when both zones are evaluated together was lowest in the spring (3.1 percent) and highest in winter (4.1 percent) with an average of 3.5 percent.

3.2.2.3 Impact Beach Swash (Zone A) Benthos and Sediments

The swash Zone A on the impact beach comtained 17 taxa and 368 individuals during the four pre-impact sample events. Two taxa, *A. virginiana* and *S. squamata,* comprised the majority of the individuals, with 177 and 44 individuals respectively. When all four pre-impact events are combined the average taxa per station was 5.5.

Grain sizes in the swash Zone A of the impact beach ranged from 0.28 mm to 2.86 mm with an average of 0.83 mm (coarse sand). In the swash Zone A, an average taxa richness of 2.3 per station was determined for the impact beach. Seasonal variation in grain sizes was minimal, with the summer having the widest range of grain sizes and the highest average grain size. Percent calcium carbonate was lowest in winter (3.5 percent) and highest in fall (4.1 percent) with an average of 3.7 percent

3.2.2.4 Impact Beach Subtidal (Zone B) Benthos and Sediments

Pre-impact sampling of subtidal Zone B on the impact beach identified 21 taxa and 263 individuals, with *S. squamata* and Nemertea as the most abundant taxa with 106 and 39 individuals respectively. The highest average taxa per station was 4.4 during the spring sampling and the lowest was 1.2 during the fall. The combined average taxa per station for all pre-impact events was 6.8. The Shannon diversity index value for Zone B was 1.92.

In the subtidal Zone B grain size ranged from 0.26 mm to 3.13 mm with an average of 0.74 mm (coarse sand). Average taxa richness for Zone B was 2.3 taxa per station. The subtidal zone had some slight seasonal variation in sediment, predominantly in the fall with a higher average grain size than other sampling events as well as a wider range of grain sizes. Percent calcium carbonate found in Zone B was lowest in spring (2.7 percent) and highest in winter (4.1 percent) with an average of 3.3 percent.

4.0 Discussion and Comparative Analysis

Both abundance and number of taxa identified varied with season. This trend was seen in both the beach and offshore stations; however, this trend was more evident at beach stations. There was little seasonal variation in number of groups identified, particularly from the beach stations. While the number of groups identified were similar between offshore impact/borrow and offshore control stations and between seasons, there was some variation in particular groups.

4.1 Comparative Analysis of Offshore Benthos and Sediment

Seasonal variation was prevalent among taxa richness, total individuals, and the dominant macroinvertebrate groups across pre-impact sampling events (Figure 4). Taxa richness was highest during the summer sampling for both the control and impact/borrow stations. The number of individuals was highest during the spring sampling at both the control and impact/borrow stations; high numbers of *Ensis directus* (razor clam) were identified from the impact/borrow stations and not the control sites. The large numbers of razor clam found in the spring from the impact/borrow sites may be anomalous or may indicate the patchy recruitment of this taxon. The number of individuals between the spring and summer events at the control stations are comparable. The control sample stations generally had higher average taxa per station when compared to the offshore impact/borrow site with the exception of the winter sampling. Figure 5 compares taxa richness between offshore impact/borrow and control stations for all sample events combined and Figure 4 compares taxa richness seasonally (per sampling event) among offshore impact and control sites. Taxa richness displayed in Figure 4 indicates a significant difference between impact/borrow and control sites during summer sampling.

As mentioned above the number of groups identified offshore did not vary much with season. The groups identified between the control and impact/borrow stations were not identical but were similar with 76 percent of identified groups in common. The spring event had 92 percent of groups between control and impact/borrow stations in common and the winter was 66 percent groups in common. Abundance in some groups indicated a seasonal preference and as might be expected, most groups' abundance peaked during the spring and summer; however, tunicates' abundance peaked during the fall and winter.

Using the Shannon diversity index to compare evenness and diversity between the offshore impact/borrow and control sites, the offshore impact/borrow area was the most diverse when all sampling events were combined (H'=2.439), compared to the control sites (H'=1.694). When evaluating diversity by season both the control and the impact/borrow sites were most diverse during the summer followed by the winter (Figure 6). The least diverse were impact/borrow stations in the spring. Factors that may contribute to a low Shannon index in this location and season are high abundances for a few taxa, creating unevenness.

Using groups to compare percent abundance between offshore control and impact/borrow stations the two locations show similar results by season. During the spring sampling mollusks dominated the impact/borrow and control locations, polychaetes dominated the summer, and tunicates were most abundant in the fall for both offshore sampling locations. In the winter tunicates were most abundant in the impact/borrow and polychaetes were most abundant in the control location (Figure 7).

When comparing grain size between impact/borrow and control sampling stations, the control sediments are slightly better sorted and have a higher mean grain size than the impact/borrow sediment; however, grain size was not significantly different between impact/borrow and control stations. Average taxa richness per station was slightly higher in the control stations; however there is no significant difference between the impact/borrow and control stations regarding taxa richness per station or taxa richness of all sample events combined.

Figure 4. Box plot of offshore impact/borrow taxa richness compared to offshore control station taxa richness for each seasonal pre-impact event. On the X axis, the "I" and "C" preceding the sample season indicate impact/borrow or control stations. 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, and the p-value is shown in bold under each seasonal event.

