca); spring post-Y1 (borrow had more Mollusca and less Polychaeta), and winter post-Y1 (control had twice the Polychaeta and almost no Mollusca). However, of particular importance, when all seasons are combined on annual basis, by post-Y2, there was very little difference between dominant groups compared to pre-nourishment.

BEACH ABUNDANCE

Figure 5 depicts seasonal variation across the control beach stations, as well as variation in pre-nourishment and post-Y1 and/or post-Y2 between the same seasons. Pre-nourishment, three fourths of summer and fall groups were from Polychaeta, but those were the only similarities among seasons pre-nourishment. The only similarities among post-Y1 events was that in summer and fall Decapoda were the dominant group at approximately 50 percent; among post-Y2 seasons, the only similarity was between the spring and summer when just over one third of the groups were Amphipoda and just under one fourth were Decapoda. On a seasonal basis across all years for the control beach, post-Y1 and -Y2 fall were similar in Decapoda percentages and pre-winter and post-Y1 winter were similar in Amphipoda percentages. After all seasons are combined, the post-Y2 distribution of species is more evenly distributed than either pre-nourishment or post-Y1. Figure 6 shows seasonal variability across the stations, as well as variability between pre-nourishment, post-Y1, and post-Y2. Slight similarity is shown between summer in both post-years for Decapoda and Amphipoda, but as for the control beach, there is little apparent similarity between either post year for any season compared to pre-nourishment. Figure 7 shows less similarity between NHB and the control beach for the pre-nourishment year than that shown in the offshore groups with two exceptions: NHB had more Decapoda and less Amphipoda in winter (although only slightly so) and spring post-Y1 where both locations were very similar. When all seasons are combined on an annual basis, the two location types (NHB and control) were notably dissimilar pre-nourishment; in fact, only spring post-Y1 was similar when NHB is compared to control beach.

Figure 2. Pie charts of pre-nourishment and post-Y1 and -Y2 abundance by season, group, and percent in offshore control stations.

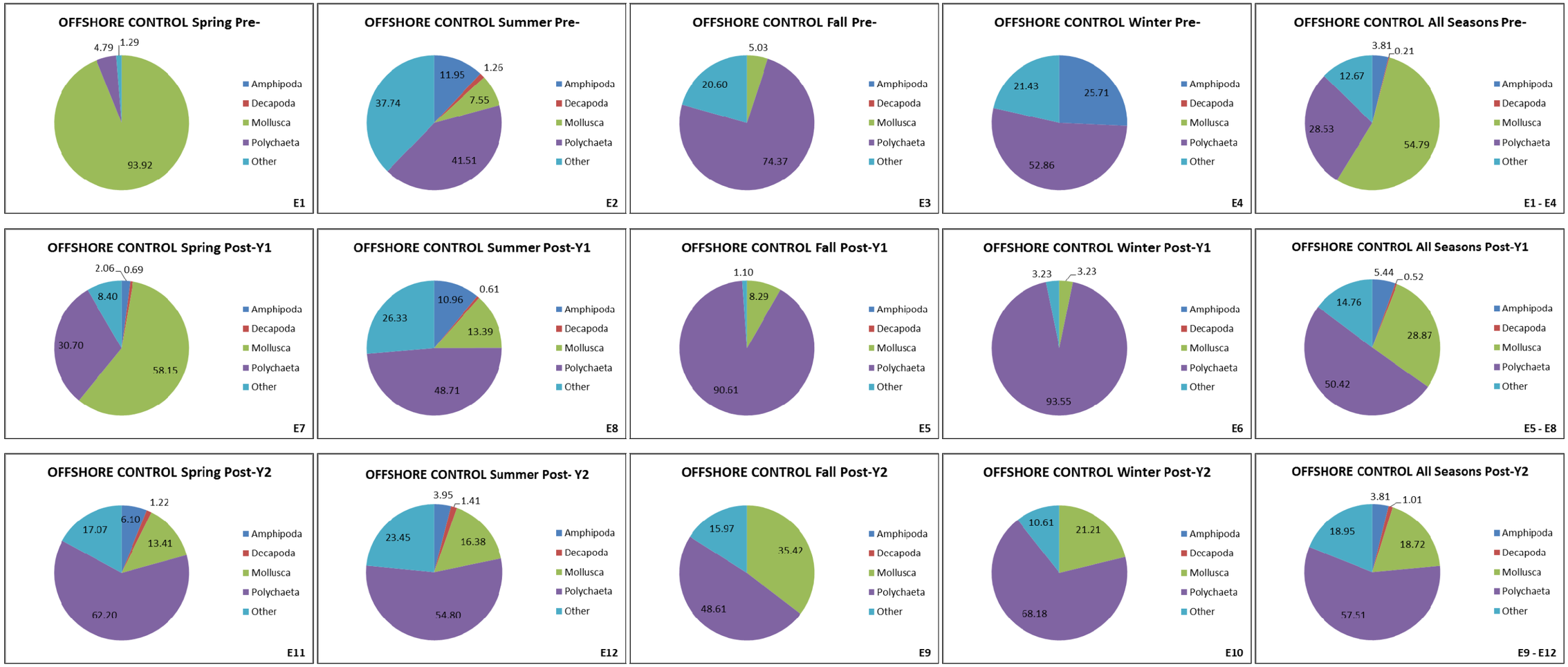


Figure 3. Pie charts of pre-nourishment and post-Y1 and -Y2 abundance by season, group, and percent in offshore borrow stations

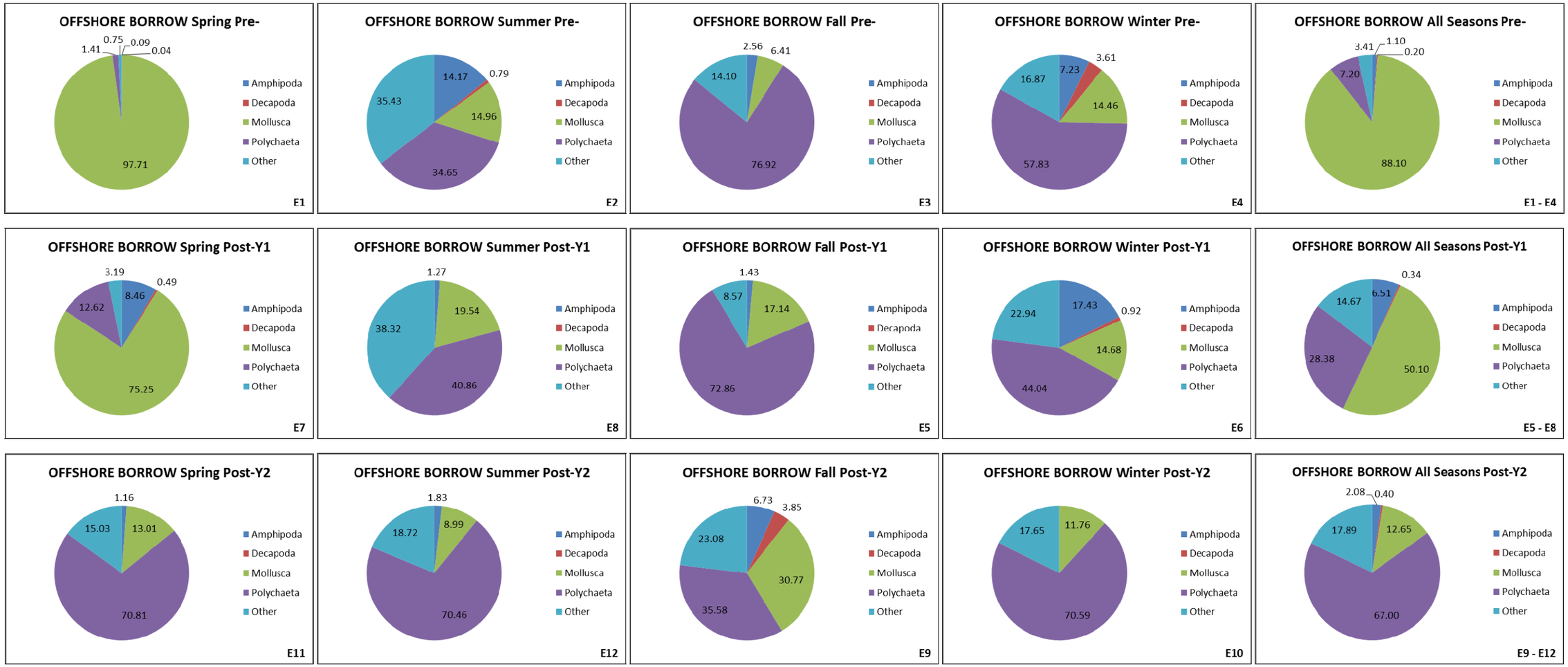


Figure 4. Pie charts of offshore borrow percent abundance by group compared to offshore control percent abundance by group on seasonal event basis and on all seasons combined annual basis.

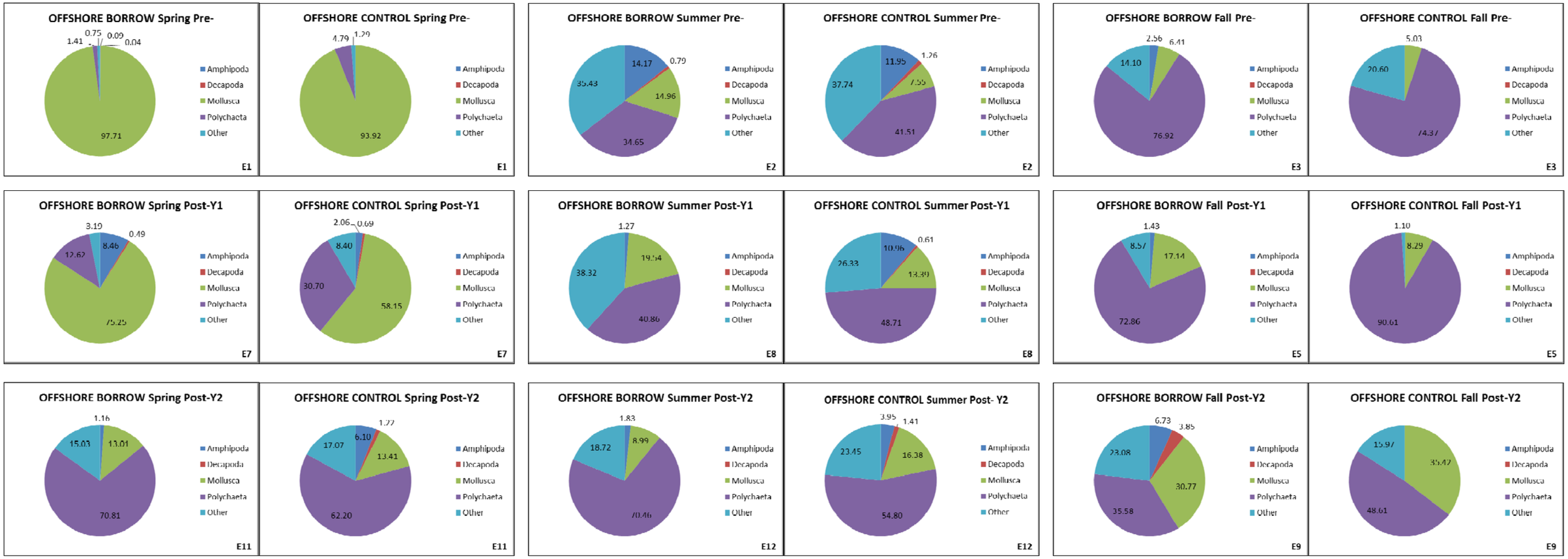


Figure 4. (continued)

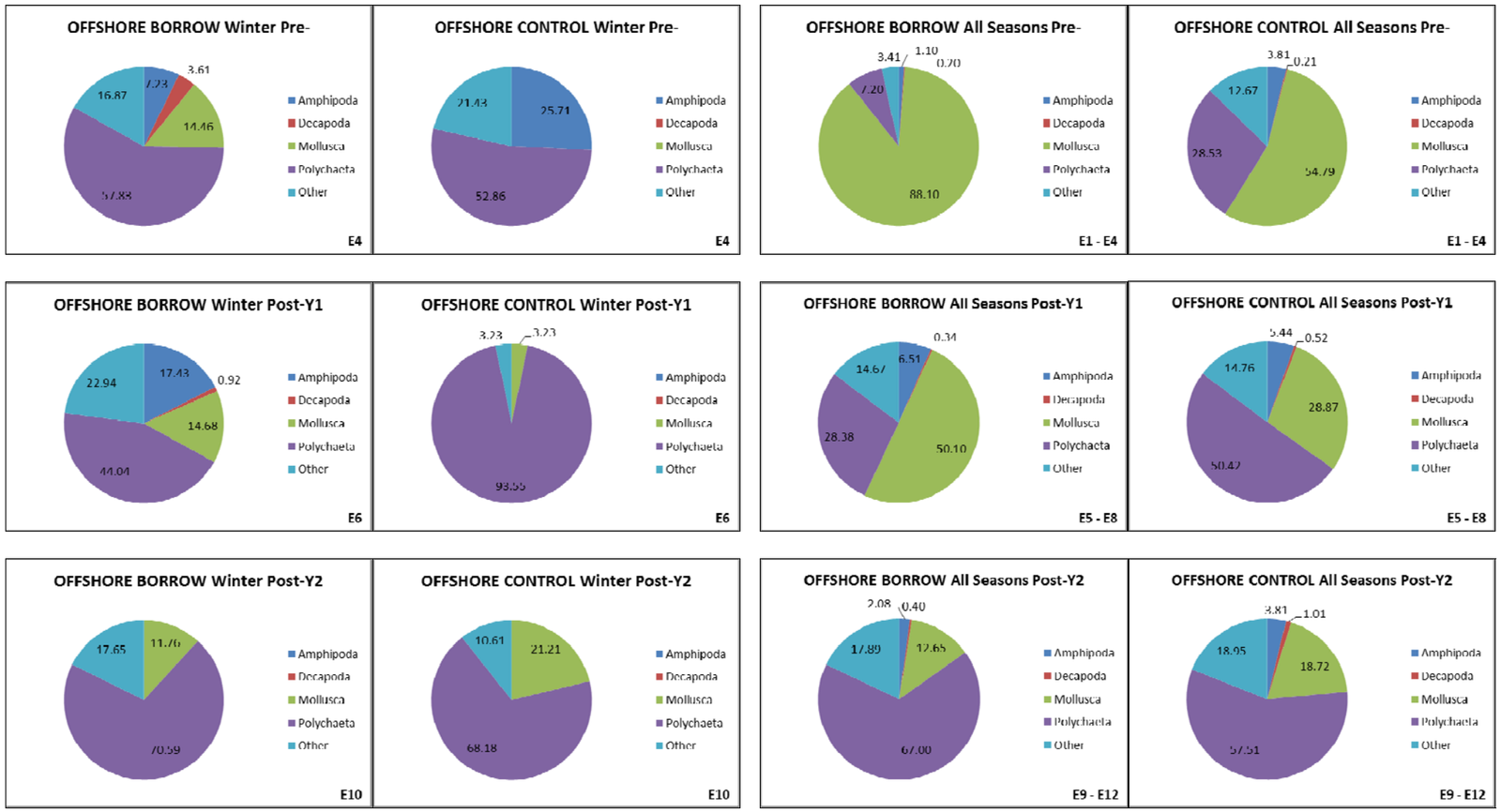


Figure 5. Pie charts of pre-nourishment and post-Y1 and post-Y2 control beach abundance by season, group, and percent for all stations combined.

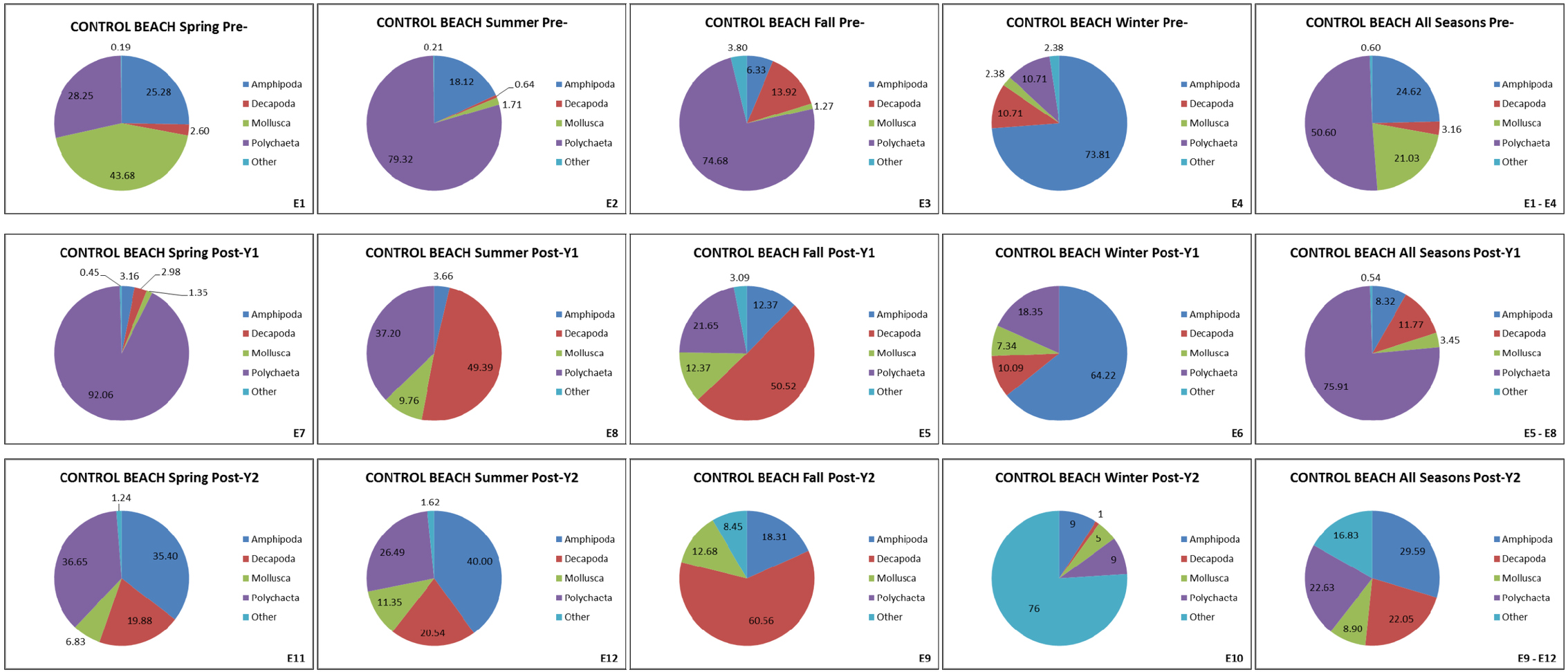


Figure 6. Pie charts of pre-nourishment and post-Y1 and post-Y2 nourished beach abundance by season, group, and percent for all stations combined.

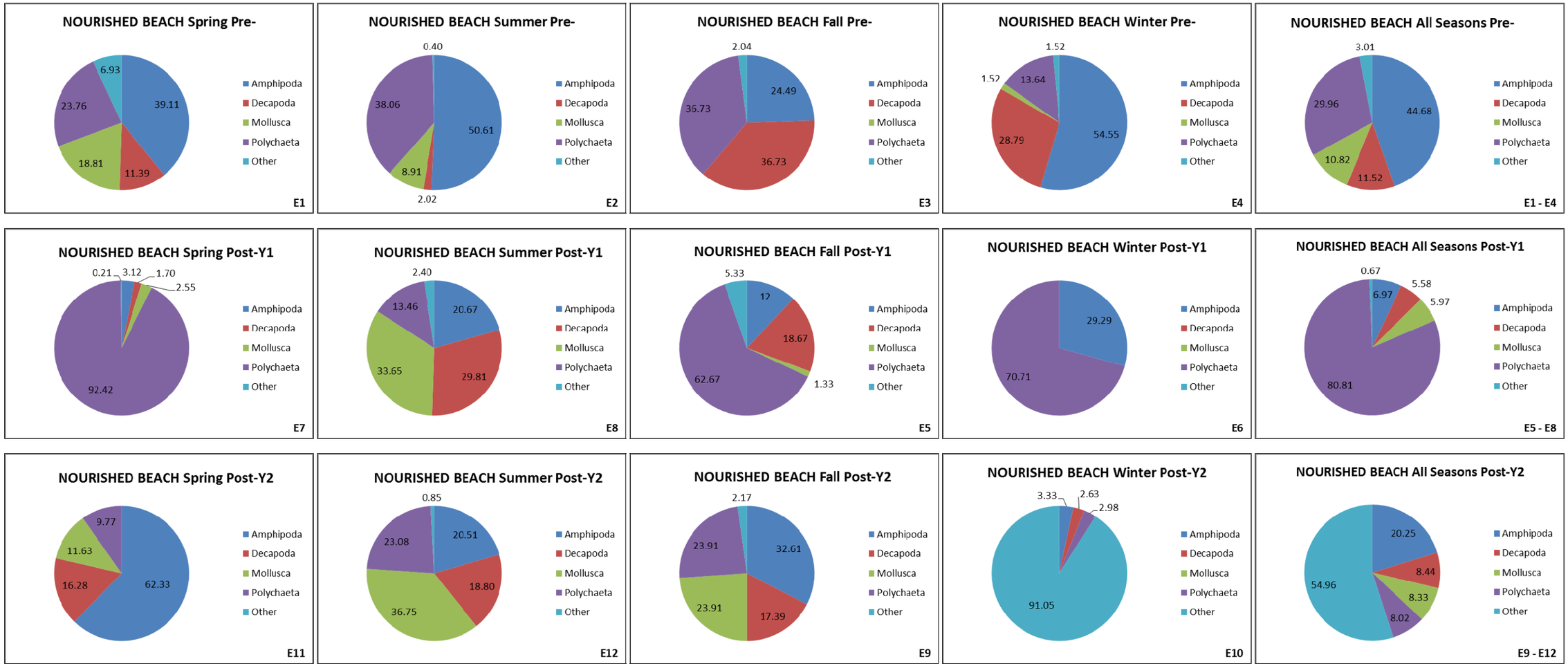


Figure 7. Pie charts of nourished beach percent abundance by group compared to control beach percent abundance by group on seasonal event basis and on all seasons combined annual basis.

