THE EFFECTS OF BEACH RENOURISHMENT ON BENTHIC MICROALGAE

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ABSTRACT

Coastal erosion threatens hundreds of miles of beach every year making beach renourishment in the southeastern United States essential to the economic health of coastal communities. Governments often fail to consider the possibility of ecological damage associated with renourishment projects and the potential for negative impacts on local fisheries through damage to benthic microalgae, the base of the food web. This study set out to determine what impact beach renourishment had on the benthic microalgal communities by measuring and comparing chlorophyll *a* concentrations before and after renourishment at Kure Beach and Carolina Beach in southeastern North Carolina.

The final data set contained 4260 chlorophyll *a* measurements that covered two beaches, 8 sites, 16 transects, and 3 elevations per treatment with 6 samples collected at each elevation. Sediment samples were also analyzed for mean grain size. Sampling design considered effects of site elevation, renourishment, and seasonality and was completed 15 times for each beach for a total of 30 sampling trips. Up-current and down current controls were included in the experimental design Chlorophyll *a* measurements ranged from 0.00 mg/m^2 to 14.88mg/m^2 with an overall mean of 3.53 mg/m^2 (σ = 2.22).

Results show no significant impact from renourishment on benthic microalgal communities at either beach. Paired comparisons between beaches, and between treatment and control sites at each elevation were made using a mixed model ANOVA (SAS) with no significant results observed. Data indicated a negative relationship between chlorophyll *a* concentrations and grain size but the source sediment for these projects was well suited for the renourished beaches. No significant change in grain size after renourishment was observed and no drop in chlorophyll *a* could be detected.

ACKNOWLEDGEMENTS

I would like to thank Dr. Lawrence Cahoon for his unyielding patience, support and guidance through my graduate career. My committee members, Dr. Michael Mallin and Dr. Lynn Leonard also deserve thanks for the advice and suggestions that gave this thesis depth and perspective. Thank you to Dr. Jim Blum for all his statistical guidance without which I would have been lost in a sea of indecipherable variance. Thanks also to Dr. Joan Willey who is an inspiration to all women in the field and who has consistently shown true compassion for her students.

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INTRODUCTION

Beaches are the number one destination for tourists worldwide. The United States Travel and Tourism Administration estimated that in 1992, beaches contributed about $170 billion dollars to the U.S. economy (Houston 2002). Beach renourishment on the southeastern coast of the United States is essential to the economic health of the region. Coastal erosion threatens hundreds of miles of beach every year, reducing property values and tourism revenue by increasing the steepness as well as narrowing public and private beaches. Beach renourishment, the process by which sand is pumped onto a diminished beach to protect it from further erosion, is the most effective method used in the battle against migrating coastlines (Houston 2002).

Benthic microalgal communities are a potentially significant source of primary production in the open beach environment. Where macroscopic vegetation is lacking, as in the high-energy swash zones of coastal southeastern North Carolina, sediment-associated microalgae are the main primary producers, constituting an important carbon source for local benthic food webs (Wulff 1997). Studies have shown that in shallow water environments benthic microalgae support as much primary production as phytoplankton (Cahoon and Cooke 1992, Krom 1991). Benthic micro-flora, typically dominated by numerous species of diatoms and blue-green algae, are grazed heavily by an assortment of organisms including isopods, amphipods, mollusks, shrimp, nematodes, and ostracods (Miller et al. 1996, Mallin et al. 1992). The grazers are then preyed upon by a host of estuarine and coastal marine fishes (Mallin et al.1992). The microbenthic algal community is thus essential as a food source for species that are both recreationally and ecologically significant. Surf fishes represent just a few of these important species and they make a substantial contribution both to the local economy and to property values in the southeastern United States (Peterson et al. 2000).

Decisions to replenish beaches are economically driven and coastal managers often fail to consider the possibility of ecological damage from beach renourishment and the potential of post-renourishment impacts from reduced benthic microalgae on local food webs. This study sought to determine what impact beach renourishment has on benthic microalgal biomass in the high-energy environment of the open sandy beach.

A review of the literature yielded a paucity of data on the effects of beach renourishment on benthic microalgae. Studies on benthic microalgae in any beach environment are difficult to find save small studies by Steele and Baird (1968), who studied primary production in a small Scottish cove, and Sousa and Davis (1996), who looked at daily variations in photosynthetic pigments on the beach. Though studies have been done on the impacts of renourishment on macrofauna such as sea turtles (Rumbold et al. 2001), bivalves (Gorzelany and Nelson 1987), crustaceans (Hayden and Dolan 1974) and fish (Wilber et al. 2003), the benthic microalgal community has largely been ignored. Without knowledge of how primary producers are impacted it is impossible to understand the full ecological impact of renourishment events.