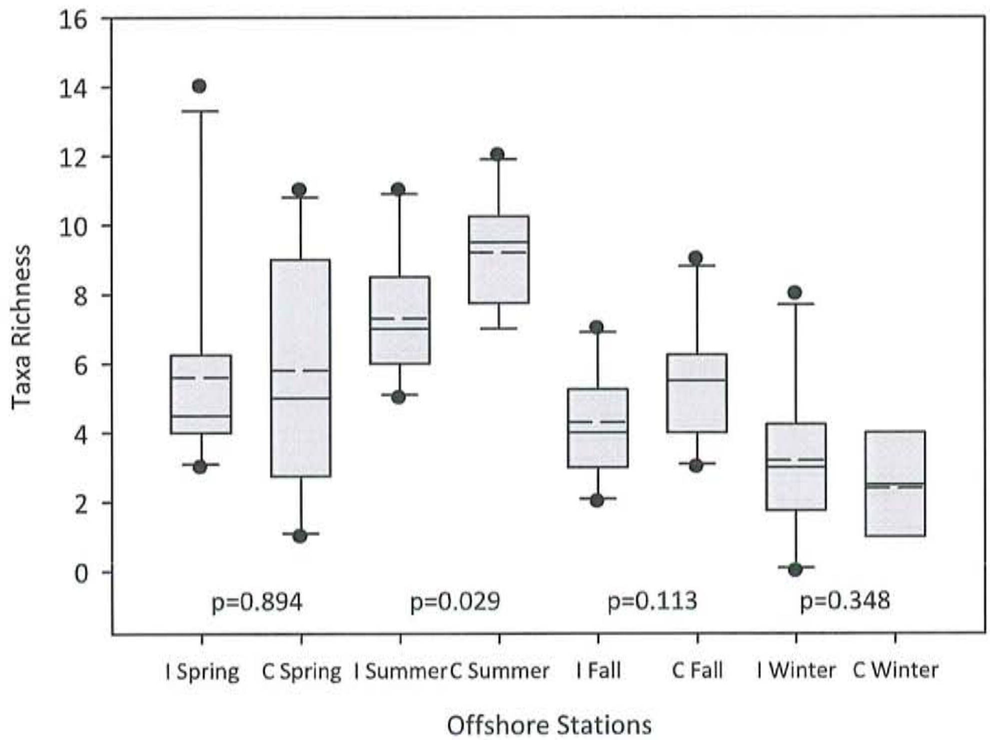


Figure 5. Box plot of combined offshore impact/borrow stations taxa richness compared to taxa richness of combined offshore control stations for all pre-impact events combined. The box boundary closest to zero indicates the 25th percentile, the box boundary farthest from zero indicates the 75th percentile, 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, and the p-value is shown in bold.

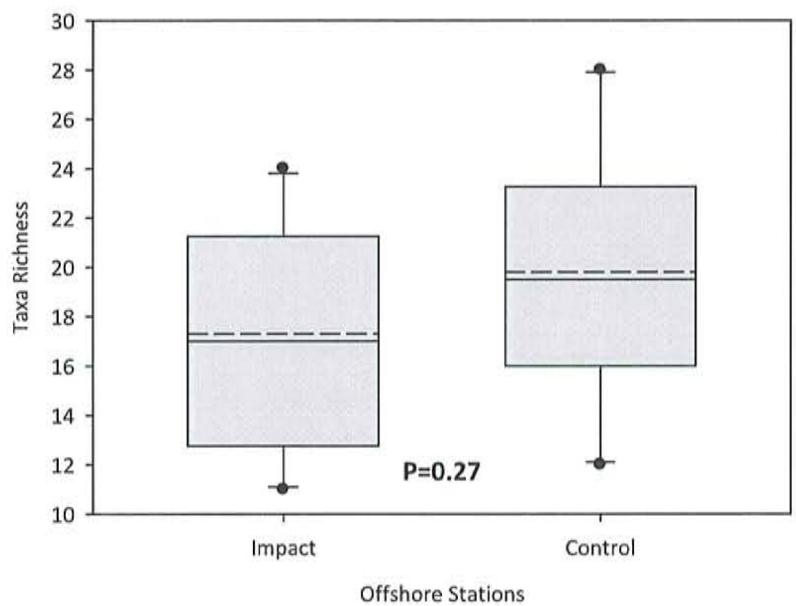


Figure 6. Bar graph with error bars comparing Shannon diversity index between the offshore impact/borrow and offshore control sample stations. Error bars depict +/-0.5. When all data are combined, the diversity index in the borrow area is greater than the control sites because more taxa overall were identified (Table 1) and abundance was more even in the impact/borrow sites.