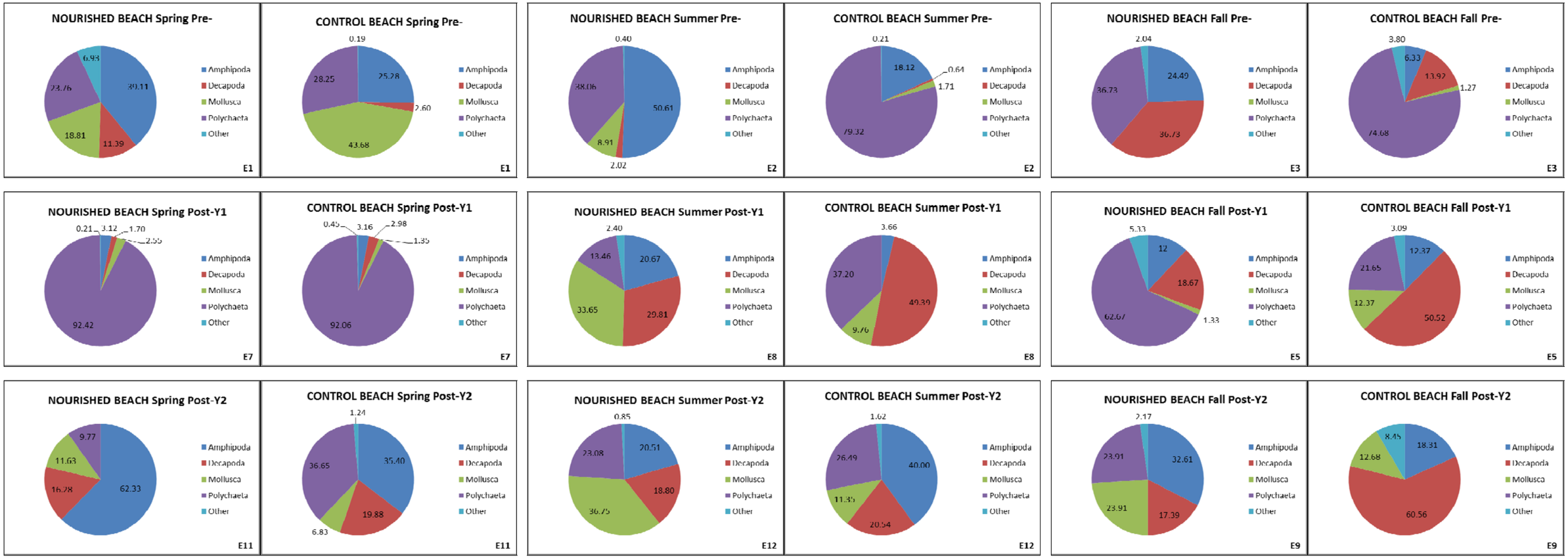
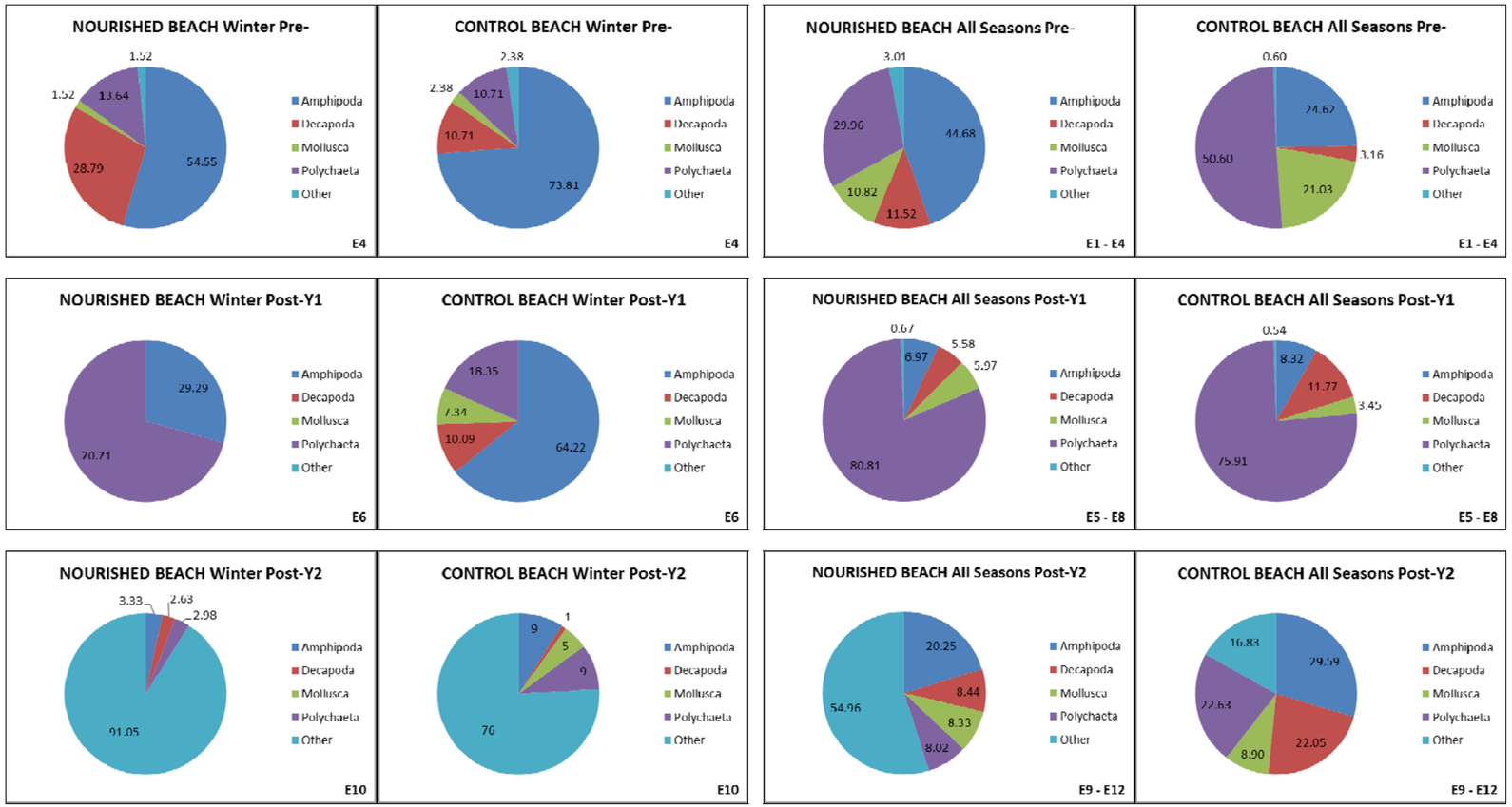


Figure 7. (Continued)



ABUNDANCE AND TAXA RICHNESS

As evident in Table 1, although the 12 events were sequential across the calendar, the first post-Y1 spring event was not the first event to occur post-nourishment. Table 2 shows the seasonal tally for each event by station type and location and all seasons combined on a sequential and an annual basis; the events are color coded by season and station type for visual ease of seasonal comparison.

Seasonally, the post-Y1 and post-Y2 offshore borrow abundances and taxa richness were similar to or exceeded the offshore control pre-year seasons; however, when combined on annual basis, the post-Y2 abundances for both station types were less than the pre-year while taxa richness was similar across all three years.

Variation between the control beach and NHB is shown across most seasons of the pre-year; however, abundances were always less on NHB than the control beach and NHB taxa richness was lower in two of the four pre-seasons. When combined on annual basis for the pre-year, taxa richness for the beaches appears more similar but abundances do not. On an annual basis, when post-Y1 and post-Y2 NHB abundance and taxa richness is compared to control beach, post-Y1 for both NHB and control beach was more diverse and had more abundance that either of the two other years. By post-Y2, NHB abundance was higher and taxa richness was lower than the pre-year NHB while the control beach showed less abundance and the same taxa richness as the pre-year.

STATISTICAL COMPARISONS

Table 3 portrays a condensed version of the following text which summarizes results of comparisons between pre-nourishment data and post-Y1 data and pre-nourishment data and post-Y2 data (by season and with all seasons combined). Richness, abundance, abundance/meter^2, grain size, and mean differences were tested using either t-tests or One-Way ANOVAs so only *statistically* significant results are presented for those parameters. The reader is reminded that a statistically significant difference carries no value judgment on magnitude or biological relevance of the effect. Statistically significant Pearson Product Moment correlations are also summarized below.

OFFSHORE COMPARISON SUMMARY OF PRE-YEAR TO POST-Y1 AND POST-Y2

Taxa richness, abundance (and abundance per square meter), and grain size-

Y1: control station abundance and abundance/meter^2 was significantly higher than pre-nourishment (p=0.009)

Y2: no significant differences on seasonal or annual basis

Mean differences (post minus pre) by station for abundance, taxa richness, and grain size-

Y1: the difference in mean pre- and post-nourishment spring abundances was significantly larger at the borrow sites (post abundances were smaller than pre abundances) than at the control borrow sites (Y1 p=0.031)

Y2: the difference in mean pre- and post-nourishment spring abundances was significantly larger at the borrow sites (post abundances were smaller than pre abundances) than at the control borrow sites (Y2 p<0.001)

Table 2. Seasonal tally of abundance and taxa richness for 2011 Nags Head Beach Nourishment Project events 1 through 12 and combined by annual totals.

BLUE = Fall GREEN = Spring
ORANGE = Winter PURPLE = Summer

PRE EVENTS		Pre-Spring (E1)			Pre-Summer (E2)		Pre-Fall (E3)		Pre-Winter (E4)		Pre-Year Totals		
DATE			8-9 June 2010		19-20 Aug 2010		17-18 Nov 2010		14-15 Apr 2011				
Location		N	Abundance	Richness	Abundance	Richness	Abundance	Richness	Abundance	Richness	N	Abundance	Richness
Beach		40	740	21	716	9	128	10	150	10	160	1,734	30
	Nourished	20	202	18	247	7	49	5	66	8	80	564	22
	Swash	10	102	10	161	7	30	4	50	4	40	343	14
	Subtidal	10	100	14	86	4	19	3	16	6	40	221	17
	Control	20	538	13	469	8	79	8	84	8	80	1,170	20
	Swash	10	359	8	263	6	64	7	41	5	40	727	15
	Subtidal	10	179	10	206	6	15	3	43	6	40	443	15
	Natl Seashore	10	327	11	299	5	56	4	67	6	40	749	15
	Swash	5	293	7	224	5	44	4	35	3	20	596	12
	Subtidal	5	34	7	75	2	12	1	32	5	20	153	9
	Kitty Hawk	10	211	6	170	8	23	5	17	4	40	421	13
	Swash	5	66	4	39	4	20	4	6	2	20	131	8
	Subtidal	5	145	5	131	6	3	2	11	3	20	290	10
Offshore		20	2,809	32	286	42	277	28	153	28	80	3,525	81
	Borrow	10	2,266	18	127	34	78	19	83	20	40	2,554	63
	Control	10	543	22	159	32	199	24	70	13	40	971	61

POST-Y1 EVENTS		Fall Y1 (E5)			Winter Y1 (E6)		Spring Y1 (E7)		Summer Y1 (E8)		Post-Y1 Totals		
DATE			15 Dec 2011 (off) 21-22 Jan 2012 (bch)		6-7 Mar 2012		19 June 2012 (off) 13-14 June 2012 (bch)		28-29 Aug 2012				
		N	Abundance	Richness	Abundance	Richness	Abundance	Richness	Abundance	Richness	N	Abundance	Richness
Beach		40	172	16	208	6	2,519	14	372	14	160	3,271	27
	Nourished	20	75	9	99	2	1,411	10	208	11	80	1,793	19
	Swash	10	63	7	33	2	138	8	93	6	40	327	14
	Subtidal	10	12	4	66	2	1,273	7	115	8	40	1,466	11
	Control	20	97	14	109	6	1,108	9	164	10	80	1,478	21
	Swash	10	74	10	59	4	96	7	103	6	40	332	13
	Subtidal	10	23	8	50	4	1,012	6	61	7	40	1,146	16
	Natl Seashore	10	18	6	94	5	858	7	61	6	40	1,031	15
	Swash	5	12	3	55	3	50	5	22	3	20	139	7
	Subtidal	5	6	4	39	3	808	5	39	5	20	892	13
	Kitty Hawk	10	79	9	15	4	250	5	103	7	40	447	15
	Swash	5	62	7	4	2	46	5	81	5	20	193	11
	Subtidal	5	17	4	11	3	204	3	22	4	20	254	8
Offshore		20	321	16	233	26	1,399	42	1,051	50	80	3,004	82
	Borrow	10	140	14	109	22	816	28	394	33	40	1,459	64
	Control	10	181	10	124	10	583	29	657	33	40	1,545	53

POST-Y2 EVENTS		Fall Y2 (E9)			Winter Y2 (E10)		Spring Y2 (E11)		Summer Y2 (E12)		Post-Y2 Totals		
DATE			27 Nov 2012 (off) 11-12 Dec 2012 (bch)		9 Apr 2013(off) 26-27 Mar 2013 (bch)		4-5 June 2013 (bch) 12 June 2013 (off)		20-21 Aug 2013 (bch) 22 Aug 2013 (off)				
		N	Abundance	Richness	Abundance	Richness	Abundance	Richness	Abundance	Richness	N	Abundance	Richness
Beach		40	117	11	670	12	376	11	302	13	160	1,465	25
	Nourished	20	46	8	570	7	215	7	117	11	80	948	16
	Swash	10	16	4	247	5	168	6	80	9	40	511	12
	Subtidal	10	30	6	323	6	47	4	37	10	40	437	15
	Control	20	71	8	100	6	161	9	185	11	80	517	20
	Swash	10	63	4	80	5	85	6	148	7	40	376	11
	Subtidal	10	8	6	20	4	76	7	37	7	40	141	17
	Natl Seashore	10	60	4	25	5	69	5	118	6	40	272	11
	Swash	5	59	4	16	5	47	3	105	4	20	227	8
	Subtidal	5	1	1	9	2	22	4	13	3	20	45	8
	Kitty Hawk	10	11	6	75	4	92	7	67	9	40	245	17
	Swash	5	4	1	64	3	38	5	43	6	20	149	9
	Subtidal	5	7	5	11	3	54	5	24	6	20	96	15
Offshore		20	248	24	83	12	674	46	899	50	80	1,904	83
	Borrow	10	104	18	17	6	346	34	545	35	40	1,012	60
	Control	10	144	14	66	9	328	29	354	36	40	892	60

N = number of samples per event/year by location

Table 3. Statistically significant results of all One-Way ANOVAs and t-tests performed on all seasonal pre-nourishment to post-Y1 and to post-Y2 comparisons and all seasons combined comparisons for each station type (offshore borrow, offshore control, nourished beach, control beach). (Only 14 of the possible relevant statistical comparisons showed a statistically significant difference, seven were favorable for offshore borrow and/or nourished beach [identified by *] and one was favorable for the combined control beaches, but it was then negated by the unfavorable result in post-Y2.)

OFFSHORE Y1	BEACH Y1	OFFSHORE Y2	BEACH Y2
Abundance&Abundance/meter^2	**Abundance&Abundance/meter^2**	**Abundance&Abundance/meter^2**	**Abundance&Abundance/meter^2**
Seasonal: no significant differences	Seasonal: no significant differences	Seasonal: no significant differences	*Seasonal: Nags Head winter p<0.001(higher post)
Seasons Combined: Control 0.009 (higher post)	Seasons Combined: no significant difference	Seasons Combined: no significant differences	Seasons Combined: Control p=0.013 (higher pre)
Xpost-Xpre Abundance	**Xpost-Xpre Abundance**	**XpostY2-Xpre Abundance**	**XpostY2-Xpre Abundance**
Seasonal: spring 0.031 (borrow had a larger difference-post was lower)	Seasonal: no significant differences	Seasonal: offshore spring p<0.001 (borrow had a larger difference-post was lower)	*Seasonal: winter p<0.001 (Nags Head had a larger difference-post was higher)
Seasons Combined: no significant differences	Seasons Combined: no significant differences	Seasons Combined: no significant differences	*Seasons Combined: Nags Head had slightly larger difference p=0.002
Richness	**Richness**	**Richness**	**Richness**
Seasonal: no significant differences	Seasonal: no significant differences	Seasonal: no significant differences	Seasonal: no significant differences
Seasons Combined: no significant differences	Seasons Combined: Nags Head 0.037 (higher pre)	Seasons Combined: no significant differences	Seasons Combined: Control p= 0.007 (higher pre)
Xpost-Xpre Richness	**Xpost-Xpre Richness**	**XpostY2-Xpre Richness**	**XpostY2-Xpre Richness**
Seasonal: no significant differences	Seasonal: no significant differences	Seasonal: no significant differences	Seasonal: no significant differences
Seasons Combined: no significant differences	Seasons Combined: no significant differences	Seasons Combined: no significant differences	Seasons Combined: no significant differences
Grain Size	**Grain Size**	**Grain Size**	**Grain Size**
Seasonal: no significant differences	*Seasonal: Nags Head fall 0.007 (larger pre)**	Seasonal: no significant differences	Seasonal: no significant differences
Seasons Combined: no significant differences	*Seasons Combined: Nags Head 0.003 (larger pre)**	Seasons Combined: no significant differences	Seasons Combined: no significant differences
*Pre vs Post NH to Borrow: Pre NH and Post Borrow (preNH larger, 0.001)	** See last paragraph Executive Summary	*Pre vs Post NH to Borrow: Pre NH and Post Borrow (preNH larger, <0.001)	
Xpost-Xpre Grain Size	**Xpost-Xpre Grain Size**	**XpostY2-Xpre Grain Size**	**XpostY2-Xpre Grain Size**
Seasonal: no significant differences	Seasonal: no significant differences	Seasonal: no significant differences	Seasonal: winter p<0.001 (Control had slightly larger difference-post higher)
Seasons Combined: no significant differences	Seasons Combined: no significant differences	Seasons Combined: no significant differences	Seasons Combined: no significant differences

Shannon index of diversity for all events combined-

Y1: post-control and post-borrow stations were more diverse (H'=3.1, control/H'=2.8, borrow) compared to pre-nourishment (H'=2.6, control/H'=1.4, borrow)

Y2: the post-control and post-borrow stations were also more diverse (H'=3.7, control/H'=3.3, borrow) compared to pre-nourishment

Shannon index of diversity on seasonal basis-

Y1: summer was most diverse (H'-3.2, pre-borrow/H'=3.1, pre-control; H'=3.0 for post-borrow and post-control)

Y2: summer was also most diverse (H'=3.3, post-borrow/H'-3.7, post-control)

Grain size differences between pre- and post-NHB to pre- and post-offshore borrow-

Y1: pre-NHB was larger than both pre- and post-offshore borrow and post-NHB, but only significantly larger than post-offshore borrow (p=0.001)

Y2: pre-NHB was larger than both pre- and post-offshore borrow and post-NHB, but only significantly larger than post-offshore borrow (p<0.001)

OFFSHORE CORRELATION SUMMARY OF PRE-YEAR AND POST-Y1 AND POST-Y2

Seasonal basis (pre- and post-borrow; pre- and post-control)

Pre: borrow spring and summer richness were negatively correlated with grain size (p=0.0495, 0.011) and summer abundance was also negatively correlated with grain size (0.033); borrow control spring abundance was positively correlated with grain size (p=0.028) and winter richness was negatively correlated with grain size (p=0.046)

Y1: no relevant significant results

Y2: borrow spring (p=0.004) and fall (p<0.001) abundances were significantly positively correlated with richness; winter abundance (p=0.007) and richness (p=0.007) were significantly negatively correlated with grain size; control borrow abundances were significantly positively correlated with richness in every season ($p \leq 0.005$)

Seasons combined (pre- and post-borrow; pre- and post-control)-

Pre: control borrow abundance was positively correlated with control borrow grain size (p=0.027)

Y1: borrow richness was negatively correlated with borrow grain size (p=0.04)

Y2: no relevant significant results

BEACH COMPARISON SUMMARY OF PRE-YEAR TO POST-Y1 AND POST-Y2

Taxa richness

Y1: NHB richness was significantly lower (p=0.037) than pre-nourishment

Y2: NSS/KHB combined was significantly lower than pre-nourishment

Mean difference in taxa richness (post-pre)

Y1: no significant differences on seasonal or annual basis

Y2: no significant differences on seasonal or annual basis

Abundance and Abundance/meter^2-

Y1: no significant differences on seasonal or annual basis

Y2: NHB winter abundance was significantly higher than pre-nourishment (p<0.001) and when the seasons were combined, KHB/NSS combined post abundance was lower than pre-nourishment (p=0.013)

Mean difference in abundance and abundance/meter^2 (post-pre)-

Y1: no significant differences on a seasonal or annual basis

Y2: NHB had a larger difference in mean winter abundances (post-Y2 mean was higher than pre) than KHB/NSS combined (p<0.001)

Grain sizes-

Y1: smallest on NSS control beach, largest on KHB control beach, with NHB grain sizes intermediate but closer to NSS; fall grain size at NHB was significantly smaller (finer) post-Y1 (p=0.007)and when all seasons were combined, NHB was significantly smaller (finer) post-Y1 (p=0.003)

Y2: smallest on NHB, largest on KHB control beach, with NSS control beach grain sizes intermediate and closer to NHB; no significant differences on a seasonal or annual basis

Mean difference in grain size

Y1: no significant differences on a seasonal or annual basis

Y2: the combined KHB/NSS had a larger difference in mean winter grain size (post-Y2 mean was higher than pre) than NHB (p<0.001); there were no significant differences when the seasons were combined

Shannon index of diversity indicated pre-NHB was slightly more diverse (H'=2.0) than pre-control beaches (H'=1.6) and -

Y1: the combined KHB/NSS was slightly more diverse (H'=1.1) than NHB (H'=0.09)

Y2: the combined KHB/NSS was slightly more diverse (H'=2.1) than NHB (H'=1.9)

BEACH CORRELATION SUMMARY OF PRE-YEAR TO POST-Y1 AND POST-Y2

Seasonal basis

Pre: NHB fall richness was positively correlated with grain size (p=0.042); KHB/NSS (combined) fall and winter abundances and winter richness were negatively correlated with grain size (p=0.031, 0.024, 0.004)

Y1: NHB fall abundance was positively correlated with grain size (p=0.049) and winter abundance was negatively correlated with grain size (p=0.002); KHB/NSS (combined) spring and winter abundances and winter richness were negatively correlated with grain size (p=0.043, 0.038, <0.001)

Y2: NHB summer richness was negatively correlated with grain size (p=0.007); KHB/NSS (combined) spring (p<0.001), fall (p=0.001), and winter (p<0.001) abundances were positively correlated with richness and spring richness was negatively correlated with grain size (p=0.002).

Seasons combined

Pre: KHB/NSS (combined) richness was negatively correlated with grain size (p<0.001)

Y1: KHB/NSS (combined) richness was negatively correlated with grain size (p=0.004)

Y2: NHB richness and grain size were just barely not significantly negatively correlated (p=0.053); KHB/NSS (combined) abundance and grain size were negatively correlated (p=0.047)

CONCLUSIONS

Benthic populations on NHB as well as the offshore borrow area are generally not different from control stations and demonstrated viable populations of organisms during the post-Y2 sample events. Seasonal variations dominate the data set whether in the impacted areas or the control areas. Benthic populations typically show abundances considerably higher in spring- or summer- sample events compared to fall-and winter-sample events. The exception was NHB post-Y2 winter event which produced the highest abundance observed during post-Y2 sampling events. Grain size was occasionally significantly correlated with richness and/or abundance, and usually negatively, which means as one number increases, the other decreases. Sediments in the borrow area did not change significantly between pre-nourishment and post-Y2 sample events. Sediments on the sampled section of NHB maintained consistency of ~0.5 mm sand during post-Y2. This reflects the characteristics of the borrow material and the burial of the unusually coarse sediment that dominated the eroding beach prior to the project, resulting in similar conditions to the natural berm in the area. Prior to nourishment, the lower surf zone contained very coarse sand, granules, and pea gravel at many stations, a lag deposit which is more common along eroding beaches(CSE 2005, USACE 2010).

This final and post-Y2 executive summary is to serve as a stand-alone document, or final report summary, as it contains condensed details of all three years' data with supporting graphics and tables. The table and figure numbers run sequentially from the executive summary to the main text of the remainder of this post-Y2 report. More detailed information on an annual basis for post-Y2 can be found in Section 3.0 of this report. Section 3.0 of each of the previous two reports contain specific detailed information for each year: post-Y1 in CZR 2013 and pre-nourishment in CZR 2011.

1.0 INTRODUCTION

This post-nourishment Year 2 (post-Y2) and final report was prepared per NCDENR/NCDCM Permit 45-10 Beach Nourishment Town of Nags Head, in accordance with the benthic monitoring plan proposed and submitted to the Town of Nags Head and regulatory agencies in April 2010 and presents methodology and results from four seasonal pre-nourishment benthic sampling events (spring 2010 – winter 2011) and eight seasonal post-nourishment benthic sampling events (Year 1 [Y1]: fall 2011 – summer 2012 and Year 2 [Y2]: fall 2012 – summer 2013). While some Y1 data are included for comparative purposes in this report, most of this report compares Y2 to the pre-nourishment data. The Y1 data were compared to pre-nourishment data and analyzed in a report submitted to the Town and agencies in July of 2013 (CZR Incorporated 2013). The supporting tables and figures of this report continue forward from the executive summary.

Associated project impacts result from placement of sediment on the beach (nourishment) and from sediment removal from the offshore borrow locations by the dredge operation. Since beach nourishment is the project goal, for the purpose of this report, all sample station data are considered either pre-nourishment (baseline year or pre-) or post-nourishment (post-Y1 or post-Y2).

2.0 METHODOLOGY

2.1 Offshore Sample Stations

Ten (10) borrow stations and 10 control stations were randomly selected within the S1 polygon identified previously by US Army Corps of Engineers (USACE) as an offshore borrow area for Outer Banks beach nourishment projects. The S1 area was further subdivided by Coastal Science and Engineering (CSE) into three polygons designated as potential borrow areas for the Nags Head Beach nourishment project (1, 2, and 3) as shown on Figure 1. These polygons are in approximately 40-50 feet of water. Five random GPS points (within the areas designated and at least 100 feet away from the polygon edge) were generated in the S1-2 polygon (B2a- B2e) and five random GPS points were generated in the S1-3 polygon (B3a-B3e); these 10 points were the offshore borrow stations. Ten (10) randomly generated GPS points were selected in the area outside of and between the three subarea polygons but still within the S1 polygon. Extensive coring and sediment analysis by the USACE and CSE indicated points within this area would serve as the 10 offshore control stations (BCE1a-BCE1j). Tables within Figure 1 contain the GPS coordinates for all sample stations.

Coordinates for all offshore stations were entered into the GPS system on the sampling boat and used to navigate and anchor the boat. Once anchored, a diver used two corers and four caps to collect the required sediment for benthic and grain size analysis (one core each). Sediment was collected with a clear 1.2 cm (0.25 in) thick acrylic tube/core with an approximately 10 cm (4-in) inside diameter and marked with tape at 15 cm (approximately 6 in) from the bottom. A full core up to the 15 cm mark contains approximately 1,180 ml (approximately 5 cups). Samples were collected via this hand-driven corer and secured with sealed caps to create a vacuum and contain sediment. The samples were then gently sieved with a 0.5-mm mesh bucket on the transom of the boat, preserved in 10 percent formalin

with added Rose Bengal, and labeled during navigation between sample stations, boat anchoring, and diver preparation for the next sample collection.

2.2 Beach Sample Stations

Ten (10) nourished beach stations and 10 control beach stations were selected based on proximity to existing beach profile stations, proximity to the beach sampling stations previously used during the CSA South benthic collections for the Town of Nags Head (CSA South 2008), and proximity to public beach accesses. With the exception of the five southern control beach stations (see Section 2.2.1 below), all other beach stations (nourished and northern control) are as shown in the monitoring plan submitted to state resource agencies in April 2010.

Each beach station (control and nourished) was comprised of two low-tide sampling zones, swash Zone A and subtidal Zone B. The sampling window for all beach stations was designated to be no more than two hours either side of the predicted low tide. The low-tide swash Zone A was the area of active wave run-up and the low-tide subtidal Zone B was an undescribed distance seaward but at depths no deeper than knee-height of the biologist. The sediment collector was the same as the corer used for the offshore sample collection. Three cores were collected at random locations in each zone and deposited in a tray. Sediments from these three cores were gently mixed in the tray and then a 1,000 ml Nalgene sample jar was filled, labeled inside and out, and transported to iced coolers.

Upon completion of beach sampling, all benthic beach samples were gently sieved through a 0.5-mm mesh bucket, placed in labeled sample jars, and preserved in 10 percent formalin with added Rose Bengal, and stored in coolers for transport. While care was taken to carefully turn and distribute the fixative throughout the sample, some samples with more than 500 ml of sand resulted in modification of the protocol; larger samples were put into multiple containers to avoid damage to preserved organisms (USEPA 2009).

2.2.1 Relocation of Cape Hatteras National Seashore Southern Control Beach Stations (NSS01-NSS05)

After submittal of the draft benthic monitoring plan in April 2010, further consultation among CSE, CZR, and NC Division of Marine Fisheries determined that the NSS control stations could be moved due to the potential during the course of the study for some, or all, of the NSS beach sampling stations identified in the draft plan to be within restricted access areas as designated by the National Park Service. The stations were moved to the vicinity of Coquina Beach Access Ramp 2 and the spacing between sites was reduced. The revised station locations were set up 100 meters (330 feet) apart with the center station, NSS03, located perpendicular from the Ramp 2 signpost as shown in Figure 1. This change was necessary in order to preserve a high likelihood that the same southern beach control stations could be used for the duration of the monitoring.

2.3 QA/QC Benthic Sorting and Identification

Benthic samples were sorted and identified by CZR; however, for quality control and quality assurance (QA/QC) ten percent of samples were sent to an outside laboratory to re-sort and re-identify (two control beach samples, two nourished beach samples, and two borrow samples). These samples were selected upon completion of the majority of the sorting and identification effort to make best use

of the QA/QC process. The selection methodology of which samples to send to the lab for QA/QC ensured that the benthic ecologist had no pre-knowledge of which samples would be selected. Benthic QA/QC was performed by Cove Corporation (Lusby, MD).

Taxa identified only to genus were not counted when another taxon identified to species shared that genus. Similarly, a taxon identified to a family level or higher was not counted when taxa in that family or group were identified to a lower taxonomic level. Appendix A contains a complete list of taxa identified seasonally from the 20 beach stations and the 20 offshore stations. Meiofauna were noted but not counted and are indicated as such in Appendix A.

2.4 Sediment Sampling

Following the same methodology as described above for benthic samples, a fourth core sample was taken at each beach station zone (40 cores) and a second core sample was taken at each offshore location (20 cores) for sediment analysis. These samples were labeled and sealed in plastic bags and analyzed for grain size and calcium carbonate content.

Sediments collected were analyzed in the CSE lab via standard dry-sieving at 0.5 phi intervals and the results provided to CZR Incorporated in a digital format. Appendix B contains graphic depictions of grain size distribution and other data from each sampling event.

2.4.1 Percent Calcium Carbonate Substituted for Percent Organic

Subsequent to the April 2010 monitoring plan submittal and after the June 2010 sampling event, additional correspondence among CZR, CSE, and NCDCM representatives (Anne Deaton of the Wilmington office and Jeff Warren of the Raleigh office) resulted in a decision to analyze the sediment for percent calcium carbonate by acid digestion for all events as opposed to percent organic content by combustion as specified in the draft plan. Analysis followed ASTM Method D2487 for classification of soils where sieve sizes range from 4.75 mm (US Standard sieve No. 4) to 63 µm (US Standard sieve No. 230) and sediments were categorized by Wentworth's classification (Wentworth 1922).

2.5 Pre- and Post-nourishment Comparative Statistical Analysis

Per the 2010 monitoring plan and contract with the Town of Nags Head, data have been quantitatively compared among sites and over time to evaluate changes in the benthic fauna abundances, diversity indices, species richness, and mean number of species per station before and after nourishment. To detect differences between sites and seasons, one-way ANOVA or other appropriate inferential statistics were performed. When the data failed normality (Shapiro-Wilk), a Kruskal-Wallis One Way Analysis of Variance on Ranks was performed. For the repeated measures beach sampling, each sample measure (three replicates per zone/per event = one sample measure) from the before data set (X_{Bi}) was paired with the sample measure taken for that location in the after data set (X_{Ai}), and the difference between the two time periods was calculated (X_{Ai} - . X_{Bi}). The mean, standard deviation, and sample size for the impact (X_I, S_I, N_I, respectively) and control stations (X_C, S_C, N_C) was calculated from the differences. For the spatially randomized samples in the borrow areas, the individual sample measure (1 replicate = 1 sample measure) was independent among time periods within the delineated impact (X_I and S_I, respectively) and control areas (X_C and S_C), resulting in means

standard deviations within the before and after impact locations (X_{IB} and S_{IB}; X_{IA} and S_{IA}, respectively and; X_{CB} and S_{CB}; X_{CA} and S_{CA}). The difference between the after and before means was calculated for the impact ($X_{IA} – X_{IB} = X_I$) and control ($X_{CA} – S_{CB} = X_C$) locations; the standard deviation of the difference was calculated as the pooled standard deviation of the before and after data at the impact (S_I) and control (S_C) locations. Sample size was calculated conservatively as the average sample size of the before and after time periods for the impact (N_I) and control (N_C) locations (Bergquist and Crowe 2009).

3.0 RESULTS

For ease of future comparison some graphic depictions of benthic data were modeled after previous sampling efforts performed by Versar for the U.S. Army Corps of Engineers (Versar 2006). The "groups" classification used in the Versar reports is not a formal taxonomic classification; class, orders, subphyla, and other formal classifications are retained under the umbrella of "group" for this report as well as for Appendix A. Taxa richness, abundance, number of groups, and diversity indices were calculated. To evaluate the diversity and evenness of all species found, the Shannon Index of diversity was utilized. Values for this index typically range from 1.5 (low diversity) to 3.5 (high diversity).

The timeline of sample events has been provided in Table 1. When results of post-nourishment are considered, as well as comparisons of those data to pre-nourishment it should be remembered that nourishment occurred over the 2011 spring and summer benthic sampling seasons and that the first post-Y1 benthic sampling occurred in fall of 2011 (Event 5). Table 2 is a tally of abundance and taxa richness for all 12 events on a seasonal and combined annual basis. Table 3 provides a summary of all statistically significant comparisons.

For all four post-Y2 events combined, the QA/QC error rate was 7.45 percent on taxonomic identification and 0.36 percent on sorting. Ten percent or below is the widely accepted error rate used by others and followed by Versar in its report(s). Comparison QA/QC data are available upon request.

3.1 Offshore Control Benthos and Sediment

Table 4 provides summary information for all 12 seasonal sampling events considered in this report (four pre- and eight post-nourishment [four Y1 and four Y2]) by season, by station, and combined across annual events. This information and comparison results between pre-data and post-Y2 data are described in the two sections below. Pre- and post-nourishment abundance data by season, group, and percent for the offshore control stations are also depicted in pie charts in Figure 2 for all 12 events. These depictions show seasonal variability across the control stations as well as variability from the pre-nourishment year to post-Y2; however, for most seasons and years, Polychaeta was the dominant group, the exceptions being the first two spring events when Mollusca was dominant.

3.1.1 Offshore Control Benthos Pre-nourishment and Post-Y2

The offshore pre-nourishment sampling events identified 61 taxa from the control stations compared to 60 in post-Y2 (Table 4) The taxa with the highest abundance for pre-nourishment were juvenile Bivalvia sp. (Mollusca) (39 individuals respectively) and post-Y2, the taxa with the highest abundance were *Spiophanes bombyx* (Polychaeta) (80 individuals respectively). The next most abundant

Table 4. Summary of benthic and sediment parameters across four seasonal survey events in the pre-nourishment year, four each in post-Y1 and -Y2, and all four seasons combined for each year.

	Pre-nourishment					Post-Y1					Post-Y2				
	Spring	Summer	Fall	Winter	Combined across events	Fall	Winter	Spring	Summer	Combined across events	Fall	Winter	Spring	Summer	Combined across events
OFFSHORE CONTROL															
Taxa richness	22	32	24	13	61	10	10	29	33	53	14	9	29	36	60
Number of taxonomic groups	8	13	8	5	16	3	3	11	11	12	6	4	7	10	13
Abundance	543	159	199	70	971	181	124	583	657	1,545	144	66	328	354	892
Average taxa per square meter	7,059	2,067	2,587	910	3,156	2,353	1,612	7,579	8,541	5,021	1,872	858	4,264	4,602	2,899
Shannon index of diversity (H')*	1.0	3.1	2.6	2.3	2.6	1.5	1.9	2.2	3.0	3.1	2.3	2.1	3.0	3.2	3.7
Average number of taxa per station	4.4	8.5	4.4	1.9	4.8	2.5	2.1	6.3	7.6	4.6	2.7	1.7	5.8	7.0	4.3
Average grain size (mm)**	0.60	0.58	0.48	0.53	0.55	0.49	0.52	0.48	0.51	0.50	0.53	0.50	0.55	0.54	0.53
Average percent calcium carbonate**	1.8	1.9	1.2	2.3	1.8	1.6	1.6	1.7	1.8	1.7	2.5	1.5	1.4	1.6	1.8
OFFSHORE BORROW															
Taxa richness	18	34	19	20	63	14	22	28	33	64	18	6	34	35	60
Number of taxonomic groups	9	13	10	7	15	8	9	8	9	10	9	3	11	10	14
Abundance	2,266	127	78	83	2,554	140	109	816	394	1,459	104	17	346	545	1,012
Average taxa per square meter	29,458	1,651	1,014	1,079	8,301	1,820	1,417	10,608	4,264	4,742	1,352	221	4,498	7,085	3,289
Shannon index of diversity (H')*	0.8	3.2	2.2	2.8	1.4	1.9	2.7	1.8	3.0	2.8	2.6	1.5	2.9	2.4	3.3
Average number of taxa per station	3.9	6.9	3.0	2.7	4.1	2.5	3.2	5.3	7.3	4.6	2.6	0.8	6.2	7.8	4.4
Average grain size (mm)**	0.50	0.49	0.47	0.45	0.48	0.48	0.43	0.42	0.43	0.44	0.43	0.41	0.44	0.44	0.43
Average percent calcium carbonate**	1.2	1.5	1.3	1.9	1.5	2.0	1.6	1.4	2	1.8	1.4	1.4	1.5	1.7	1.5

Nourishment occurred in spring and summer 2011.

Table 4. (continued)

	Pre-nourishment					Post-Y1					Post-Y2				
	Spring	Summer	Fall	Winter	Combined across events	Fall	Winter	Spring	Summer	Combined across events	Fall	Winter	Spring	Summer	Combined across events
CONTROL BEACH[a]															
Taxa richness	13	8	8	8	20	14	6	9	10	21	8	6	9	11	20
Number of taxonomic groups	5	5	6	5	8	6	4	6	4	8	6	5	5	6	9
Abundance	538	469	79	84	1,170	97	109	1,108	164	1,478	71	100	161	185	517
Taxa per square meter (average of 2 zones)	3,497	3,049	514	546	1,901	631	709	7,202	1,066	2,402	462	650	1,047	1,203	840
Shannon index of diversity (H')*	1.5	0.8	1.3	1.6	1.6	1.8	1.2	0.5	1.5	1.1	1.4	1.5	1.4	1.6	2.1
Swash Zone A	1.5	1.0	1.4	0.9	1.6	1.5	0.8	1.8	0.8	1.7	1.0	1.4	1.1	1.4	1.9
Subtidal Zone B	1.0	1.1	0.6	1.4	1.5	1.7	1.2	0.2	1.6	0.6	1.7	1.1	1.0	1.3	1.8
Average number of taxa per station															
All control stations	2.8	2.1	1.2	1.5	1.9	1.8	1.2	1.9	1.8	1.7	0.8	0.8	1.8	2.1	1.4
Swash Zone A	2.9	2.2	1.8	1.1	2.0	1.8	1.2	2.4	1.5	1.7	0.9	1.1	1.9	2.5	1.6
Subtidal Zone B	2.7	2.0	0.5	1.8	1.8	1.0	1.2	1.4	2.0	1.4	0.6	0.5	1.7	1.7	1.1
KH swash Zone A	2.6	1.4	1.6	0.6	1.6	2.2	0.4	2.2	2.0	1.7	0.4	1.2	2	2.2	1.5
KH subtidal Zone B	2.6	2.4	0.4	1.2	1.7	1.0	0.8	1.0	1.6	1.1	1.0	0.6	2.0	2.0	1.4
NSS swash Zone A	3.2	3.0	2.0	1.6	2.5	1.4	2.0	2.6	1.0	1.8	1.4	1.0	1.8	2.8	1.8
NSS subtidal Zone B	2.8	1.6	0.6	2.4	1.9	1.0	1.6	1.8	2.4	1.7	0.2	0.4	1.4	1.4	0.9
Average grain size (mm)**															
All control stations	1.17	0.79	1.50	0.81	1.07	1.01	0.89	1.00	0.79	0.92	0.95	1.58	0.83	0.68	1.01
Swash Zone A	1.11	0.69	1.04	0.86	0.93	0.95	0.91	0.82	1.05	0.93	1.20	1.38	1.02	0.93	1.13
Subtidal Zone B	1.22	0.89	1.96	0.76	1.21	1.07	0.86	1.17	0.53	0.91	0.70	1.77	0.65	0.44	0.89
KH swash Zone A	1.76	1.07	1.50	1.16	1.37	1.26	1.37	1.22	1.31	1.29	1.90	1.97	1.01	1.41	1.57
KH subtidal Zone B	2.05	1.36	2.95	1.12	1.87	1.81	1.32	1.85	0.75	1.43	0.82	2.35	0.51	0.33	1.00
NSS swash Zone A	0.47	0.32	0.59	0.57	0.49	0.64	0.46	0.42	0.79	0.58	0.51	0.79	1.03	0.45	0.69
NSS subtidal Zone B	0.38	0.42	0.97	0.39	0.54	0.33	0.40	0.50	0.30	0.38	0.57	1.20	0.79	0.55	0.78
Average percent calcium carbonate**															
All control stations	3.3	3.2	4.9	3.8	3.8	2.8	2.8	2.5	4	3.0	2.7	4.4	3.0	3.6	3.4
Swash Zone A	3.6	2.5	4.6	4.5	3.8	3.3	2.7	2	4.7	3.2	3.2	3.9	3.3	3.1	3.3
Subtidal Zone B	3.1	3.9	5.1	3.1	3.8	2.5	2.9	3.1	3.4	3.0	2.3	4.9	2.7	4.2	3.5
KH swash Zone A	3.8	2.8	4.2	3.1	3.5	3.2	2.8	2.7	3.5	3.1	4.1	4.3	4.1	3.1	3.9
KH subtidal Zone B	4	5	2.6	3.2	3.7	2.9	4.2	3.8	4.8	3.9	2.2	5.5	2.1	2.4	3.1
NSS swash Zone A	3.3	2.2	5	5.9	4.1	3.4	2.6	1.3	5.9	3.3	2.3	3.5	2.5	3.0	2.8
NSS subtidal Zone B	2.1	2.7	7.6	3	3.9	2.0	1.6	2.3	1.9	2.0	2.3	4.2	3.3	6.0	4.0

Nourishment occurred in spring and summer 2011.