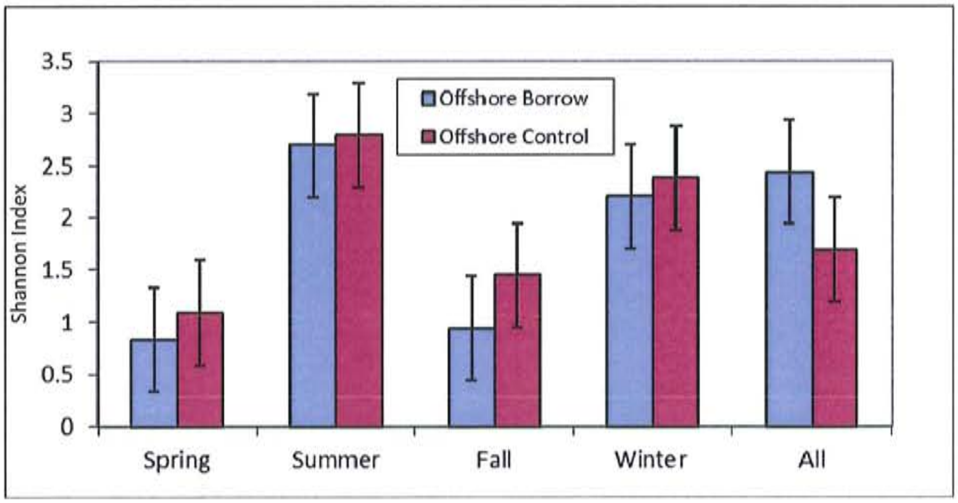
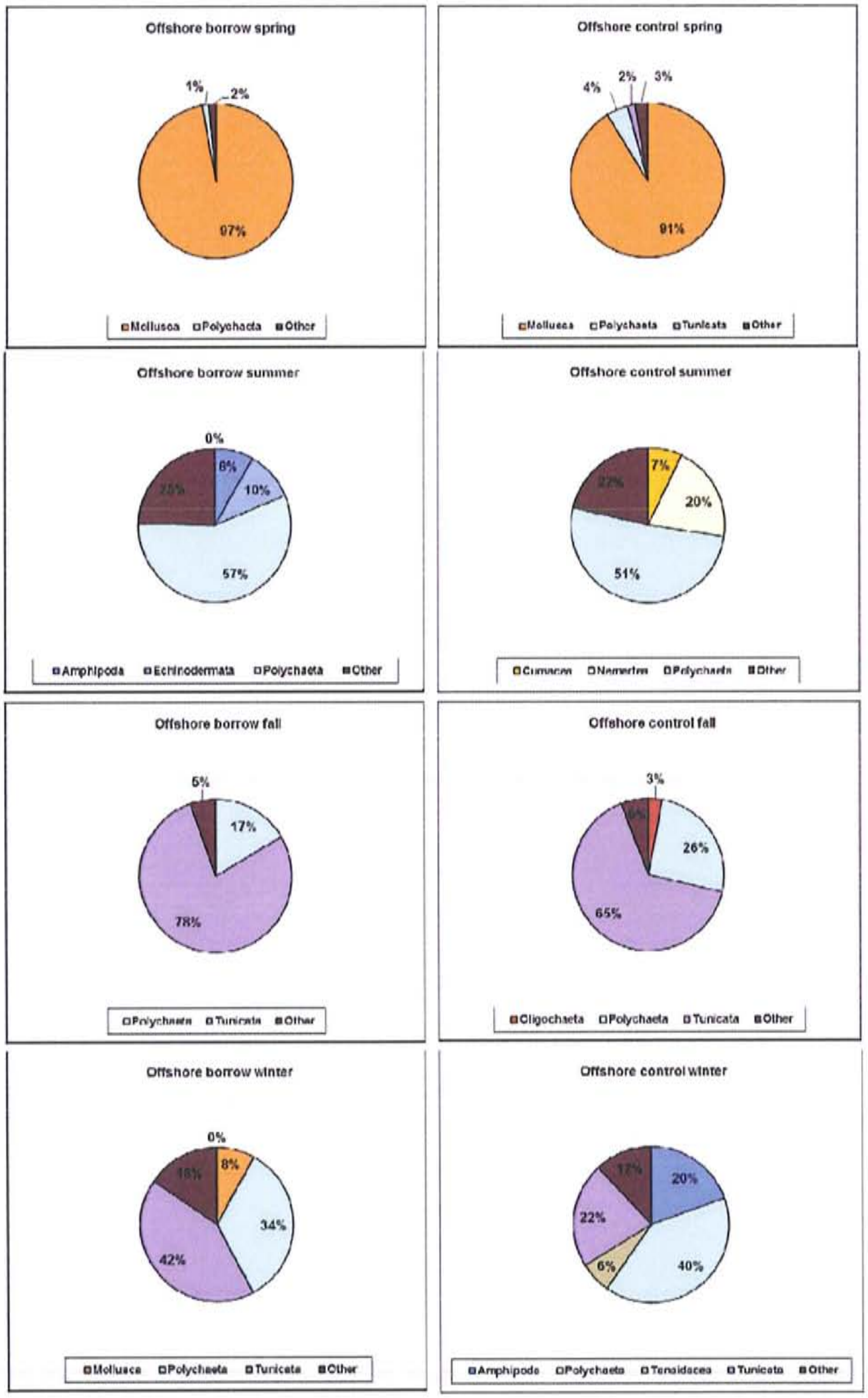


Figure 7. Pie charts comparing groups of taxa found in offshore impact/borrow and control stations by event.



4.2 Comparative Analysis of Beach Benthos and Sediment

Taxa richness for all pre-impact events was higher on the impact beach with 28 taxa identified, compared to the 26 taxa identified on control beaches. The mean taxa richness from the control and impact beach was 5.5 and 6.1, respectively. Comparing groups found in the swash Zone A of the impact and control beaches showed similar numbers of amphipods between the control and impact beaches. Additionally the control beach had more worms (Platyhelminthes and Polychaetes) than the impact beach; however the impact beach had more decapods identified than the control beach (Figure 8). Groups found in the subtidal Zone B of the control beach had consistently more individuals across the majority of groups identified, with the exception of Tanaidacea (crustacean) which was only found on the impact beach (Figure 9). Comparing these groups using an ANOVA found no statistically significant difference (Figure 10). When comparing taxa richness seasonally no significant differences were found between the impact beach and control beach within each season (Figure 11). In further comparison of the impact and control beach, swash Zone A and subtidal Zone B were separated and analyzed. No significant difference was found in taxa richness between the control and impact beach in either zone (Figure 12.

The control swash Zone A produced a higher average number of taxa per station than the subtidal Zone B for every season except winter. The impact beach showed a different outcome with a higher average taxa per station generally found in Zone B on the impact beach when compared to Zone A. The exception occurred in the summer when the swash zone was higher, and in the fall when they were the same. The combined control beach Zones A and B had an average taxa richness of 5.5 for all pre-impact events. The 18 total taxa from the swash Zone A on the control beaches is comparable to the 17 taxa identified in the swash Zone A of the impact beach; however, the number of individuals enumerated in these zones was very different, with 368 individuals from the impact beach compared to 910 individuals found on the control beach. Similarly, the subtidal Zone B of the control beach had 605 individuals and 19 taxa identified while the impact beach had 263 individuals and 21 taxa identified.

Using the Shannon diversity index to evaluate impact and control stations, the impact beach was found to be slightly more diverse (H=2.06) compared to the control beach (H'=1.92). When evaluating swash and subtidal zones separately, the control swash Zone A is more diverse (H'=1.86) than the impact swash Zone A (H'=1.66). Conversely, the subtidal impact zone is slightly more diverse (H'=1.92) than the subtidal control zone (H'=1.74) (Figures 13 and 14).

As mentioned, seasonal variation in abundance and taxa numbers occur in the beach sampling stations. In swash Zone A the amphipods were most abundant on the impact beach during the spring and summer. Platyhelminthes were most abundant on the control beach during the spring; however no platyhelminthes were found in the beach swash zone after spring sampling. During the summer and fall sampling polychaetes dominated the control beach in swash Zone A. During the winter sampling amphipods were most abundant in both control and impact beaches in swash Zone A (Figure 15). In the subtidal Zone B amphipods, mollusks and polychaetes were essentially equally abundant on the impact beach during the spring; comparatively, mollusks were most abundant on the control beach during the spring sampling. Polychaetes were most abundant during the summer and fall on both the control and

Figure 8. Combined macroinvertebrate abundance in control swash Zone A compared to impact beach swash Zone A for all pre-impact sample events.