Table 4. (concluded)

	Pre-nourishment					Post-Y1					Post-Y2				
	Spring	Summer	Fall	Winter	Combined across events	Fall	Winter	Spring	Summer	Combined across events	Fall	Winter	Spring	Summer	Combined across events
NOURISHED BEACH[b]															
Taxa richness	18	7	5	8	22	9	2	10	11	19	8	7	7	11	16
Number of taxonomic groups	6	4	4	5	8	5	2	5	6	8	5	4	4	5	6
Abundance	202	247	49	66	564	75	99	1411	208	1,793	46	570	215	117	948
Taxa per square meter (average of 2 zones)	1,313	1,606	319	442	920	488	644	9,172	1,352	2,914	299	3705	1,398	761	1,541
Shannon index of diversity (H')*	2.3	1.3	1.4	1.5	2.0	1.3	0.6	0.6	2.0	0.9	2.0	1.0	1.4	2.0	1.9
NHB Swash Zone A	1.9	1.0	1.1	1.0	1.6	1.1	0.7	1.3	1.2	1.6	1.3	1.1	1.2	1.8	2.0
NHB Subtidal Zone B	2.0	1.1	0.6	1.3	1.9	1.1	0.6	0.2	1.8	0.6	1.8	0.7	1.3	1.8	1.6
Average number of taxa per station															
All NHB stations	3.9	2.2	1.0	1	2.0	1.1	0.7	2.3	1.5	1.4	1.0	1.7	2.2	2.3	1.8
NHB Swash Zone A	3.3	2.5	1.0	0.9	1.9	1.3	0.7	2.3	1.2	1.4	0.7	1.8	2.6	2.6	1.9
NHB Subtidal Zone B	4.4	1.9	1.0	1.0	2.1	0.8	0.6	2.3	1.8	1.4	1.3	1.5	1.8	2.0	1.7
Average grain size (mm)**															
All NHB stations	0.73	0.85	0.89	0.68	0.79	0.49	0.48	0.55	0.55	0.52	0.50	0.55	0.62	0.42	0.52
NHB Swash Zone A	0.84	1.04	0.76	0.7	0.83	0.59	0.52	0.65	0.61	0.59	0.69	0.50	0.69	0.45	0.58
NHB Subtidal Zone B	0.62	0.67	1.02	0.66	0.74	0.40	0.45	0.44	0.49	0.45	0.31	0.60	0.54	0.39	0.46
Average percent calcium carbonate**															
All NHB stations	3.1	3.4	3.7	3.8	3.5	1.9	1.6	2.5	2.3	2.1	3.2	2.2	2.5	1.9	2.5
NHB Swash Zone A	3.5	3.6	4.1	3.5	3.7	2.1	1.3	2.4	2.4	2.1	3.7	1.8	2.6	2.1	2.6
NHB Subtidal Zone B	2.7	3.1	3.3	4.1	3.3	1.8	1.8	2.6	2.2	2.1	2.6	2.5	2.4	1.8	2.3

Nourishment occurred in spring and summer 2011.

[a] Control beaches: KH=Kitty Hawk NSS=National Seashore
[b] Nourished beach: NHB=Nags Head
* Shannon diversity index H'=Index commonly used to characterize species diversity in a community. Shannon's index accounts for both abundance and evenness of the species present. Values for this index typically range from 1.5 (low diversity) to 3.5 (high diversity).
** Mean calculated from seasonal totals

taxa for the offshore control stations were *Ensis directus* in the pre-nourishment year and *Bivalvia sp.* (Mollusca) in post-Y2 (123 and 67 individuals respectively).

Taxa richness for the 10 control stations across events varied between 13 and 32 with an average of 4.8 taxa per station for the pre-nourishment samples and between 9 and 36 with an average of 4.3 per station for post-Y2. A total of 16 groups and 971 individuals were identified from the pre-nourishment samples compared to 13 groups and 892 individuals for the post-Y2 samples. When all sampling events were evaluated for diversity on an annual basis, the Shannon diversity index value (H') was 2.6 for the pre-nourishment year and 3.7 for post-Y2.

In both sample years, summer had the highest taxa richness with 32 taxa identified pre- and 36 taxa post-Y2. The highest pre-nourishment abundances occurred in spring with 543 individuals, while the highest abundance post-Y2 occurred in the summer (354) followed closely by Y2-spring abundance of 328. Summer was the season with the most number of groups present for both the pre-year (13) and the post-Y2 (10). For both sample years, summer had the highest average number of species and the highest Shannon score (H') with 8.5 taxa and H' = 3.1 in the pre- and 7.0 taxa and H' = 3.2 in the post-Y2.

3.1.2 Offshore Control Sediment Pre-nourishment and Post-Y2

The pre-nourishment offshore control sediment sample means ranged from 0.34 mm during fall to 0.75 mm during spring with an average of 0.55 mm (coarse sand) while post-Y2 means ranged from 0.39 mm in winter to 0.97 mm in spring with an average of 0.53 mm. The fall pre-nourishment sediment samples had the lowest average grain size (0.48 mm) while the winter season was lowest post-Y2 (0.50 mm). The spring pre-nourishment season had the highest seasonal average (0.6 mm) as did spring for post-Y2 (0.55 mm). Percent calcium carbonate per station ranged from 3.7 percent during the winter to 0.8 percent during the fall for the pre-nourishment and ranged from 0.9 in winter and spring to 6.0 percent during fall post-Y2. The annual average of percent calcium carbonate was 1.8 for both years.

3.2 Offshore Borrow Benthos and Sediment

Table 4 provides summary information for all 12 seasonal sampling events (four pre- and eight post-nourishment [four Y1 and four Y2]) by season, by station, and combined across all seasonal events. This information and comparison results between pre-data and post-Y2 data are described in the two sections below. Pre-nourishment and post-Y2 abundance data by season, group, and percent for the offshore borrow stations are depicted in pie charts in Figure 3. Similar to the offshore control stations, there is a large degree of seasonal variability. Post-Y2 spring appears to be the most different from its pre-nourishment counterpart among all post-seasons; at least somewhat due to the large number of razor clams found in the pre-nourishment sample which increased the percent of mollusks for that event.

3.2.1 Offshore Borrow Benthos Pre-nourishment and Post-Y2

Within the offshore borrow stations 63 taxa were identified during the pre-nourishment year compared to 60 taxa in post-Y2 (Table 4). The most abundant taxa were in the Mollusca group for the pre-nourishment year, *Ensis directus* (1,532 individuals) and Bivalvia sp. juv (688 individuals). During post-Y2 the most abundant taxa were *Polygordius jouinae* (Polychaeta) (260 individuals). Similar to offshore control samples, taxa richness ranged from 18 to 34 taxa per season with an average richness of 4.1 taxa per station in the pre-nourishment year compared to 6 to 35 taxa per season with average richness of 4.4 per

station for post-Y2. The number of groups ranged from 7 to 13 in the pre-nourishment year and from 3 to 11 in post-Y2. Total groups pre-nourishment was 15 while in post-Y2 the total number of groups was 14. The Shannon's index of diversity (H') for all pre-nourishment events combined was 1.4, which was considerably lower than the combined post-Y2 score of 3.3.

Taxa richness was highest in the summer for both years with little difference between years (34 pre-nourishment compared to 35 in post-Y2). Abundance was highest in the spring in pre-nourishment year with 2,266 individuals (1,532 of which were *Ensis directus*) compared to 545 individuals in post-Y2 summer.

3.2.2 Offshore Borrow Sediment Pre-nourishment and Post-Y2

The offshore borrow sediment sample means ranged in size from 0.31 mm in summer to 0.76 mm in fall with an average of 0.48 mm (medium sand) in the pre-nourishment year compared to a range of 0.27 mm in winter to 0.58 mm in fall with an average of 0.43 mm (medium sand) in post-Y2. Average grain size was lowest during winter (0.45 mm) and highest during the spring (0.5 mm) in the pre-nourishment year, lowest during winter (0.41 mm), and highest during spring and summer (0.44 mm) in post-Y2. Seasonal differences were small in all years. The percent calcium carbonate ranged from 0.7 in spring to 2.4 in winter in the pre-nourishment year and from 0.9 in the fall to 2.9 in the summer and fall of post-Y2. The annual average percent for calcium carbonate was 1.5 for all borrow stations in both years.

3.3 Graphic and Statistical Comparisons for Offshore Stations

Figure 4 depicts pie charts of major taxonomic groups collected in the offshore borrow stations compared to offshore control stations by season and by all seasons combined annually. This rearrangement shows a large degree of similarity of dominant groups when the offshore borrow events are compared to offshore controls with a few exceptions: winter pre- (control had no Mollusca); spring post-Y1 (borrow had more Mollusca and less Polychaeta), and winter post-Y1 (control had twice the Polychaeta and almost no Mollusca). However, when all seasons are combined on annual basis, by post-Y2, there was little difference between dominant groups compared to pre-nourishment.

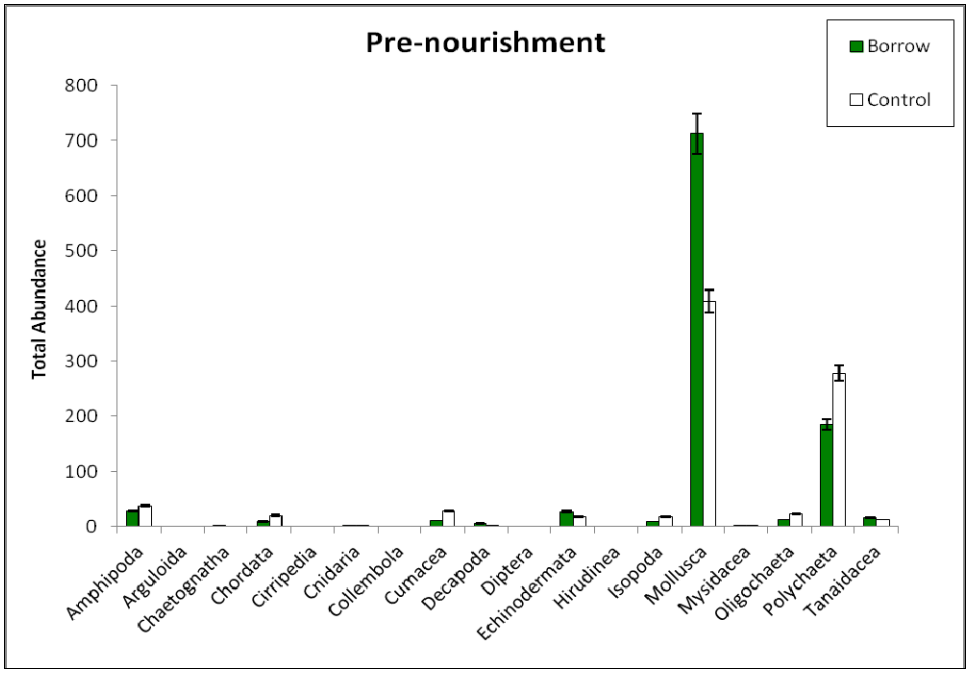
Table 3 lists all statistically significant results of all one-way ANOVAs and t-tests performed on all seasonal pre-nourishment/post-Y2 comparisons and all seasons combined pre-nourishment/post-Y2 comparisons for each station type. Various comparisons of abundance, tax richness, diversity, and sediment data for pre-nourishment and post-Y2 offshore stations are depicted in bar graphs and box plots and are described in the three subsections below (Figures 8 – 21). These graphical depictions present the data shown in Table 4 plus additional data in different combinations.

3.3.1 Offshore Abundance

Figure 8 shows that total abundance in all the offshore stations was dominated by the same two groups (Mollusca and Polychaeta) in the pre-nourishment year and in post-Y2; however, in post-Y2, there was a slight increase in abundance in three additional groups (Echinodermata, Chordata, and Oligochaeta) in both station types. Polychaeta were dominant in post-Y2 for both station types while Mollusca were higher during pre-nourishment. Figure 9 is a bar graph display of offshore abundance combined by type and by season for pre-nourishment and post-Y2. Post-Y2 fall abundance is higher than pre-fall in the borrow stations and lower in the control stations. Post-Y2 winter abundance is lower than pre-winter in both the borrow stations and the control stations. Pre-spring abundance was higher for both station types than post-Y2. Summer post-Y2 abundance was higher for both station types than pre-

summer. Spring and fall were the pre-nourishment seasons with the highest abundances at the control stations compared to spring and summer for the borrow stations; for post-Y2, spring and summer had the highest abundances for both station types. Seasonal similarities in offshore abundance were observed for both station types during winter pre-nourishment and spring post-Y2. (Text continues on Page 21.)

Figure 8. Bar graphs of pre-nourishment and post-Y2 offshore total abundance by macroinvertebrate group in borrow stations compared to control stations, minus 1,532 *Ensis directus* found in the borrow stations during spring pre-nourishment event. Error bars depict +/- 0.5.



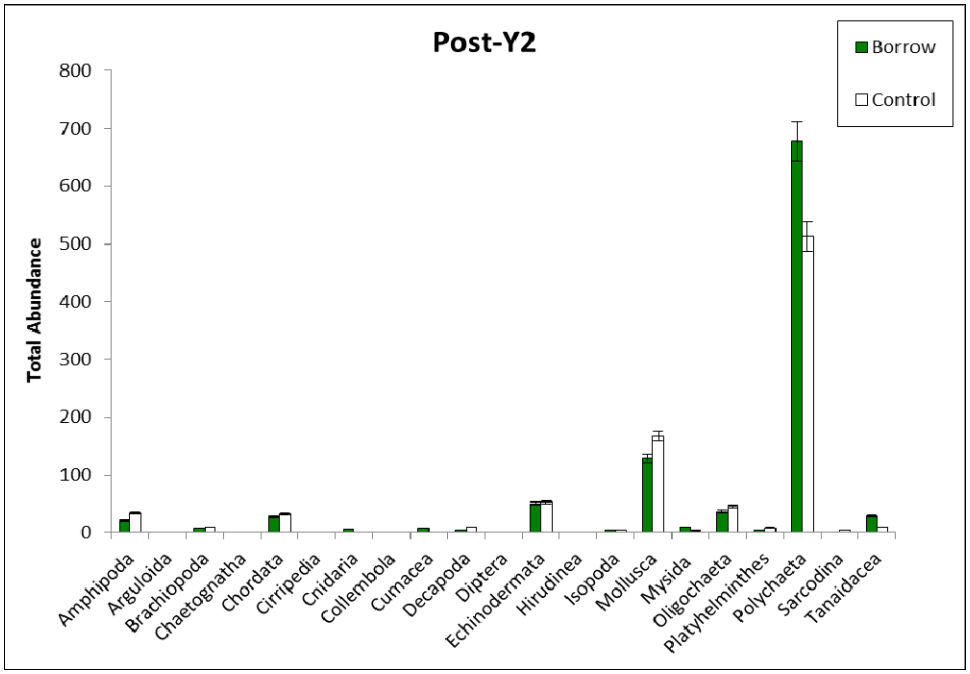


Figure 9. Bar graph of pre-nourishment and post-Y2 total abundance by season for offshore borrow stations compared to control stations. Due to extremely high abundances, 1,532 *Ensis directus* (razor clam) have been removed from the pre-nourishment spring offshore borrow data. Seasonal sample events are shown in the order they occurred. Error bars depict +/-0.5.

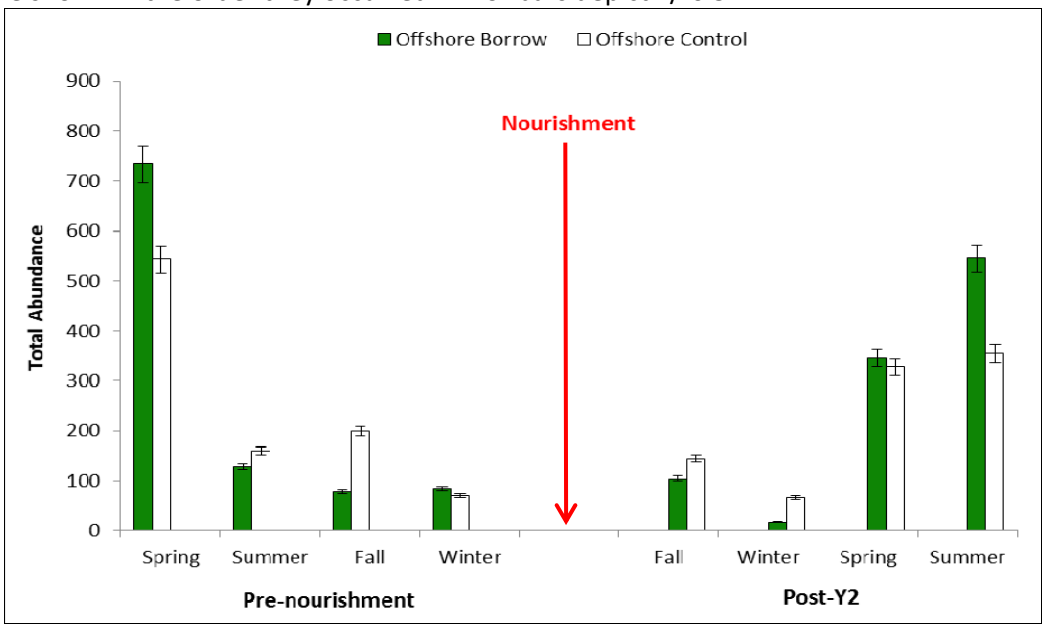


Figure 10. Box plots of pre-nourishment and post-Y2 abundance for offshore stations combined by season and station type. Due to extremely high abundances, 1,532 *Ensis directus* (razor clam) were removed from the spring borrow pre-nourishment event. The box boundary closest to zero is the 25th percentile, the box boundary farthest from zero is the 75th percentile, and the error bars are the 10th and 90th percentiles. Values shown above and below the error bars are singular data points outside of the 10th or 90th percentile. The solid line shown is the median; the dashed line is the mean.

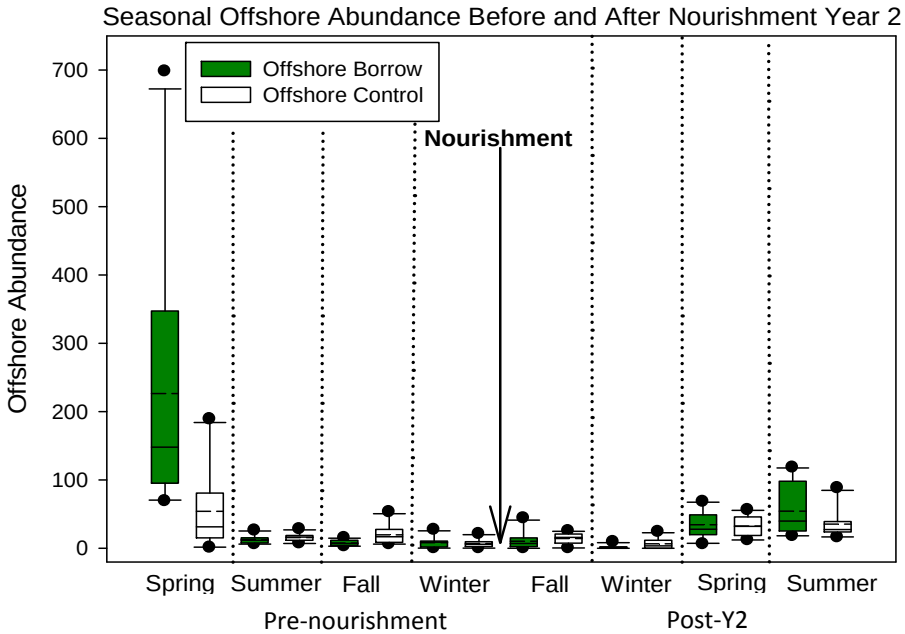


Figure 11. Box plots of pre-nourishment and post-Y2 offshore abundance compared annually by station type. Due to extremely high abundances, 1,532 *Ensis directus* (razor clam) were removed from the spring borrow pre-nourishment event. The box boundary closest to zero is the 25th percentile, the box boundary farthest from zero is the 75th percentile, and the error bars are the 10th and 90th percentiles. Values shown above and below the error bars are singular data points outside of the 10th or 90th percentile. The solid line is the median; the dashed line is the mean.