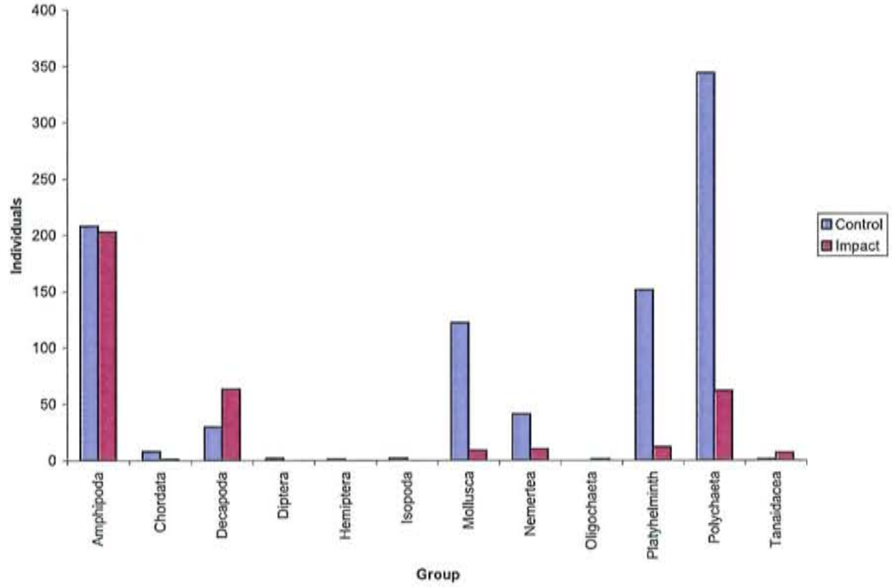


Figure 9. Combined macroinvertebrate abundance in the control beach subtidal Zone B compared to impact beach subtidal Zone B for all pre-impact sample events.

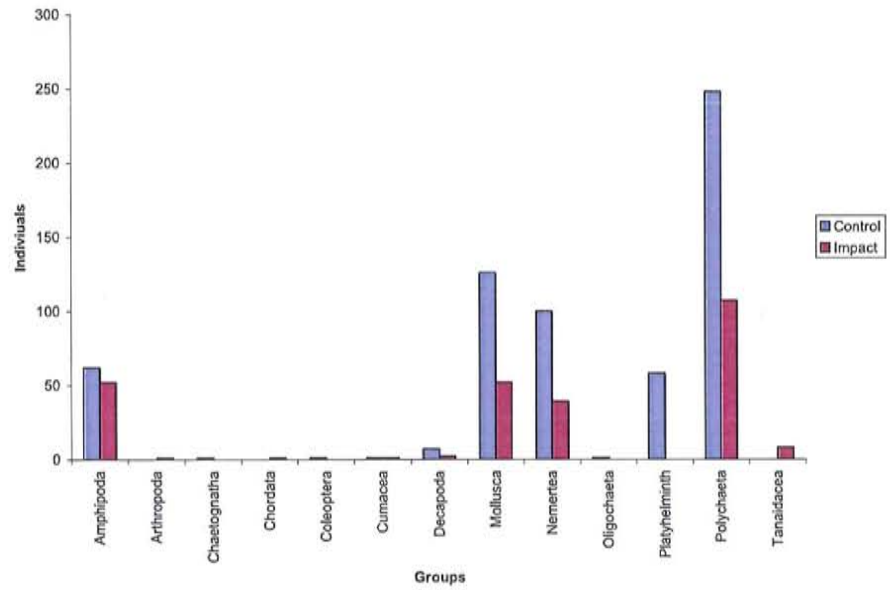


Figure 10. Box plot of impact beach Zones A (swash) and B (subtidal) combined compared to beach control Zone A and Zone B combined. Impact and control boxes represent all sampling events combined. The box boundary closest to zero indicates the 25th percentile, the box boundary farthest from zero indicates 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, and the p-value is shown in bold.

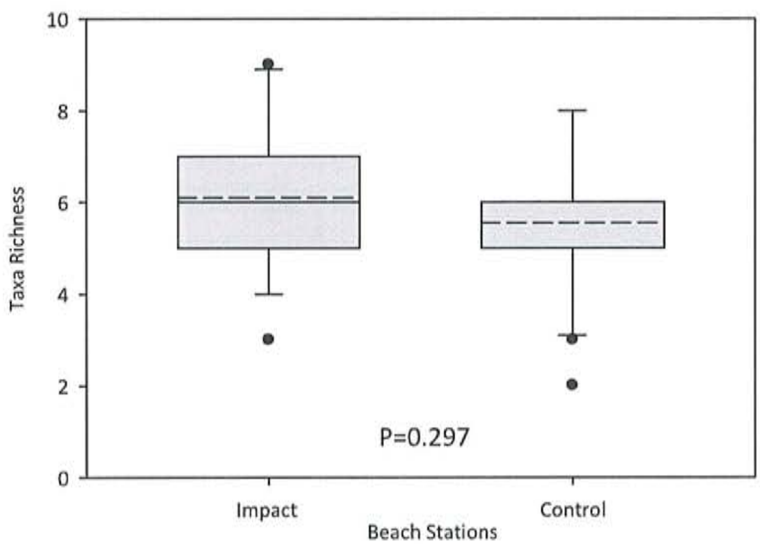


Figure 11. Box plot of impact beach taxa richness compared to control beach taxa richness for the pre-impact sampling events. On the X axis, the "I" and "C" preceding the sample season indicate impact/borrow or control sites. The box boundary closest to zero indicates the 25th percentile, the box boundary 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, and the p-value is shown in bold under each seasonal event.

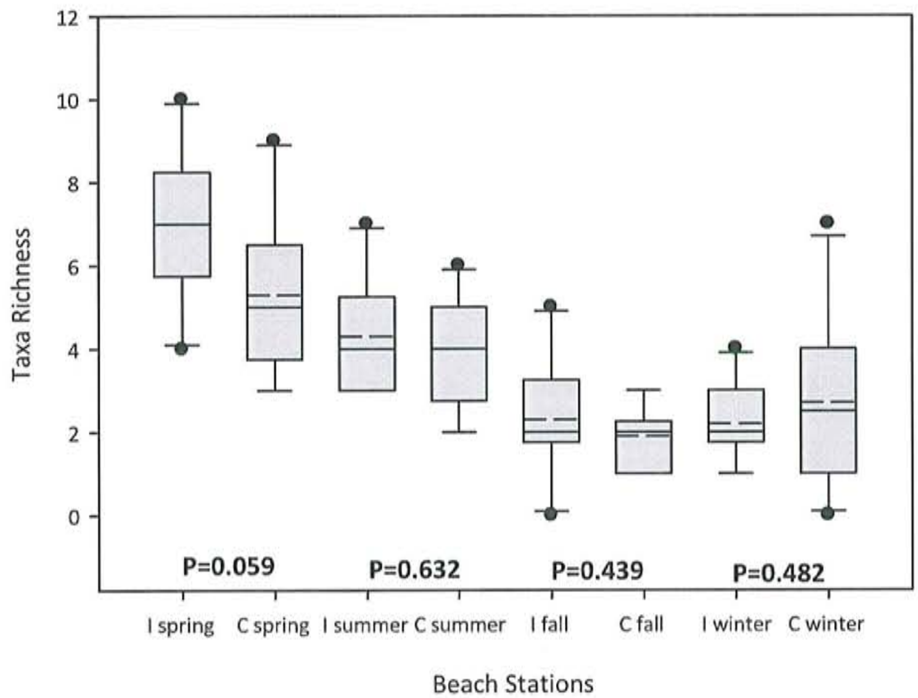


Figure 12. Zone A and Zone B taxa richness box plot of all pre-impact sample events for beach impact and control stations. The box boundary closest to zero indicates the 25th percentile, the box boundary farthest from zero indicates the 75th percentile, and the error bars indicate the 10th and 90th percentiles. 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, and the p-value is shown in bold.

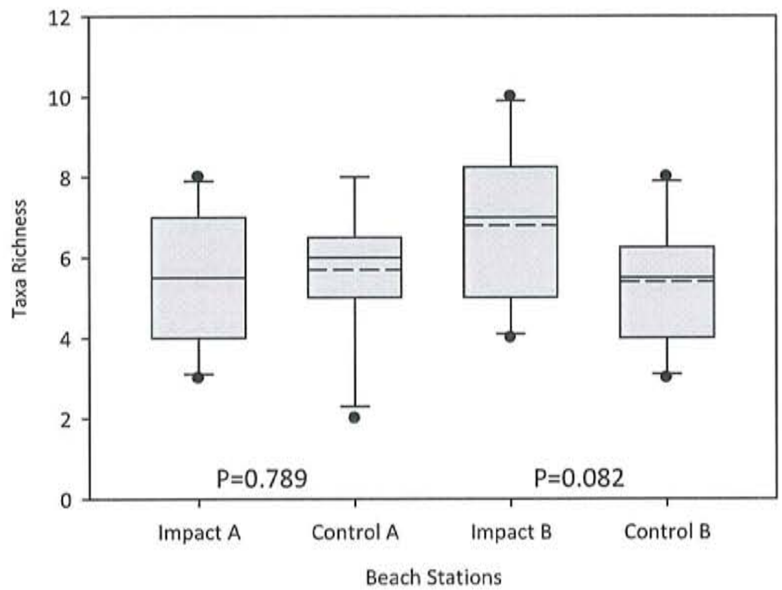


Figure 13. Bar graph with error bars comparing Shannon diversity index between the impact and control beach for the swash Zone A. Error bars depict +/-0.5.

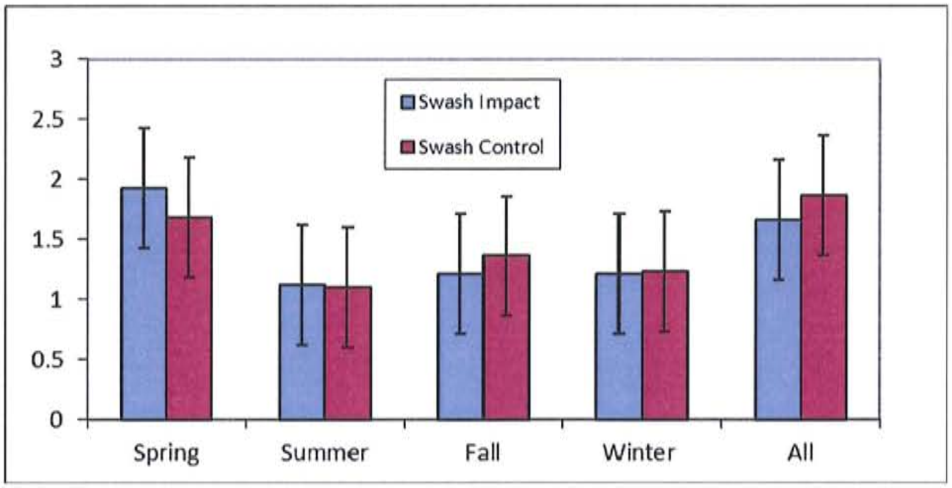


Figure 14. Bar graph with error bars comparing Shannon diversity index between the impact and control beach for the subtidal Zone B. Error bars depict +/-0.5.

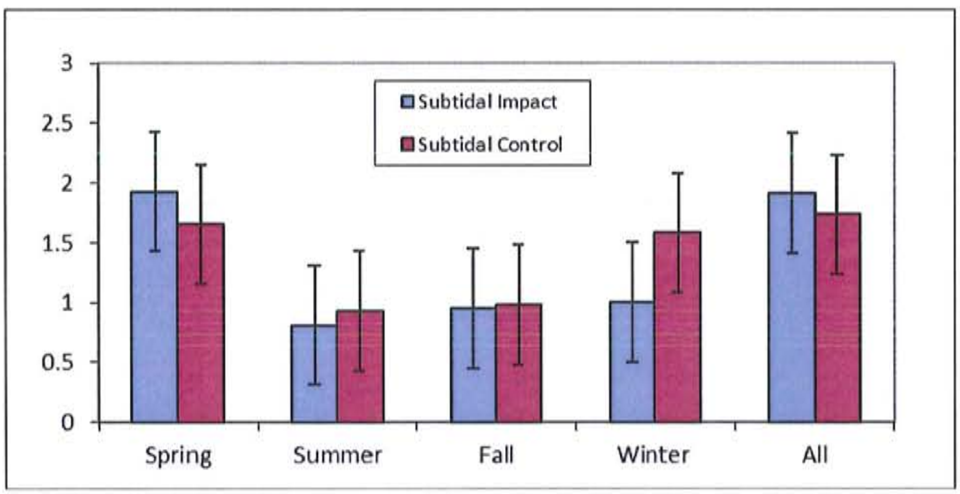


Figure 15. Pie charts comparing groups of taxa found in the swash Zone A of impact and control beach stations by event.