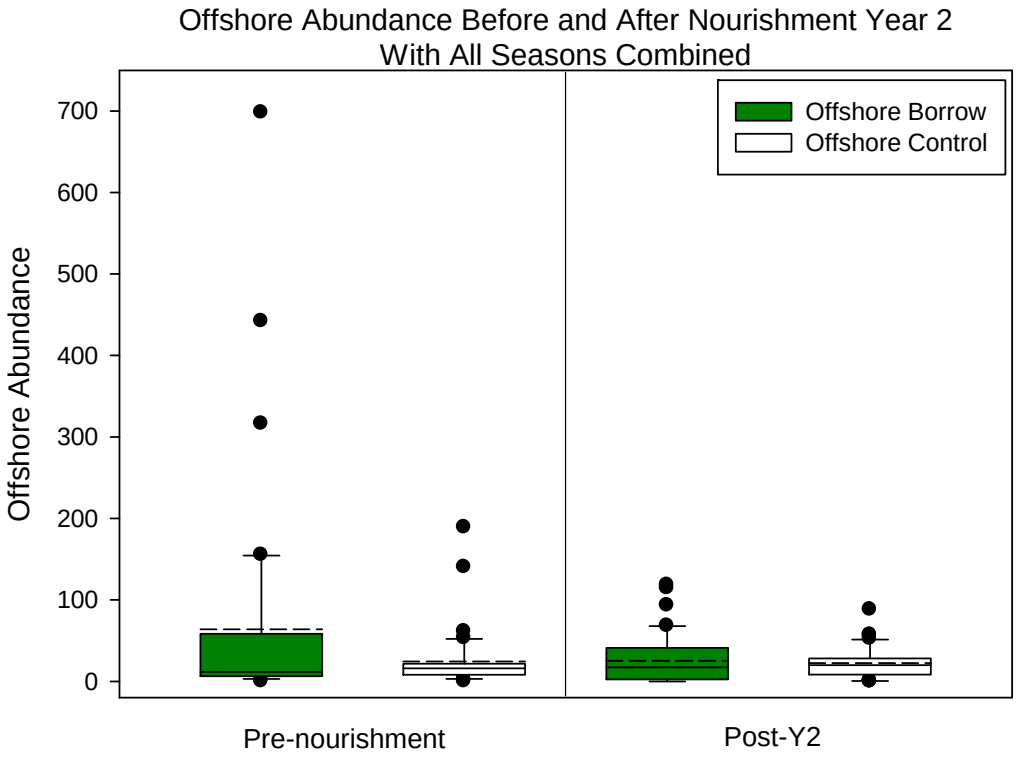
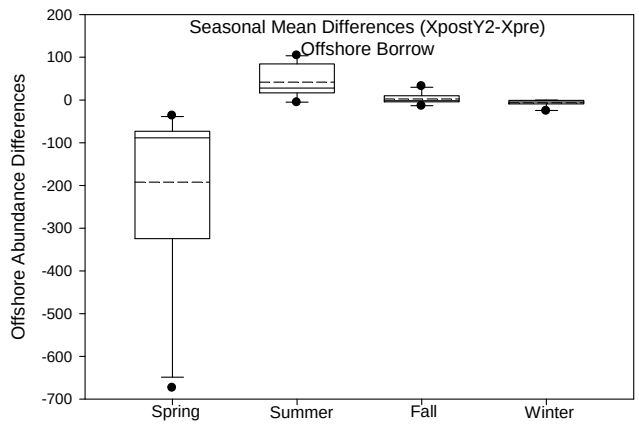
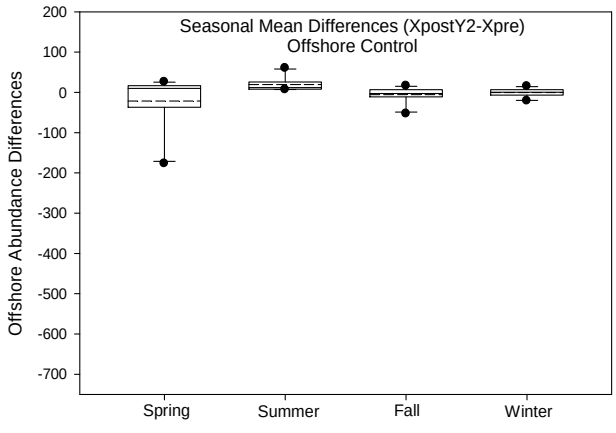


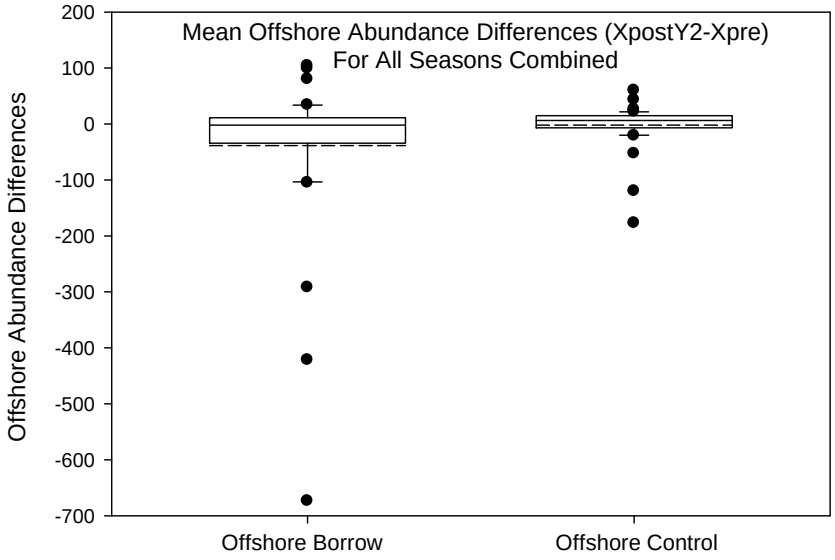
Figure 12. Box plots of seasonal mean differences (XpostY2-Xpre) for offshore abundance by station type and for all seasons combined by station type. The box boundary closest to zero is the 25th percentile, the box boundary farthest from zero is the 75th percentile, and the error bars are the 10th and 90th percentiles. Values shown above and below the error bars are singular data points outside of the 10th or 90th percentile. The solid line is the median; the dashed line is the mean. Spring mean differences were statistically significantly different (p<0.001)



a)



b)



c)

Figure 13. Bar graph of pre-nourishment and post-Y2 offshore total taxa richness combined by season for borrow stations compared to control stations. Error bars depict +/-0.5.

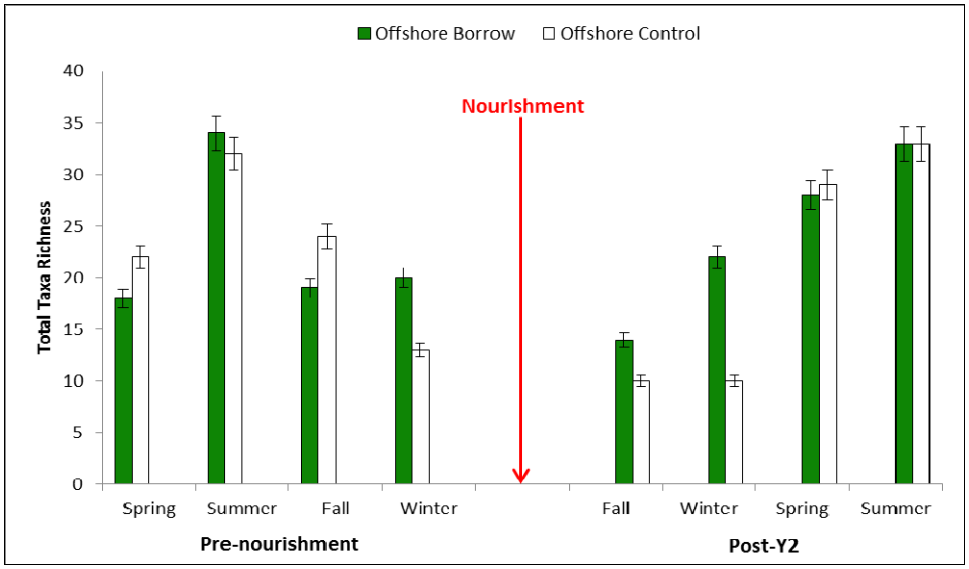


Figure 14. Box plots of pre-nourishment and post-Y2 taxa richness for offshore stations combined by season and by station type. The box boundary closest to zero is the 25th percentile, the box boundary farthest from zero is the 75th percentile, and the error bars are the 10th and 90th percentiles. Values shown above and below the error bars are singular data points outside of the 10th or 90th percentile. The solid line is the median; the dashed line is the mean.

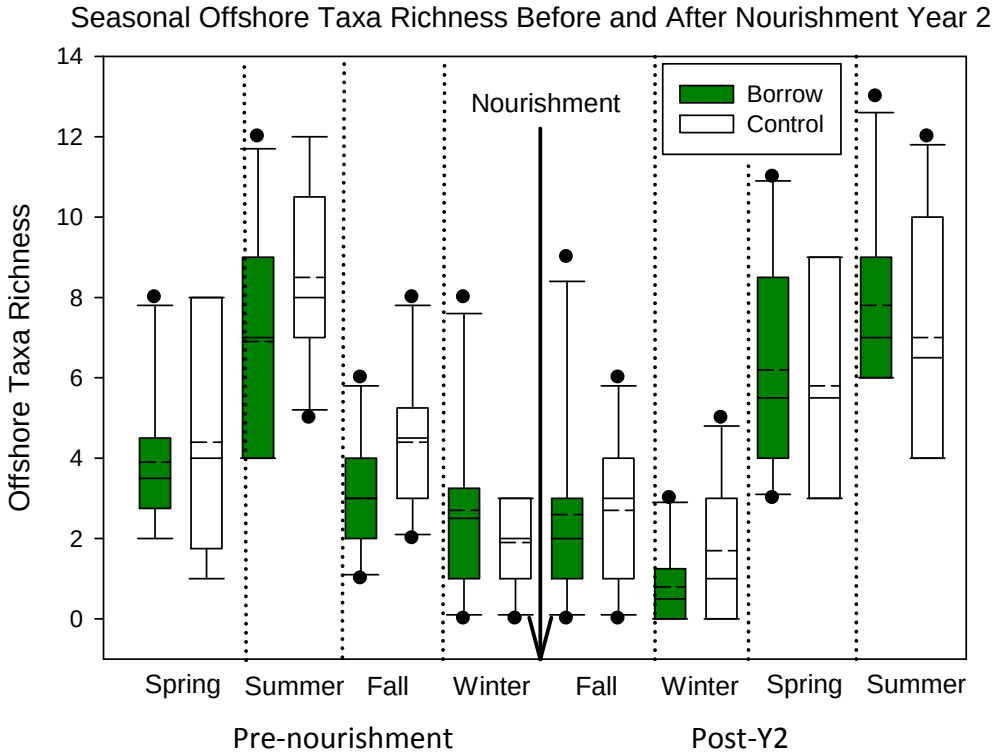


Figure 15. Box plots of pre-nourishment and post-Y2 offshore taxa richness in all borrow and all control stations. Borrow and control boxes represent all seasonal sampling events combined. The box boundary closest to zero is the 25th percentile, the box boundary farthest from zero is the 75th percentile, and the error bars are the 10th and 90th percentiles. Values shown above and below the error bars are singular data points outside of the 10th or 90th percentile. The solid line is the median, the dashed line is the mean.

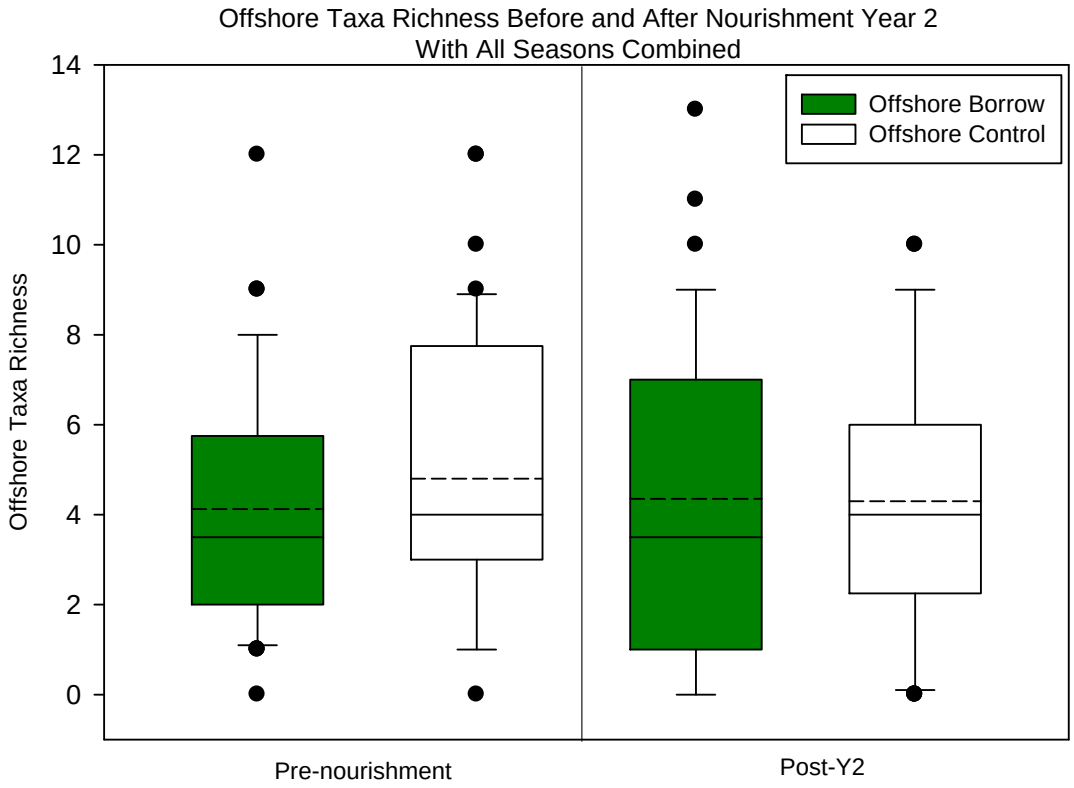


Figure 16. Box plots of seasonal mean differences (XpostY2-Xpre) for offshore taxa richness by station type and for all seasons combined by station type. The box boundary closest to zero is the 25th percentile, the box boundary farthest from zero is the 75th percentile, and the error bars are the 10th and 90th percentiles. Values shown above and below the error bars are singular data points outside of the 10th or 90th percentile. The solid line is the median, the dashed line is the mean.

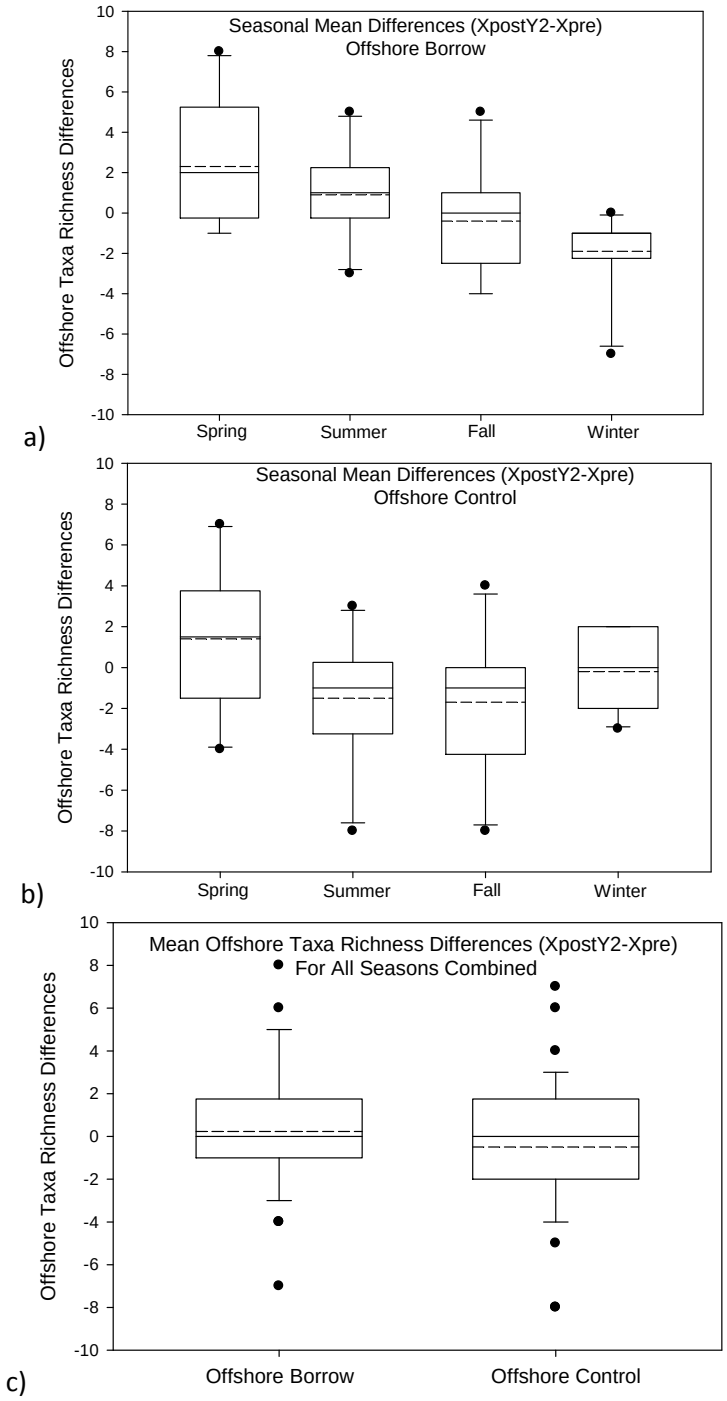


Figure 17. Bar graph of pre-nourishment and post-Y2 offshore Shannon diversity indices combined by season for borrow stations compared to control stations.

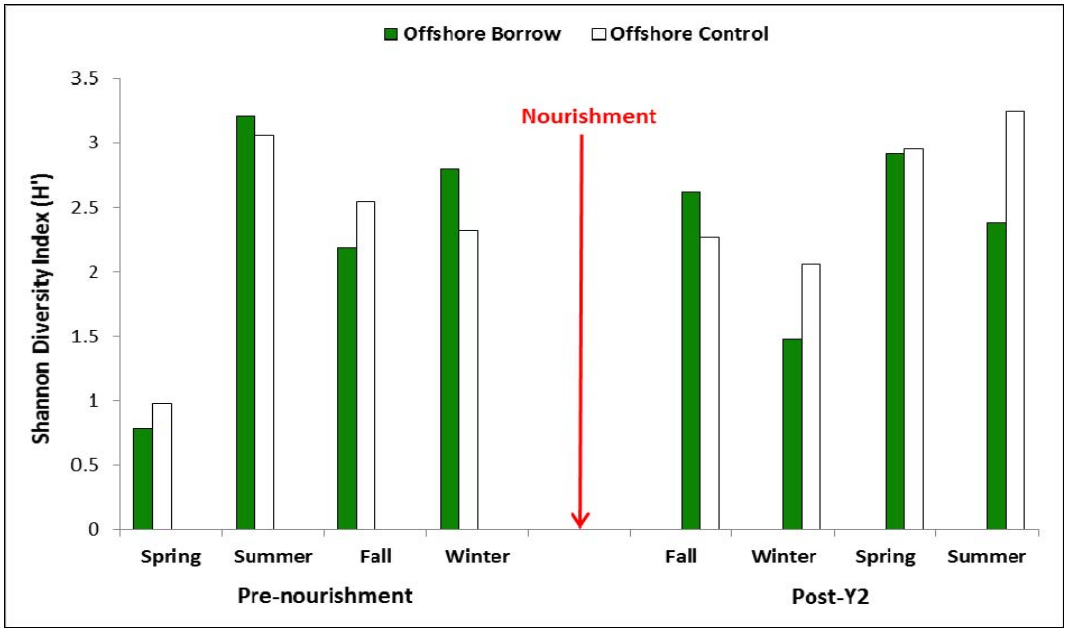


Figure 18. Bar graph of average grain size of offshore stations combined by season compared by station type for the pre-nourishment year and post-Y2.

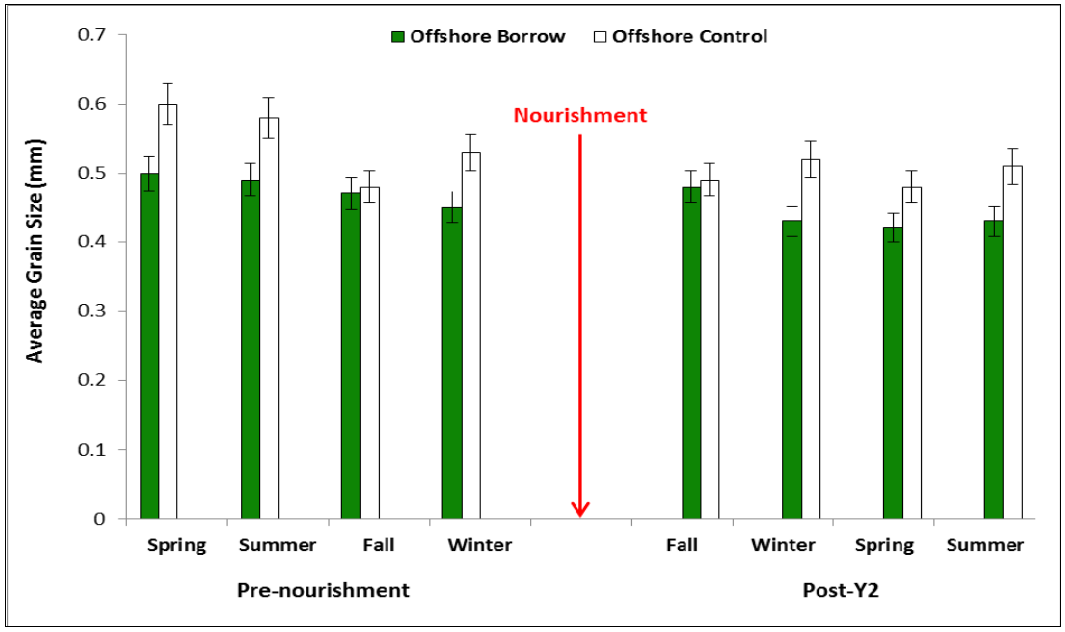


Figure 19. Box plots of pre-nourishment and post-Y2 grain size (mm) for offshore stations combined by season and by station type. The box boundary closest to zero is the 25th percentile, the box boundary farthest from zero is the 75th percentile, and the error bars are the 10th and 90th percentiles. Values shown above and below the error bars are singular data points outside of the 10th or 90th percentile. The solid line is the median; the dashed line is the mean.

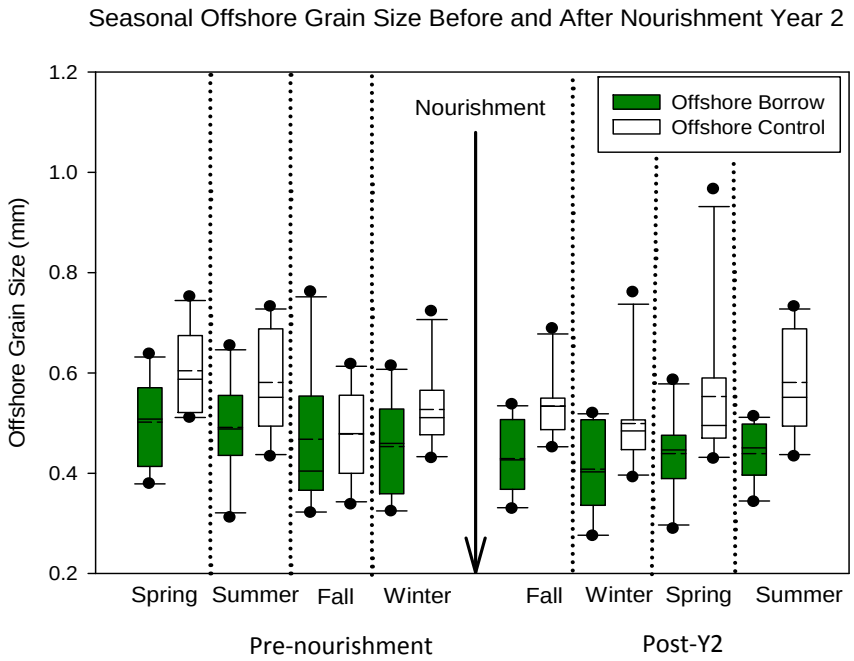


Figure 20. Box plots of pre-nourishment and post-Y2 grain size (mm) for offshore stations combined annually by station type. The box boundary closest to zero is the 25th percentile, the box boundary farthest from zero is the 75th percentile, and the error bars are the 10th and 90th percentiles. Values shown above and below the error bars are singular data points outside of the 10th or 90th percentile. The solid line is the median; the dashed line is the mean.