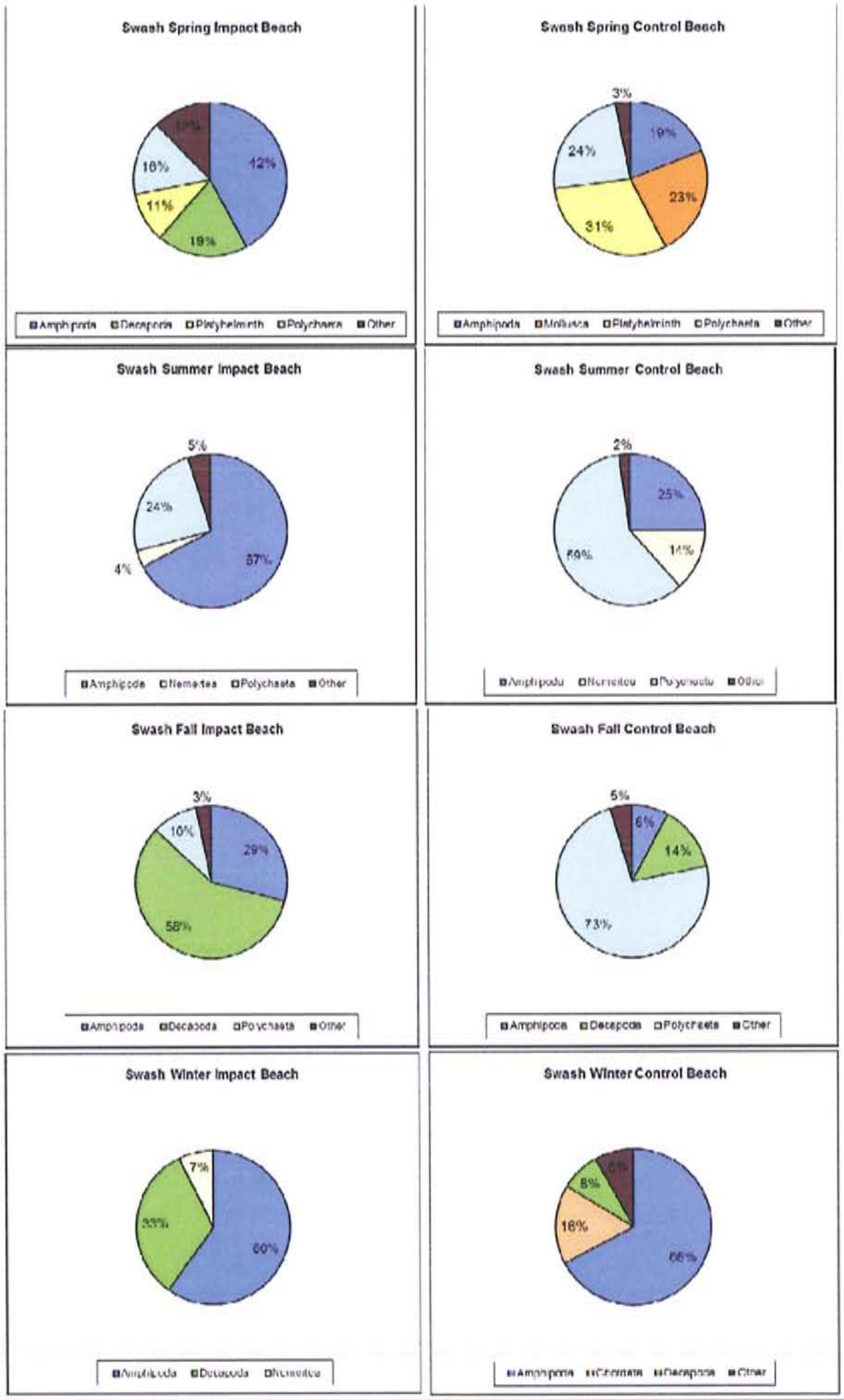
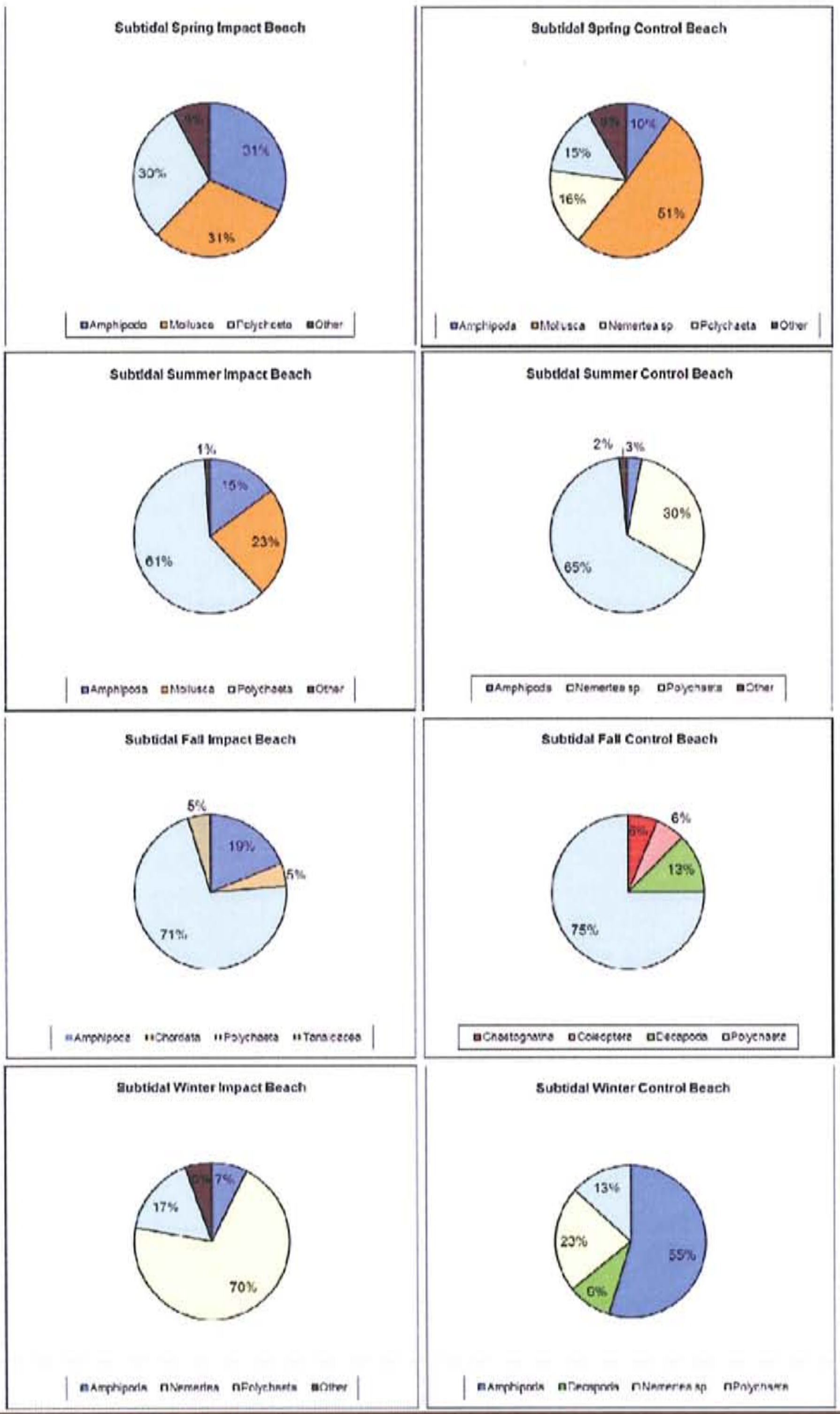