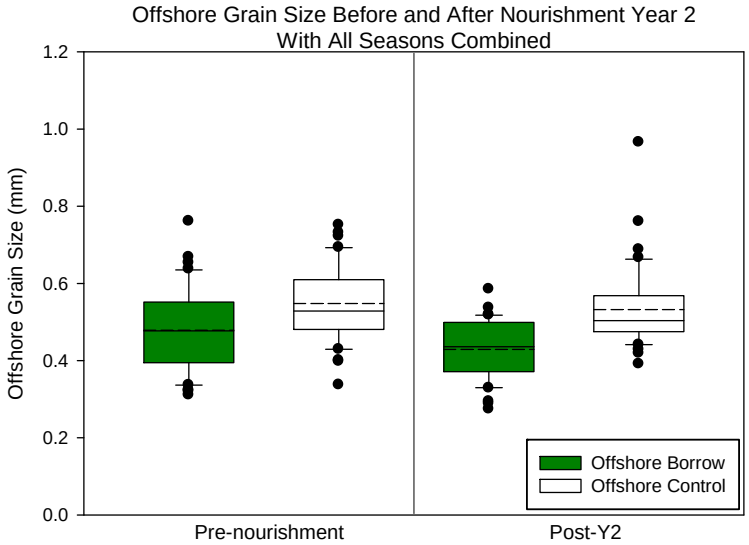
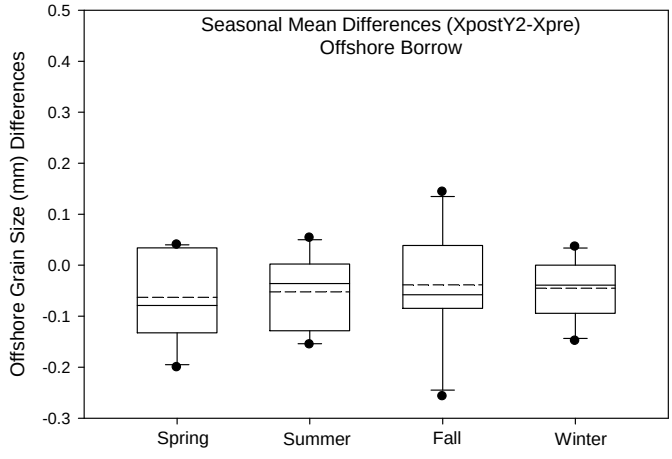
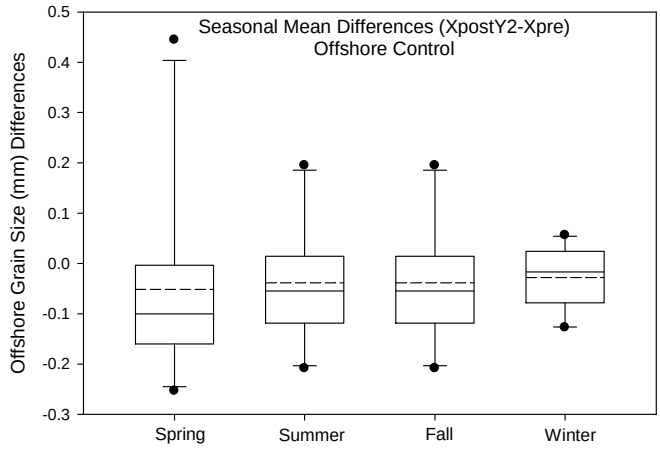


Figure 21. Box plots of seasonal mean differences (XpostY2-Xpre) for offshore grain size by station type and for all seasons combined by station type. The box boundary closest to zero is the 25th percentile, the box boundary farthest from zero is the 75th percentile, and the error bars are the 10th and 90th percentiles. Values shown above and below the error bars are singular data points outside of the 10th or 90th percentile. The solid line is the median; the dashed line is the mean.



a)



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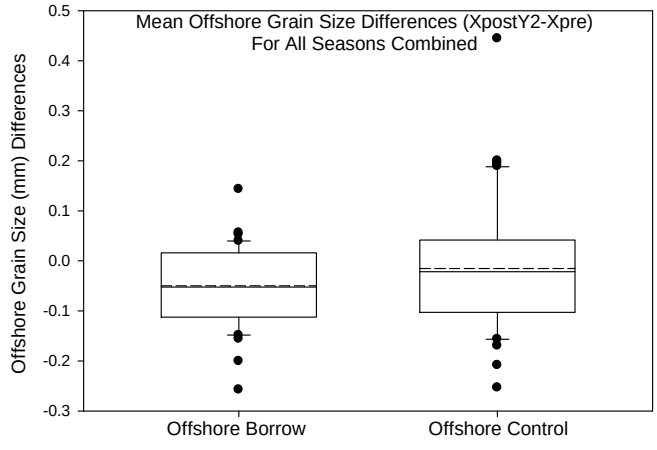


c)

Figure 10 is a box plot depiction of combined abundance data with the two station types paired by season; there were no statistically significant comparisons between pre- and post-abundance for any season at either station type. Figure 11 is a box plot depiction of abundance data combined annually and compared pre- to post-nourishment by station type; there were no statistically significant comparisons between pre- and post- abundance for any season at either the borrow or the control stations. The same statistical results of the abundance comparisons occurred when testing the abundance per meter^2. Including the high numbers of razor clams collected in the spring pre-nourishment event, borrow stations' pre-nourishment mean abundance per meter^2 was 8,301 compared to 3,159 in the control stations, but the numbers were much closer in post-Y2 with borrow mean abundance per meter^2 at 3,289 compared to 2,899 in the control stations. Lastly, the differences in mean abundances were significantly different only in the spring at the offshore borrow stations (p<0.001) and there were no significant differences when all seasons were combined (Figure 10).

3.3.2 Offshore Taxa Richness and Diversity

Figure 13 depicts taxa richness in the same format as Figure 9 and shows that the post-Y2 fall taxa richness was below the pre-fall richness for all stations. By the next sample event, post-Y2 winter, richness was similar to pre-winter for the borrow stations but the control stations were below the pre-winter number. By post-Y2 spring and summer, richness exceeded the pre-spring richness and was similar to pre-summer richness in the borrow stations and met or exceeded the pre-nourishment values in the control stations. Figure 14 is a box plot depiction of combined taxa richness with the two station types paired by season; there were no statistically significant comparisons between pre-and post-taxa richness for any season at either station type. When taxa richness is combined for each station type and for each year (all pre- vs all post-Y2 by type), no significant differences were found between pre- and post-Y2 for either station type (Figure 15). The differences in mean taxa richness between pre-nourishment and post-Y2 were not significantly different. The mean differences at the control stations varied more than the borrow stations, seen by the higher upper percentiles and outliers (Figure 16).

In the same format as the bar graphs of Figure 9 and Figure 14, Figure 17 compares pre-nourishment and post-Y2 offshore Shannon diversity scores (H') among station types by season. Diversity was lower in both offshore station types in the post-Y2 winter compared to pre-winter, but the rest of post-Y2 seasons for both station types either closely matched or surpassed pre-nourishment diversity (Figure 17). Summer had the highest diversity score for both pre- and post-Y2 control stations; however, for the borrow stations, summer was the most diverse pre-nourishment but spring was the most diverse post-Y2. The lowest diversity among all eight seasons and both station types was pre-spring; however, for post-Y2 the control and borrow stations were least diverse in the winter.

3.3.3 Offshore Sediment Grain Size

The average grain size at the offshore control stations was larger than the borrow stations in each season, except only slightly in the fall, both pre-nourishment and post-Y2 (Figure 18). There were no significant differences between any season pre-nourishment and post-Y2 for either borrow or offshore control stations and there was not much seasonal variability in grain size (Figure 19). Additionally, there were no significant differences in grain sizes pre- and post-nourishment with all seasons combined and the spread of data is comparatively similar, with the most variability post-nourishment at the offshore control stations (Figure 20). The differences in the mean grain sizes

between pre- and post-nourishment were small and not significant between seasons or with all seasons combined, except for winter (Figure 21).

When grain size of all offshore stations is combined by type and compared by season to other parameters (e.g., all pre-control fall richness or abundance compared to each pre-season, etc.), the correlation between grain size and taxa richness was almost always negative. Seasonal grain size was only significantly correlated with abundance (P=0.007) and also with richness (P=0.007) in the winter post-nourishment at the borrow stations. With all seasons combined, grain size was significantly correlated with richness pre-nourishment at the borrow stations (P=0.034) and with abundance pre-nourishment at the control stations (P=0.027).

3.4 Control Beach Benthos and Sediment

Table 4 provides summary information for all 12 seasonal sampling events (four pre-nourishment and eight post-nourishment [four post-Y1 and four post-Y2]) by season, by station, by zone (A= swash and B= subtidal), and combined across events for the five National Seashore (NSS) and five Kitty Hawk (KHB) control beach stations. This information and additional data details are described in the three sections below. Pre- and post-nourishment abundance data by season and percent by group for the beach control stations are depicted in pie charts on Figure 5. These depictions show seasonal variation in species diversity, as well as variation in species diversity pre-nourishment and post-Y2 between the same seasons. Pre-nourishment, three fourths of summer and fall groups were from Polychaeta, but those were the only similarities among seasons pre-nourishment. The only similarities among post-Y2 seasons were between the spring and summer when just over one third of the groups were Amphipoda and just under one fourth were Decapoda. After all seasons are combined, the post-Y2 distribution of species is more evenly distributed than pre-nourishment and there are not any similarities in groups between pre- and post-nourishment.

3.4.1 Control Beach Benthos and Sediment Pre-nourishment and Post-Y2

Pre- nourishment sampling identified 20 taxa from the control beach stations in both zones and post-Y2 also pre- nourishment sampling identified 20 taxa from the control beach stations in both zones and post-Y2 also identified 20, one less than post-Y1 (Table 4). The most abundant taxa pre-nourishment included *Scolelepis squamata* (Polychaeta) (507 individuals), *Amphiporeia virginiana* (Amphipoda) (239 individuals), and post-Y2 included *Amphiporeia virginiana* (Amphipoda) (125 individuals), *Emerita talpoida* (Decapoda) (114 individuals), and *Scolelepis squamata* (Polychaeta) (106 individuals). Thirteen (13) taxa were identified in the KHB stations in the pre-nourishment year compared to 17 in post-Y2. The most abundant pre-nourishment taxa on KHB were *S. squamata* and *Donax variabilis* with 160 and 119 individuals, respectively and the most abundant taxa post-Y2 was *S. squamata* with 76 individuals. At the NSS stations, 15 taxa were identified pre-nourishment and 11 were identified in post-Y2. Eight of the 11 were also found in the KHB stations. The most abundant taxa identified from the NSS stations pre-nourishment were *S. squamata* and *A. virginiana* (347 and 227 individuals) and the most abundant taxa in post-Y2 were *A. virginiana* and *Emerita talpoida* (97 and 96 individuals).

Pre-nourishment taxa richness was highest for the control stations during the spring (13 taxa) and lowest in the other three seasons (eight taxa each) while post-Y2 taxa richness was highest in the summer with 11 and lowest in the winter with six. Pre-nourishment, abundance was highest in the spring (538 individuals) and post-Y2, abundance was highest in the summer (185 individuals.) For both

years, abundance was lowest in the fall (79 individuals pre-nourishment and 71 post-Y2). While number of taxa and abundance fluctuated with season, in both years the range of groups present was narrow and similar (five to six). A total of eight groups were represented pre-nourishment and nine were represented post-Y2. The average number of taxa per station for all pre-nourishment seasons combined was 1.9 and for post-Y2 was 1.4. The Shannon diversity index (H') for all control beach stations was 1.6 pre-and 2.1 post-Y2.

3.4.1.1 Control Beach Zone A and Zone B Benthos Pre-nourishment and Post-Y2

Seasonal differences between control beach Zone A and Zone B benthic stations were often small and subtle. However, in post-Y2, Zone A values for average taxa per station, Shannon diversity scores, and grain size were usually higher than Zone B (Table 4).

Pre-nourishment Zone A from the combined control stations identified a total of 15 taxa and 727 individuals compared to Zone B with 15 taxa and 443 individuals. The most abundant taxa in pre-Zone A included *S. squamata* and *A. virginiana* with 280 and 212 individuals, respectively. The most abundant taxa in pre-Zone B included *S. squamata* (227). Post-Y2 Zone A from the combined control stations identified a total of 11 taxa and 376 individuals compared to Zone B with 17 taxa and 141 individuals. The most abundant taxa in post-Y2-Zone A included *Emerita talpoida* (110) and *A. virginiana* (117). The most abundant taxa in post-Y2-Zone B included *S. squamata* (76).

The average number of taxa per station in both Zone A and B pre-nourishment was highest in the spring, but post-Y2 was highest in the summer for Zone A and spring and summer were tied for highest in Zone B. The average number of taxa per station in Zone A pre-nourishment was lowest in the winter and in Zone B was lowest in the fall; the opposite occurred post-Y2, (Zone A lowest in fall and Zone B lowest in winter).

3.4.1.2 Control Beach Zone A and Zone B Sediment Pre-nourishment and Post-Y2

Sediment parameters (average grain size and average percent calcium carbonate) in the control beach stations were slightly lower post-Y2 than in the pre-nourishment year (Table 4). For most pre-nourishment seasons (and seasons combined), Zone B tended to be slightly coarser (ranged from 0.76 to 1.96 mm) than Zone A sediments (ranged from 0.69 to 1.11 mm), but post-Y2, Zone A tended to have slightly more coarse sediment (ranged from 0.60 to 3.94 mm compared to 0.80 to 3.36 mm for Zone B). KH stations had coarser sediment than NSS in both Zone A and B, across all seasons and both years (Table4).

Percent calcium carbonate tended to be similar overall between zones, between KH and NSS and between pre- and post-Y2 (Table 4). Pre-nourishment, stations in NSS had higher calcium carbonate in Zone A than post-Y2; the same was true for KH Zone B. When control beaches were combined by season, post-Y2 values were lower than pre-nourishment values with one exception (summer Zone B).

3.5 Nourished Beach (Nags Head Beach or NHB) Benthos and Sediment

Table 4 provides summary information for all 12 seasonal sampling events (four pre-nourishment and eight post-nourishment [four post-Y1 and four post-Y2]) by season, by station, by zone (A = swash and B = subtidal), and combined across events for the NHB stations. This information and comparison results are described in the three sections below. Pre-nourishment and post-Y2 abundance data by season and percent by group for the NHB stations are depicted in pie charts on Figure 6. These depictions show much seasonal variability across the stations, as well as variability between pre-nourishment and post-Y2; however, pre-fall and post-Y2 fall have similar percentages of the dominant group, Decapoda.

3.5.1 NHB Benthos and Sediment Pre-nourishment and Post-Y2

A total of 22 taxa and 564 individuals were identified from the Nags Head beach stations during the pre-nourishment year compared to 16 taxa and 948 individuals during post-Y2 (Table 4). The most abundant pre-nourishment taxa included *A. virginiana* and *S. squamata* with 193 and 150 individuals identified, respectively. The most abundant post-Y2 taxa were *Oligochaeta* sp. (413) and *A. virginiana* (143).

Pre-nourishment taxa richness in NHB stations was highest during the spring (18 taxa) and lowest in the fall (5 taxa). Post-Y2 taxa richness was highest in the summer (11) and lowest in the spring and winter (7 each). Pre-nourishment abundance was highest in the summer with 247 individuals and lowest in the fall with 49 individuals. Post-Y2 abundance was highest in the winter (570) and also lowest in the fall (46). The number of groups identified from NHB stations showed little seasonal variation between pre-nourishment (four to six) and post-Y2 (four to five). Taxa richness per station for all pre-nourishment events averaged 2.0 taxa and 1.8 taxa post-Y2. Pre-nourishment, Shannon diversity was lowest in summer and highest in spring. Post-Y2, Shannon diversity was lowest in winter and highest in summer and fall. When all events are combined by year, NHB stations had a Shannon diversity index of 2.0 pre-nourishment and 1.9 post-Y2 (Table 4).

Pre-nourishment, average percent calcium carbonate and grain size on NHB was higher in all seasons with one exception (fall post-Y2 percent calcium carbonate). Pre-nourishment, percent calcium carbonate was lowest in the spring (3.1) and highest in the winter (3.8) with an average of 3.5 percent in the pre-nourishment year and in post-Y2 the percent was highest in fall (3.2) and lowest in the summer (1.9) with a combined annual average of 2.5.

3.5.1.1 NHB Zone A and Zone B Benthos Pre-nourishment and Post-Y2

During the four pre-nourishment sample events, NHB Zone A contained 15 taxa and 727 individuals and Zone B contained 15 taxa and 443 individuals. Pre-nourishment, the most abundant taxa in Zone A were *A. virginiana* and *E. talpoida,* (175 and 62 individuals respectively) and the most abundant in Zone B were *S. squamata* and *Donax varibilis* (106 and 33 respectively). Post-Y2, Zone A contained 12 taxa and 511 individuals and Zone B contained 15 taxa and 437 individuals. The most abundant taxa in Zone A were *A. virginiana* and *Oligochaeta* sp. (115 and 142 respectively) and in Zone B was *Oligochaeta* sp. (271). Typically, Zone A had slightly higher taxa per stations than Zone B during post-Y2, but there was not a pattern pre-nourishment. Seasonal pre-nourishment and post-Y2 differences between zones were variable (Table 4). Even though there were pre and post differences in

Shannon diversity scores in each zone among seasons, the overall diversity was very similar between pre- and post-values.

3.5.1.2 NHB Zone A and Zone B Sediments Pre-nourishment and Post-Y2

With the exception of pre-fall and post-winter, grain size was always coarser in Zone A compared to Zone B in both years, although sometimes the differences were small.

Pre-nourishment grain size in Zone A of NHB had a wide range of sizes but averaged 0.83 mm (coarse sand) compared to Zone B which averaged 0.74 mm (coarse sand). Seasonal variation in Zone A pre-nourishment grain sizes was minimal, with the summer having the widest range of grain sizes and the highest average grain size. Post-Y2 grain size in Zone A of NHB averaged 0.58 mm (coarse sand) while Zone B averaged 0.46 mm (medium sand). Pre-nourishment, in Zone A the coarsest sediment was collected in the summer and in Zone B the coarsest sediment was collected in the fall. Post-Y2, in Zone A the coarsest sediment was collected in the fall and in Zone B the coarsest sediment was collected in the winter.

Percent calcium carbonate was most often higher in Zone A than Zone B across both years. Pre-nourishment percent calcium carbonate was lowest in Zone A in spring and winter (3.5 percent) and highest in fall (4.1 percent) with an average of 3.7 percent. Zone B was lowest in spring (2.7) and highest in winter (4.1) with an average of 3.3. Post-nourishment calcium carbonate in Zone A was lowest in winter (1.8 percent) and highest in fall (3.7 percent) with an average of 2.6 percent; Zone B was lowest in summer (1.8 percent) and highest in fall (2.6 percent) with an average of 2.3 percent. Overall, percent calcium carbonate was lower in post-Y2 than in pre-nourishment.

3.6 Graphic and Statistical Comparisons for Beach Stations

Figure 7 depicts pie charts of major taxonomic groups collected in the NHB stations compared to control beach stations by season and all seasons combined annually. This rearrangement of the pie charts shows that when NHB group abundance is compared to control beach group abundance on a seasonal basis, the dissimilarity evident pre-nourishment continued post-Y2 with the exception of winter post-Y2, when NHB beach was most similar to control beach. When all seasons are combined annually, NHB appeared similar to control beach only in post-Y1.

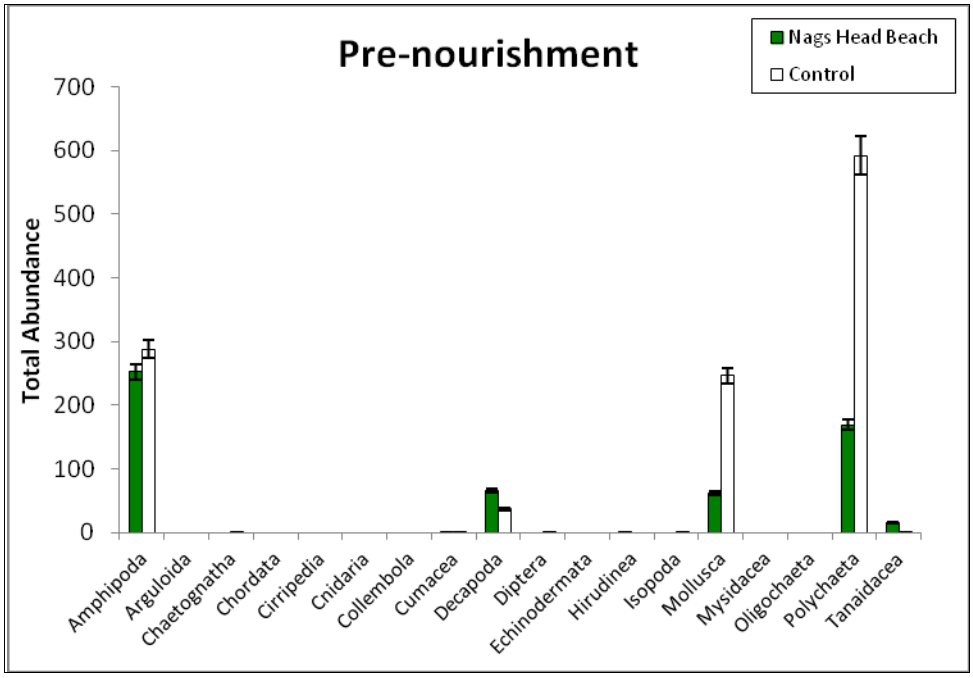
Table 3 lists all statistically significant results of all one-way ANOVAs and t-tests performed on all seasonal pre-nourishment and post-Y2 comparisons and all seasons combined pre-nourishment and post-Y2 comparisons for each station type. Abundance, taxa richness, diversity, and grain size were used to compare benthic and sediment variation in the NHB stations and in the control beach stations pre-nourishment and post-Y2. These data are depicted in bar graphs and box plots and are described in the three subsections below (Figures 22-35). These graphical depictions present the data shown in Table 4 plus additional data in different combinations.

3.6.1 Beach Abundance.

Figure 22 is a bar graph depiction of total abundance by group for NHB and control beach stations. Polychaeta was the most dominant group pre-nourishment and Amphipoda was the most dominant group post-Y2 at the control beach stations. At NHB, Amphipoda was the most dominant group pre-nourishment and Oligochaeta was the most dominant group post-Y2. Overall

abundance was higher post-Y2 at NHB, likely due to the significantly higher winter abundance. However, it was lower at the control beaches post-Y2, largely due to the large decrease in spring and summer abundances (Table 4). Figure 23 is a bar graph comparison of beach total abundance for the NHB and control stations combined by season and station type. Abundances were lowest in fall in both years at NHB and control beach stations and winter was nearly as low in both years at control beach stations. Abundance was highest before nourishment in the spring and post-Y2 in the summer at the control beach stations. At NHB stations before nourishment, abundance was highest in the summer, but post-Y2 it was highest in the winter. Figure 24 is a box plot of combined abundance data with the two station types paired by season; there were no statistically significant comparisons between pre-nourishment and post-Y2 abundance for any season at either NHB or the control beach stations, except the pre-nourishment winter season was significantly lower than post-Y2 at NHB ($P<0.001$). Figure 25 is a box plot of abundance data combined annually and compared pre-nourishment to post-Y2 by station type; there were no statistically significant comparisons between pre- and post- abundance for any season at either NHB or the control beach stations, except the pre-nourishment control beach stations were significantly higher than post-Y2 control beach stations ($P=0.013$). (Text continues on Page 37.)

Figure 22. Bar graphs of pre-nourishment and post-Y2 total abundance by station type and macroinvertebrate group, combined nourished beach stations compared to combined control beach stations.



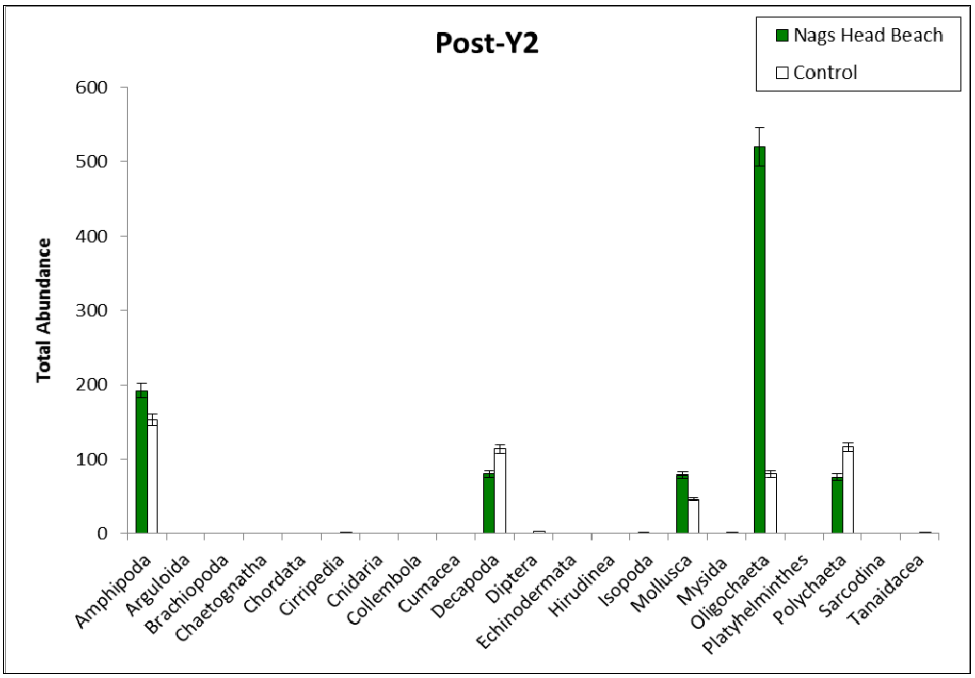


Figure 23. Bar graph comparison of pre-nourishment and post-Y2 beach total abundance by season between combined nourished and combined control stations. Error bars depict +/-0.5.

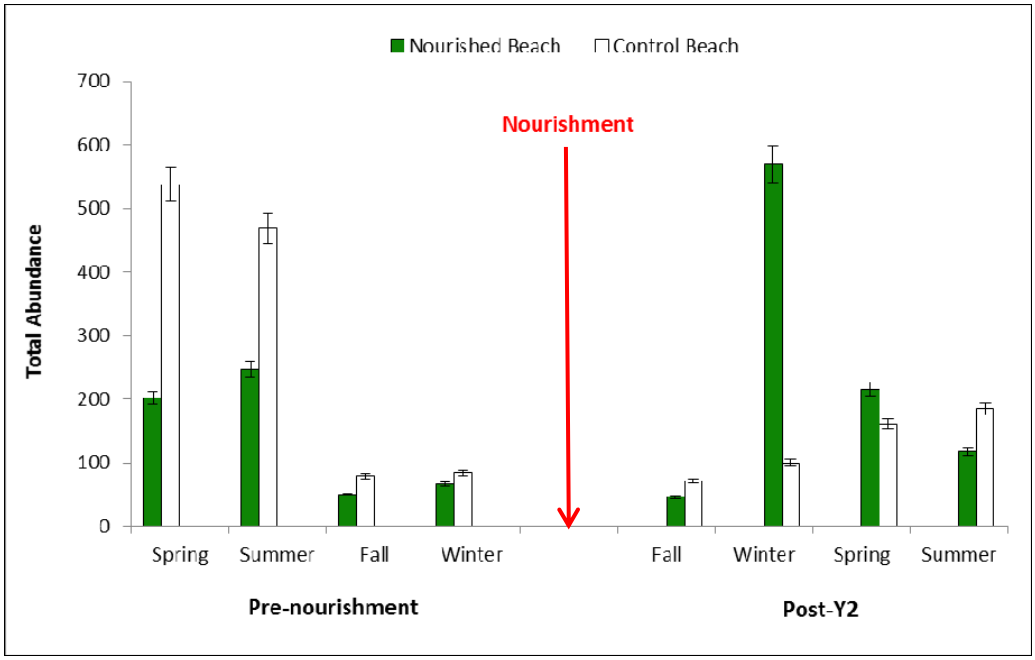


Figure 24. Box plots of pre-nourishment and post-Y2 abundance for beach stations by season and by type. The box boundary closest to zero is the 25th percentile, the box boundary farthest from zero is the 75th percentile, and the error bars are the 10th and 90th percentiles. Values shown above and below the error bars are singular data points outside of the 10th or 90th percentile. The solid line is the median, the dashed line is the mean. Winter at NHB was statistically significant different (p<0.001)

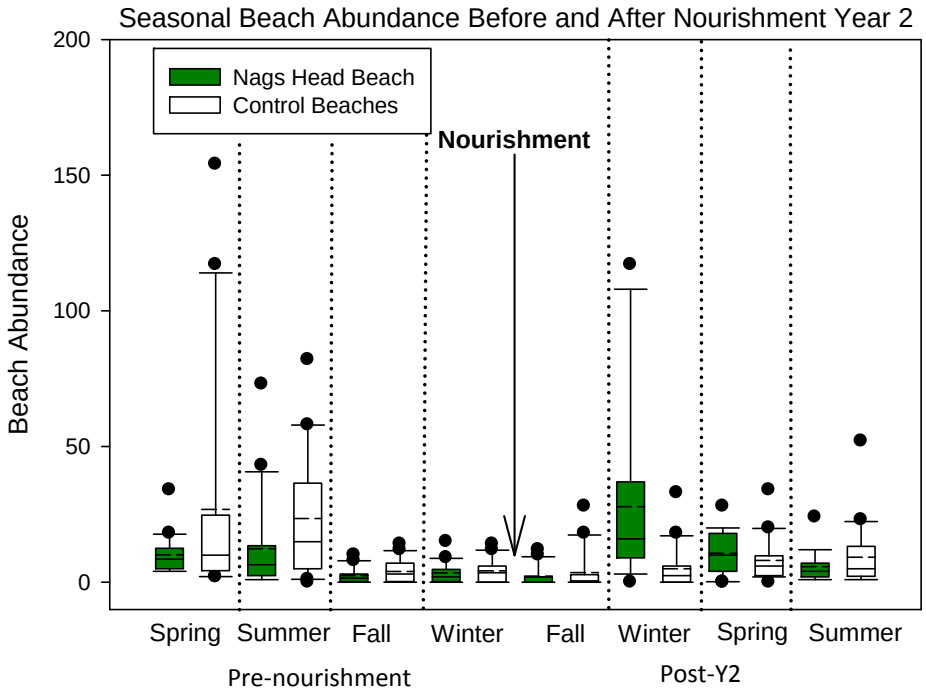


Figure 25. Box plots of pre-nourishment and post-Y2 beach abundance for nourished and control beach stations combined by type and by each control beach. The box boundary closest to zero is the 25th percentile, the box boundary farthest from zero is the 75th percentile, and the error bars are the 10th and 90th percentiles. Values shown above and below the error bars are singular data points outside of the 10th or 90th percentile. The solid line is the median, the dashed line is the mean. Control beaches were significantly higher pre-nourishment (p=0.013)

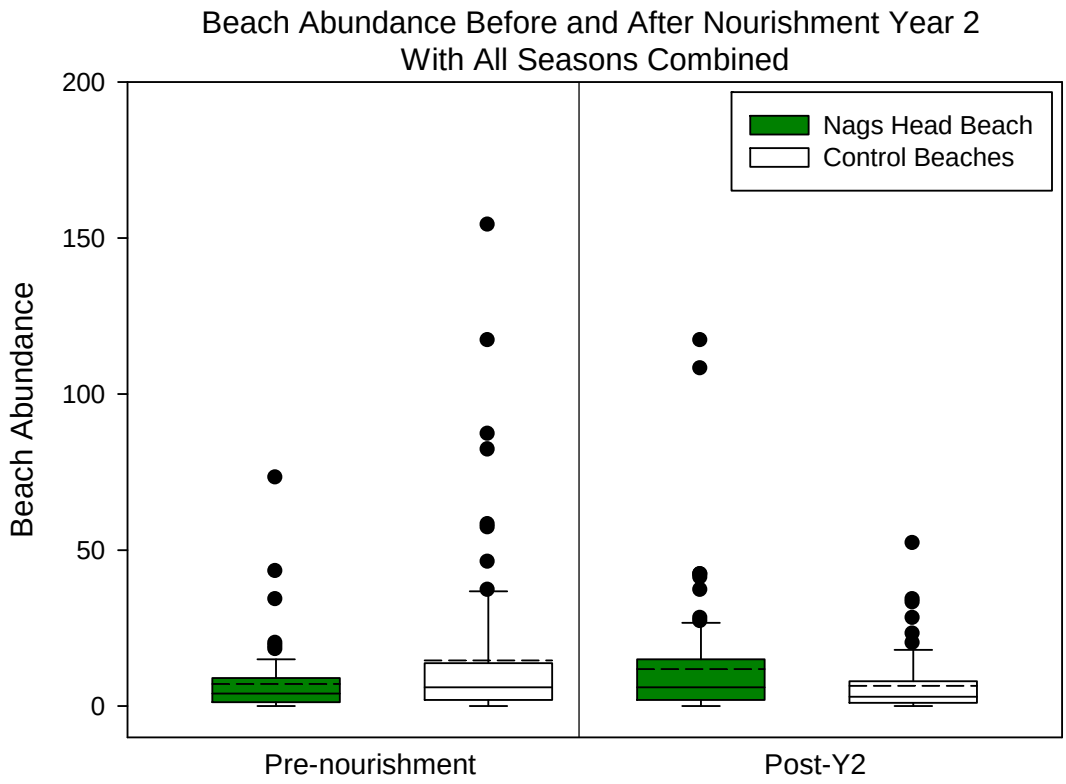


Figure 26. Box plots of seasonal mean differences (XpostY2-Xpre) for Nags Head beach abundance by station type and for all seasons combined by station type. The box boundary closest to zero is the 25th percentile, the box boundary farthest from zero is the 75th percentile, and the error bars are the 10th and 90th percentiles. Values shown above and below the error bars are singular data points outside of the 10th or 90th percentile. The solid line is the median; the dashed line is the mean. Significant differences: winter (NHB had a larger difference in means $p<0.001$); seasons combined NHB had a larger mean difference ($p=0.002$).

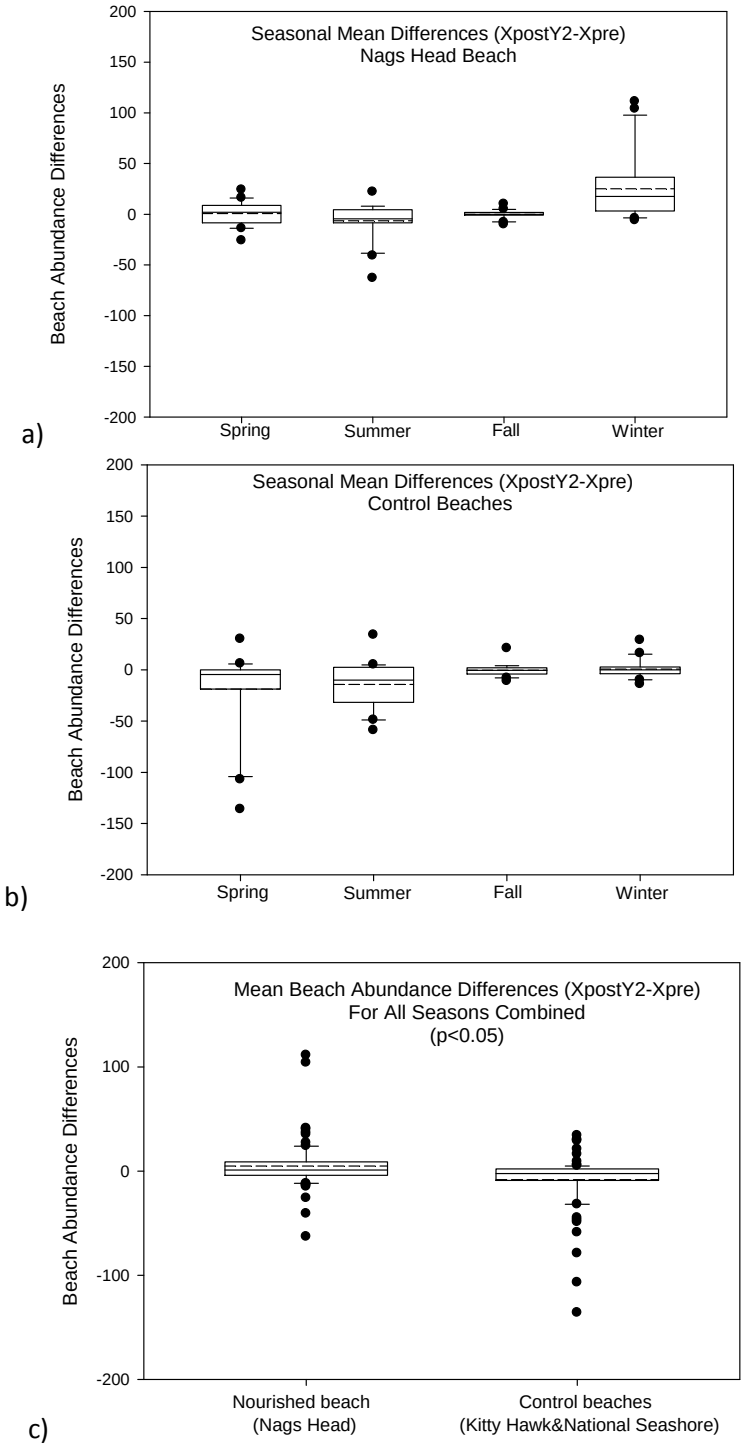


Figure 27. Bar graph comparison of pre-nourishment and post-Y2 beach total taxa richness by season between the combined nourished and combined control stations. Error bars depict +/-0.5.

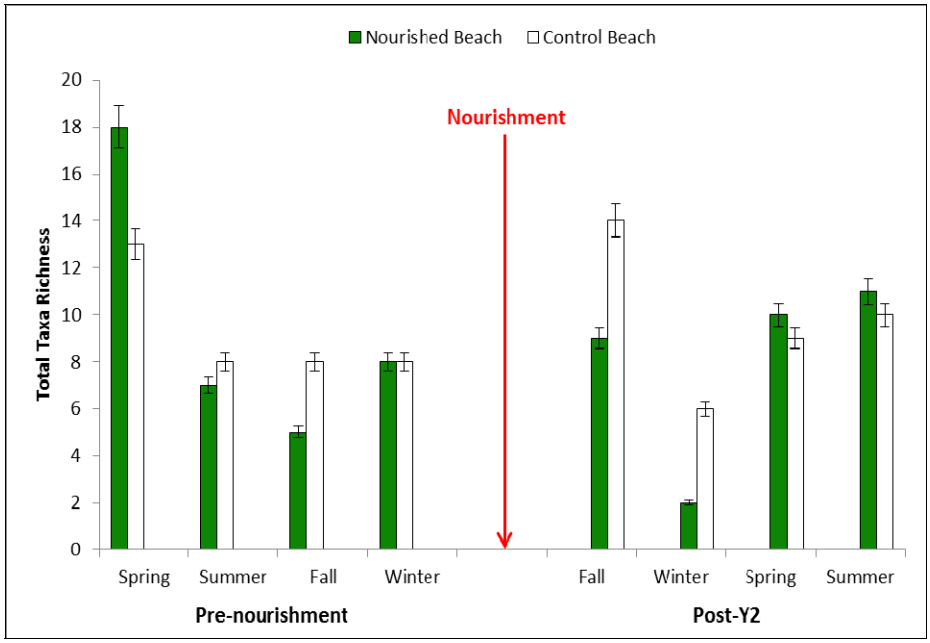


Figure 28. Box plots of pre-nourishment and post-Y2 beach taxa richness combined by season and by station type. The box boundary closest to zero is the 25th percentile, the box boundary farthest from zero is the 75th percentile, and the error bars are the 10th and 90th percentiles. Values shown above and below the error bars are singular data points outside of the 10th or 90th percentile. The solid line is the median, the dashed line is the mean.

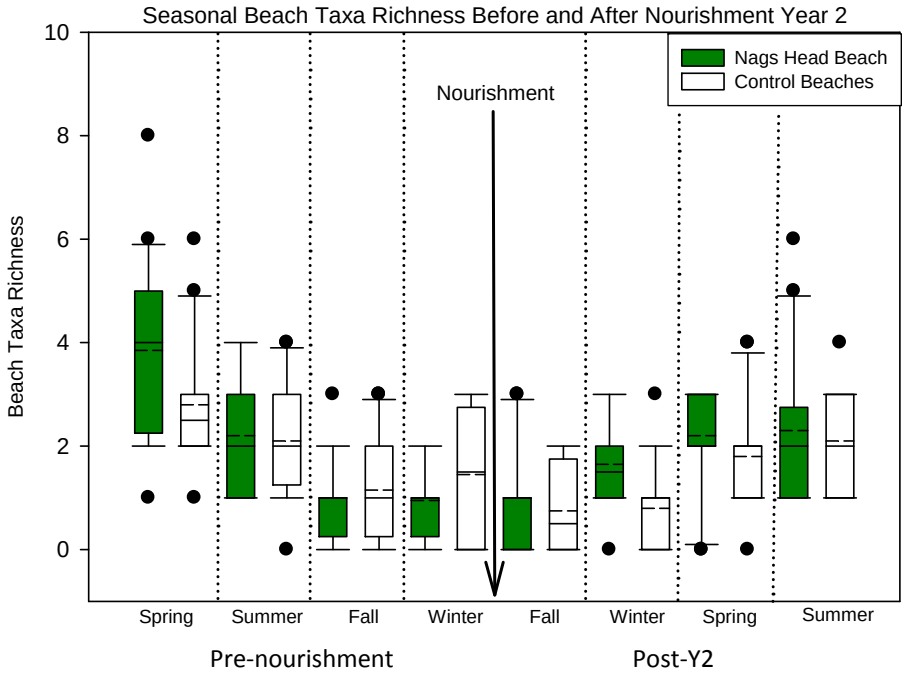


Figure 29. Box plots of beach taxa richness for pre-nourishment and post-Y2 combined by season and by station type. The box boundary closest to zero is the 25th percentile, the box boundary farthest from zero is the 75th percentile, and the error bars are the 10th and 90th percentiles. Values shown above and below the error bars are singular data points outside of the 10th or 90th percentile. The solid line is the median, the dashed line is the mean. Significant differences: control beach higher pre-nourishment (p=0.007)