Figure 16. Pie charts comparing groups of taxa found in the subtidal Zone B of impact and control beach stations by event.



impact beaches; similar to what was found in swash Zone A of the control beach (Figure 16). While the number of groups identified show little seasonal variation, the specific groups identified are not necessarily the same between impact and control beaches. Overall the groups identified from the control and impact beaches during the fall sampling are the most different with only 43 percent of the groups identified in common.

Grain sizes were largest on the Kitty Hawk control beach and smallest on the National Seashore control beach, with the impact beach having a mean grain size between the two control beaches. This is consistent with CSE 2005 and USACE 2010 which documented a decrease in mean grain size from north to south along Nags Head. When comparing the swash and subtidal zones on the Kitty Hawk and National Seashore control beaches the swash Zone A sediments are smaller on average and better sorted. In contrast, the impact beach swash Zone A sediments showed little to no difference in grain size compared to the subtidal Zone B and sorting differences between zones was minimal.

Seasonal comparison of grain sizes showed no significant differences among the National Seashore control beach stations; however, very poor sediment sorting was found in both swash and subtidal zones in the fall compared to other seasons. This trend of similar grain size but different sorting characteristics was also seen in the subtidal zone of the Nags Head impact beach. The Kitty Hawk beach exhibited some seasonal variation in grain size; the fall sediment samples had significantly larger grain sizes than the summer and winter sampling events.

The swash and subtidal zone grain size of the Kitty Hawk and National Seashore control stations are significantly different from each other; the grain sizes of the Nags Head impact beach zones fall between the Kitty Hawk and National Seashore grain sizes. The Kitty Hawk control beach (north of Nags Head) has a larger grain size than the National Seashore control beach (south of Nags Head). Swash Zone A of the Nags Head impact beach was significantly different from the swash zones of both control beaches ($p=0.007$ Kitty Hawk and $p=0.024$ National Seashore). Subtidal Zone B of the Nags Head impact beach was significantly different from the Kitty Hawk Zone B control ($p=0.010$); however, it was not significantly different from the National Seashore Zone B control ($p=0.249$).

When average grain size of the Nags Head impact beach stations is compared to offshore impact/borrow and control stations, some significant differences were found. Swash Zone A on the Nags Head impact beach was significantly different from both the offshore impact/borrow ($p<0.001$) and the offshore control ($p=0.007$); however, no significant difference was found when the subtidal Zone B of the Nags Head impact beach was compared to the offshore control and impact/borrow areas ($p=0.496$ and $p=0.151$ respectively).

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APPENDIX A

Taxa enumerated from each Pre-impact benthos sampling event in support of the Nags Head Beach Nourishment Project (2010-2011)

Class/Group	Taxa	Spring				Summer				Fall				Winter			
		Offshore		Beach		Offshore		Beach		Offshore		Beach		Offshore		Beach	
		Control	Impact	Control	Impact	Control	Impact	Control	Impact	Control	Impact	Control	Impact	Control	Impact	Control	Impact
Anthozoa																	
	Actiniaria sp. juv.					X											
	Zoantharia sp.	X															
Ascidiacea																	
	Ascidiacea sp.	X	X			X	X			X	X		X	X	X	X	
	Molgula arenata					X	X										
Asteroidea																	
	Asterias forbesi					X	X										
Bivalvia																	
	Bivalvia sp. juv.	X	X	X		X	X	X	X	X	X	X			X		
	Corbula contracta						X										
	Donax variabilis			X	X			X	X								
	Ensis directus	X	X												X		
	Mytilus edulis															X	
	Pandora trilineata		X														
	Periploma margaritaceum					X				X							
	Periploma sp.						X										
	Spisula raveneli		X														
	Spisula solidissima					X	X										
	Tellina sp.					X	X			X							
	Thracia sp.	X	X														
Cephalochordata																	
	Branchiostoma caribaeum	X	X			X	X			X	X				X		
Chordata																	
	Tunicata sp.	X	X														
Clitellata																	
	Clitellio arenicolas	X	X			X				X	X						
	Heterodrilus arenicolus													X	X		
	Hirudinea sp.								X								
	Oligochaeta sp.	X		X													
	Oligochaeta spp.		X														
	Tubificidae w/o hair	X								X	X				X		
Echinodermata																	
	Echinodermata sp. juv.		X														
Echinoidea																	
	Echinoidea sp. juv.		X			X	X										
	Mellita isometra		X							X	X						
	Moira atropos	X															
Gastropoda																	
	Caecum sp.						X										
	Corambe obscura	X															
	Cylichna sp.					X	X										
	Doridella sp.																X
	Gastropoda sp.	X				X	X				X						

		Spring				Summer				Fall				Winter			
		Offshore		Beach		Offshore		Beach		Offshore		Beach		Offshore		Beach	
Class/Group	Taxa	Control	Impact	Control	Impact	Control	Impact	Control	Impact	Control	Impact	Control	Impact	Control	Impact	Control	Impact
	Polinices duplicatus																
	Vitrinellidae sp.	X															
Hydrazoa																	
	Hydractinia echinata						X										
Insecta																	
	Aphididae			X													
	Diptera sp.															X	
	Staphylinidae											X					
	Mucrogammarus mucronata				X												
Malacostraca																	
	Acanthohaustorius bousfieldi					X											
	Acanthohaustorius sp.						X										
	Amakusanthura magnifica													X			
	Ameroculodes spp. *complex*															X	X
	Americamysis bigelowi									X							
	Amphiporeia virginiana			X	X			X	X			X	X		X	X	X
	Amphipoda sp.			X	X												
	Ancinus depressus									X							
	Apocorophium louisianum				X												
	Apocorophium sp.												X				
	Brachyura sp. juv.					X											
	Chirodotea (caeca)		X							X							
	Chiradoter arenicola														X		
	Cirolani polita	X				X											
	Corophiidae sp.												X				
	Cumacea w/ telson sp. juv.					X	X										
	Cyclaspis varians						X										
	Diastylis sp. juv.						X										
	Edotea sp.					X	X					X					
	Emerita talpoida			X	X			X	X			X	X			X	X
	Flabellifera sp. juv.													X			
	Haustoriidae sp.				X						X						
	Haustorius canadensis			X				X	X								
	Haustorius sp. D			X	X							X				X	X
	Idoteidae sp. juv.		X														
	Lepidactylus dytiscus														X		
	Lepidactylus cf. triarticulatus			X	X												
	Leptocheliidae juv. sp.			X	X												
	Leptocheliidae sp.				X								X				X
	Mancocuma juv. sp.				X												
	Microprotopus raneyi				X	X	X							X			
	Mysidacea sp.										X						
	Ovalipes ocellatus			X												X	X

Class/Group	Taxa	Spring				Summer				Fall				Winter			
		Offshore		Beach		Offshore		Beach		Offshore		Beach		Offshore		Beach	
		Control	Impact	Control	Impact	Control	Impact	Control	Impact	Control	Impact	Control	Impact	Control	Impact	Control	Impact
	Oxyurostylis smithi	X				X	X	X									
	Pagurus annulipes														X		
	Pagurus longicarpus						X										
	Pagurus pollicaris		X														
	Palaemonetes (P.) pugio				X												
	Parahaustorius attenuatus			X	X												
	Parahaustorius longimerus			X	X												
	Processa sp.					X											
	Protohaustorius cf. bousfieldi				X												
	Protohaustorius cf. wigleyi														X		
	Rhepoxynius epistomus														X		
	Tanaissus psammophilus														X		
	Tanaissus sp.		X			X	X			X				X			
	Tiron tropakis					X	X										
	Unicola irrorata						X							X			
	Unicola serrata		X														
Nemertea																	
	Nemertea sp.	X		X	X		X	X	X					X		X	X
Ostracoda																	
	Ostracoda sp.						X				X						
Polychaeta																	
	Aricidea (Acmira)									X							
	Aglaophamus verrilli		X			X	X										
	Aphelochaeta sp.	X					X										
	Brania wellfleetensis	X	X			X	X										
	Capitella capitata	X	X			X	X										
	Caulleriella killariensis		X			X	X										
	Chaetogordius canalicul														X		
	Cirratulidae sp.	X				X	X			X	X						
	Cirrophorus sp.		X							X							
	Dindymenides concinna					X											
	Diopatra cuprea														X		
	Dorvillidae sp.	X															
	Eteone heteropoda	X			X	X	X										
	Eteone lactea									X							
	Glycera sp.	X				X	X										
	Harmothoe sp.									X							
	Hemipodus sp.									X							
	Hesionides pettiboneae			X	X			X	X			X					
	Hesionura coineaui														X		
	Lumbrineridae sp.									X							
	Lumbrinerides dayi	X								X							
	Lysarete brasiliensis					X											
	Lysidice ninetta					X											

Class/Group	Taxa	Spring				Summer				Fall				Winter			
		Offshore		Beach		Offshore		Beach		Offshore		Beach		Offshore		Beach	
		Control	Impact	Control	Impact	Control	Impact	Control	Impact	Control	Impact	Control	Impact	Control	Impact	Control	Impact
	Lysilla sp.									X	X						
	Mediomastus ambiseta				X												
	Nephtys bucera									X	X			X	X		
	Onuphis sp.					X	X										
	Ophelia denticulata						X			X	X						
	Ophelia sp.						X										
	Opheliidae sp. juv.						X				X						
	Owenia sp.					X	X										
	Paraonis pygoenigmatica	X															
	Parougia caeca	X				X	X			X	X			X	X		
	Phyllodocidae sp.	X				X				X				X	X		
	Pionosyllus sp.										X			X			
	Polydora cornuta						X										
	Polydora socialis						X			X							
	Polydora websteri										X						
	Polygordius jouinae					X	X			X	X			X	X		
	Polynoidae sp.			X													
	Protodriloides chaetifer										X						
	Ramphobrachium atlanticum					X	X										
	Scolelepis squamata			X	X			X	X			X	X			X	X
	Sigalion sp.	X				X								X			
	Spiophanes bombyx	X	X			X	X										
	Streblospio benedicti							X									
	Streptosyllis pettiboneae	X	X				X				X			X	X		
	Syllidae sp. juv.					X				X							
	Terebellidae sp.														X		
	Tharyx sp. A					X				X	X				X		
Sagittoidea																	
	Sagitta sp.										X	X					