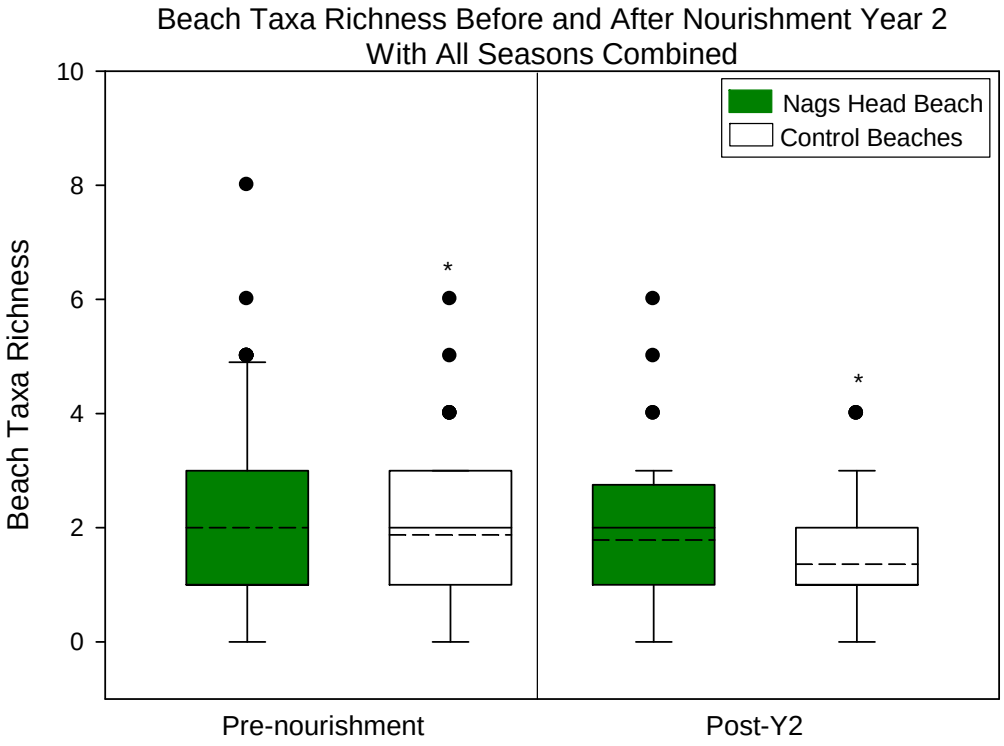
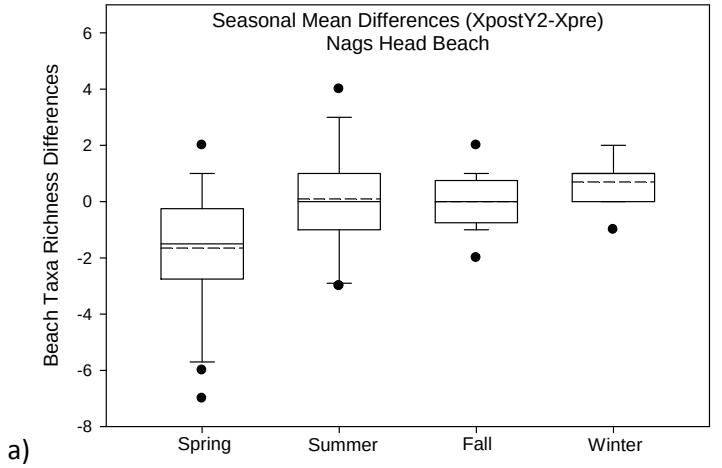
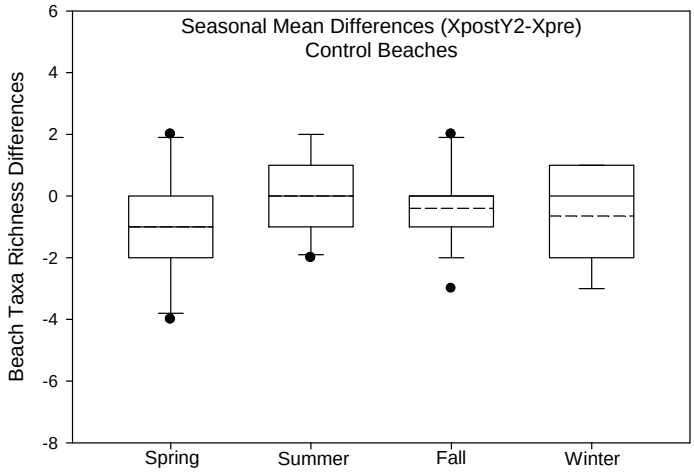


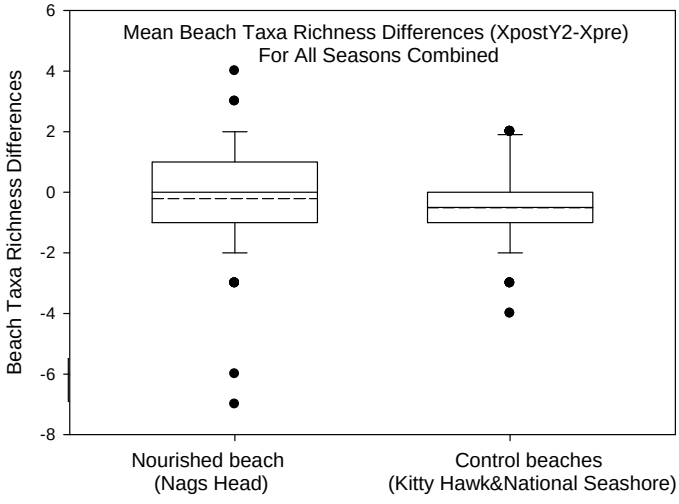
Figure 30. Box plots of seasonal mean differences (XpostY2-Xpre) for Nags Head beach taxa richness by station type and for all seasons combined by station type. The box boundary closest to zero is the 25th percentile, the box boundary farthest from zero is the 75th percentile, and the error bars are the 10th and 90th percentiles. Values shown above and below the error bars are singular data points outside of the 10th or 90th percentile. The solid line is the median; the dashed line is the mean.



a)



b)



c)

Figure 31. Bar graph comparison of beach Shannon diversity index values by season between the combined nourished and combined control stations. Seasonal sample events are shown in the order they occurred.

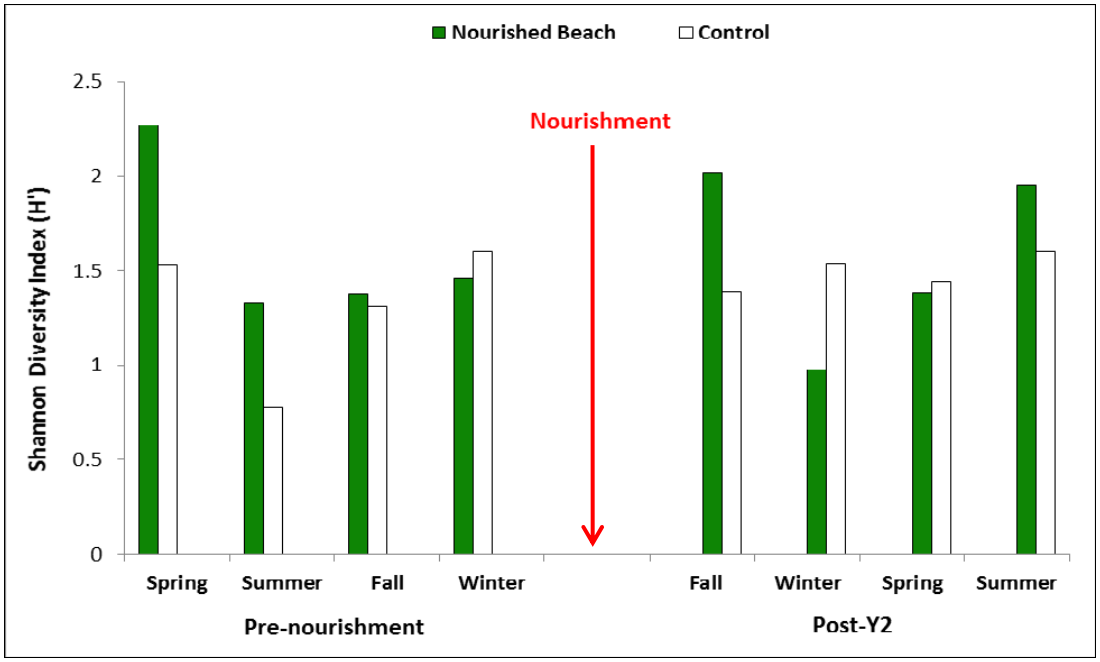


Figure 32. Bar graph of pre- and post- nourishment year 2 beach grain size by season and station type. Error bars depict +/-0.5.

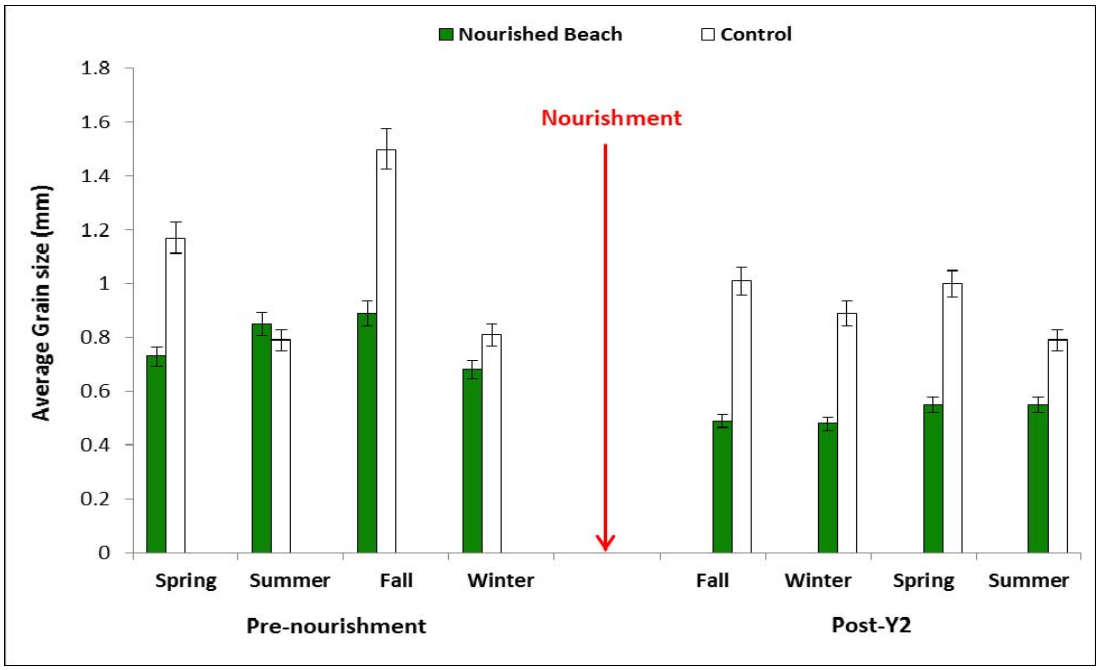


Figure 33. Box plots of pre-nourishment and post-Y2 beach grain size (mm) grouped by season and by station type. The box boundary closest to zero indicates the 25th percentile, the box boundary farthest from zero indicates the 75th percentile, and the error bars indicate the 10th and 90th percentiles. Values shown above and below the error bars are singular data points outside of the 10th or 90th percentile. The solid line shown indicates the median, the dashed line indicates the mean.

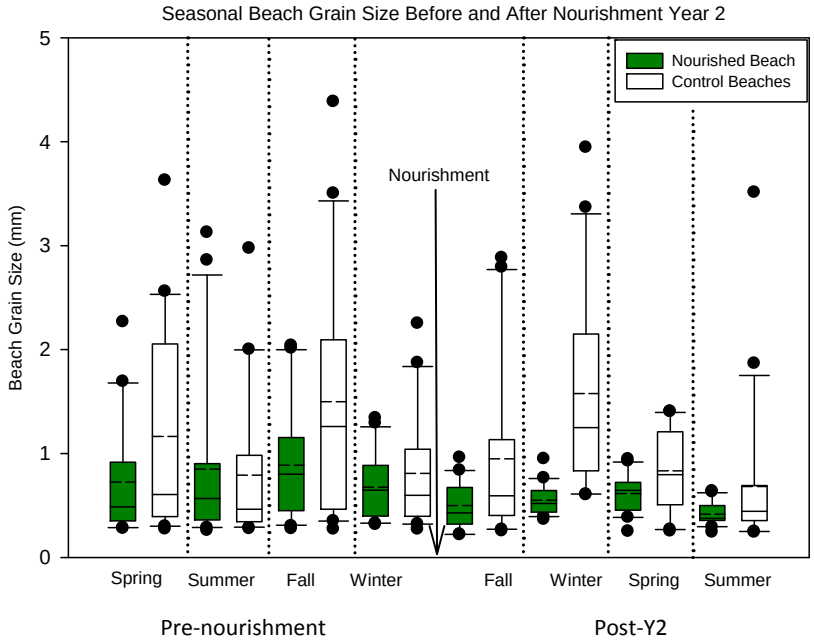


Figure 34. Box plots of beach grain size for pre- and post-Y2 combined by station type and location. The box boundary closest to zero indicates the 25th percentile, the box boundary farthest from zero indicates the 75th percentile, and the error bars indicate the 10th and 90th percentiles. Values shown above and below the error bars are singular data points outside of the 10th or 90th percentile. The solid line shown indicates the median, the dashed line indicates the mean.

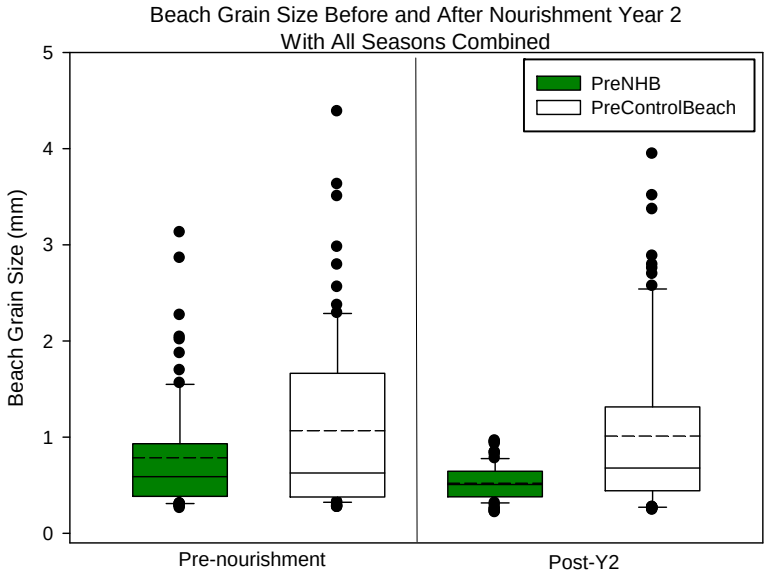
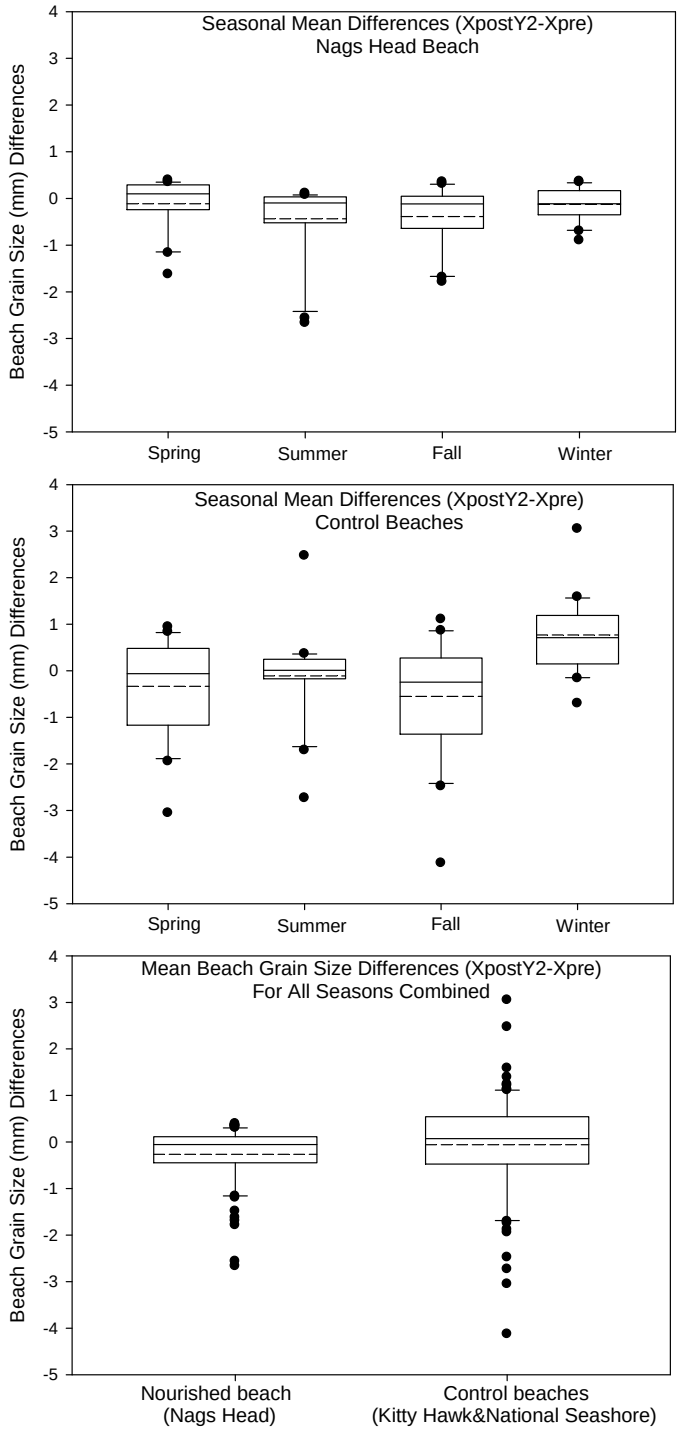


Figure 35. Box plots of seasonal mean differences (XpostY2-Xpre) for Nags Head beach grain size by station type and for all seasons combined by station type. The box boundary closest to zero is the 25th percentile, the box boundary farthest from zero is the 75th percentile, and the error bars are the 10th and 90th percentiles. Values shown above and below the error bars are singular data points outside of the 10th or 90th percentile. The solid line is the median; the dashed line is the mean. Significant differences: winter (control had a larger difference in means $p<0.001$).



The same statistical results of the abundance comparisons occurred when testing the abundance per meter^2. Lastly, the differences in mean abundances were only significantly different in the winter (p<0.001). When all seasons were combined, the NHB difference in means was slightly larger (p=0.002).

3.6.2 Beach Taxa Richness and Diversity

Figure 27 is a bar graph depiction of pre-nourishment and post-Y2 total taxa richness by season between combined NHB and combined control stations. Pre-nourishment taxa richness was highest in the spring at both NHB and control beach while NHB taxa richness was lowest in the fall, but at the control beach, the other three seasons were tied for lowest richness. Post-Y2, taxa richness was lowest in the winter at NHB and control beach. Figure 28 is a box plot of beach taxa richness grouped by season and by station type. No seasons were significantly different between pre-nourishment and post-Y2. Figure 29 is a box plot of beach taxa richness with all seasons combined by station type. Pre-nourishment taxa richness at control beach stations was significantly higher than post-Y2 taxa (p=0.007). There were no significant differences between the mean richness differences (XpostY2-Xpre) of NHB and the control beach either seasonally or with seasons combined-the differences were all similar (Figure 30).

Shannon diversity scores for combined NHB stations compared to combined control stations by season are depicted on a bar graph in Figure 31. Combined pre-spring, -summer, and -fall Shannon scores were all higher on NHB stations than the control beach stations; post-Y2 winter and spring scores were higher on the control beach stations. Pre-nourishment, spring had the highest Shannon diversity for NHB while winter was highest at the control beach. Post-Y2, NHB fall had the highest Shannon diversity overall, followed closely by NHB summer, while at the control beach stations, the four seasons were similar, with winter and summer slightly higher than the other seasons. At NHB, post-Y2 spring and winter diversity decreased from pre-nourishment but fall and summer diversity increased. At the control beach, diversity was similar pre- and post-Y2 for all seasons except summer, which had a large increase post-Y2.

3.6.3. Beach Grain Size

Seasonally, average grain size at the Nags Head beach compared to the control beaches was always smaller except for pre-summer (Figure 32). Figure 33 is a box plot of pre-nourishment and post-Y2 grain size grouped by season and station type. Grain size at NHB was lower every season post-Y2, but none of the decreases were significant. Post-Y2, grain size at the control beach stations was lower in spring and fall, but none of the decreases (or increases in other seasons) were significant. When all seasons were combined, the overall pre-nourishment and post-Y2 increases and decreases at both NHB and control beach stations were small and insignificant. The seasonal differences in mean grain size were similar between NHB and the control beach for each season, except for winter when the post-Y2 control beach stations had a larger difference in means (p<0.001) (Figure 35). There was no significant difference in mean differences between the control beaches and NHB when seasons were combined.

Borrow and NHB grain sizes were compared before and after nourishment in both post-years. Pre-nourishment NHB grain size was typically the largest and was statistically significantly larger than the borrow grain size in both post-Y1 and post-Y2 (p=0.001, <0.001).

4.0 CONCLUSIONS

Benthic populations in the nourished beach as well as the offshore borrow area remained viable and diverse over the monitoring period. Seasonal variations were evident in abundance and richness, but less evident in grain size. There were few significant differences (eight of approximately 50) for any parameter at the offshore borrow or NHB stations, and none were a cause for concern. Out of all the statistical comparisons between pre- and post-nourishment by season and with seasons combined, only 14 resulted in a statistically significant difference. Seven of those were favorable towards the offshore borrow sites or nourished beach. One was favorable towards the combined control beaches, but the result was then negated by the post-Y2 result. Benthic populations typically showed higher abundances and richness in spring and summer sample events compared to fall and winter sample events. Sediments on the sampled section of the nourished beach were finer post-Y2, which reflects the characteristics of the borrow material and burial of the coarse sediment that dominated the eroding beach prior to the project. The post-Y2 NHB (i.e. lower surf zone sample areas) now consists of ~0.5 mm sand (similar to the natural berm in the area), which is more favorable. Prior to nourishment, the lower surf zone contained very coarse sand, granules, and pea gravel at many stations, a lag deposit which is more common along eroding beaches (CSE 2005, USACE 2010). Additionally, the similarity of sediments in the borrow area before and after dredging likely contributed to the rapid recovery of the benthic population.

This study showed that biological communities in the surf zone are highly variable and exhibit seasonal changes. Artificial manipulations such as nourishment produce short-term impacts that are rapidly mitigated by replacement of organisms, just as the benthic populations adjust continually with the seasons. If manipulations are performed responsibly, diverse and abundant benthic populations will be found shortly after the work is completed. Post-Y1 results showed a significant decrease in richness at Nags Head beach, although it was not a large difference, but by post-Y2, richness was only slightly (not statistically significant) lower than before nourishment. The finer sand grains present after nourishment likely contributed to the increase in richness. (At the combined control beach sites, richness was significantly lower post-Y2 than pre-nourishment.) Abundance was not significantly different between pre-nourishment and post-Y1 or -Y2 at either the offshore borrow site or Nags Head beach, except the post-Y2 winter abundance at Nags Head beach was significantly higher in the post-Y2. (Abundance at the combined control beaches was significantly higher in post-Y1 but significantly lower in post-Y2.)

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