The literature lacks data on renourishment impacts on benthic microalgae on the open beach, but a few studies on burial impacts in estuarine environments do exist. Panasik (2003) studied the recruitment of benthic microalgae after the addition of dredged material in the marshes of Masonboro Island in North Carolina. That study found that after a sharp decline in benthic microalgal biomass immediately following the addition of the dredged material (determined through chlorophyll a quantification), chlorophyll a values increased dramatically, even surpassing pre-deposit values. Panasik (2003) showed a propensity for benthic microalgae to recolonize rapidly but did not examine the high-energy environment found at the open beach. The stabilizing presence of *Spartina alterniflora* (Panasik 2003) coupled with the low energy environment of the marsh draw a sharp contrast to the unvegetated and dynamic open beach landscape. Benthic microalgae in the estuarine ecosystems are limited to the upper few millimeters of sediment, while viable benthic microalgae can be found as deep as tens of centimeters in the well mixed sandy sediments of the open beach (MacIntyre et al. 1996). Such distribution differences may be highly significant when considering the potential for recovery or survival in a rapid turnover situation as occurs with beach renourishment. Benthic microalgae, though most likely significant primary producers in both estuaries and the open beach, cannot be assumed to behave identically in such dichotomous environments. It is therefore important to examine the open beach community of benthic primary producers as a separate entity.

OBJECTIVES

The primary objective of this study was to determine if beach renourishment had a significant impact on benthic microalgae biomass in the open beach environment. Knowing that organisms are likely to respond across an elevation gradient due to the dynamic nature of the environment, and knowing that even the timing of beach renourishment is mandated by a seasonal pattern in recruitment, can we uncover a renourishment effect on top of or even amidst these other variables? It is also known that grain size may affect species composition based on size and type of material, but will it also regulate biomass? And if so, will there be a beach renourishment effect on top of, or even because of this grain size effect? In order to answer these questions, I examined four different variables known to regulate benthic microalgae biomass in the environment. Temporal or seasonal changes, spatial changes, elevation differences, and grain size composition were all tracked during the course of the study and evaluated in the final analysis. Environmental factors were also considered in the experimental design. Water temperature, ultraviolet radiation intensity and observational weather descriptions were considered when establishing hypotheses and noted during and after field sampling.

The second objective of this study was to establish a baseline data set for benthic microalgae biomass in the open beach environment. As of July 2005, there were no data in the literature relating to this topic. Using the data collected from this study, the scientific community may begin comparing the productivity of beaches around the world. Any addition to the scientific knowledge of primary production will help determine human impacts on food chains and may lead to a better understanding of our more complicated coastal fisheries.

The study objectives were accomplished by testing four separate null hypotheses. The first hypothesis asserted that there would be no significant temporal difference in the microalgal biomass measured over the course of the study. Similarly, the other hypotheses asserted that there would be no significant differences measured at the study sites based on the renourishment project, elevation differences, or mean grain size. Although testing null hypotheses, I did expect to see both seasonal differences in microalgal biomass and differences based on elevation. I also expected to see an overall effect on chlorophyll *a* stemming from the beach renourishment event itself and a negative relationship between average sediment grain size and chlorophyll *a* concentration at the individual beaches.

Though not initially intended as an objective for this project, developing guidelines for future studies of this nature became a natural evolution as the analysis of the current sampling design progressed.

METHODS

This study was conducted at Kure and Carolina Beaches in southeastern North Carolina. Sampling began December 2003 and concluded December 2004. Renourishment at Kure Beach began March 15, 2004 and ended March 31, 2004. Dredging was executed with a hopper dredge with intermittent deposition points along the beach. Two hundred and seventy thousand, two hundred cubic yards of sand were deposited along one mile of beach between N 33°58.59.337′, W 077°54.565′ and N 33°58.530′, W 077º54.864′ (Figure 1). Renourishment at Carolina Beach began March 21, 2004 and ended in mid April 2004. A pipeline dredge was used in the project and the deposition of sand was continuous along the beach. Seven hundred and thirty eight thousand, four hundred cubic yards of sand were deposited along six thousand feet of beach between N 34º03.659′, W 077º52.809′and N 34º01.716′, W 077º53.650′ (Figure 2).

Four sites were selected on each beach based on the location of planned renourishment and prevailing longshore currents. One site (Site 1) north, or up-current of the renourishment starting point was used as a control site. Dominant longshore currents flow from north to south along Kure and Carolina Beaches. Two sites within the proposed renourishment project were used as treatment sites (Site 2 and Site 3). One site (Site 4) south, or down-current, of the renourishment end-point was used as a second control site. For each site, two transects were taken approximately ten meters apart and parallel to each other running east to west, perpendicular to the shore. Each transect was sampled below the high tide line, in the swash zone, and approximately five meters into the subtidal zone. Transects for Kure beach were labeled A through H (Figure 1). Transects for Carolina Beach were labeled J through Q (Figure 2).

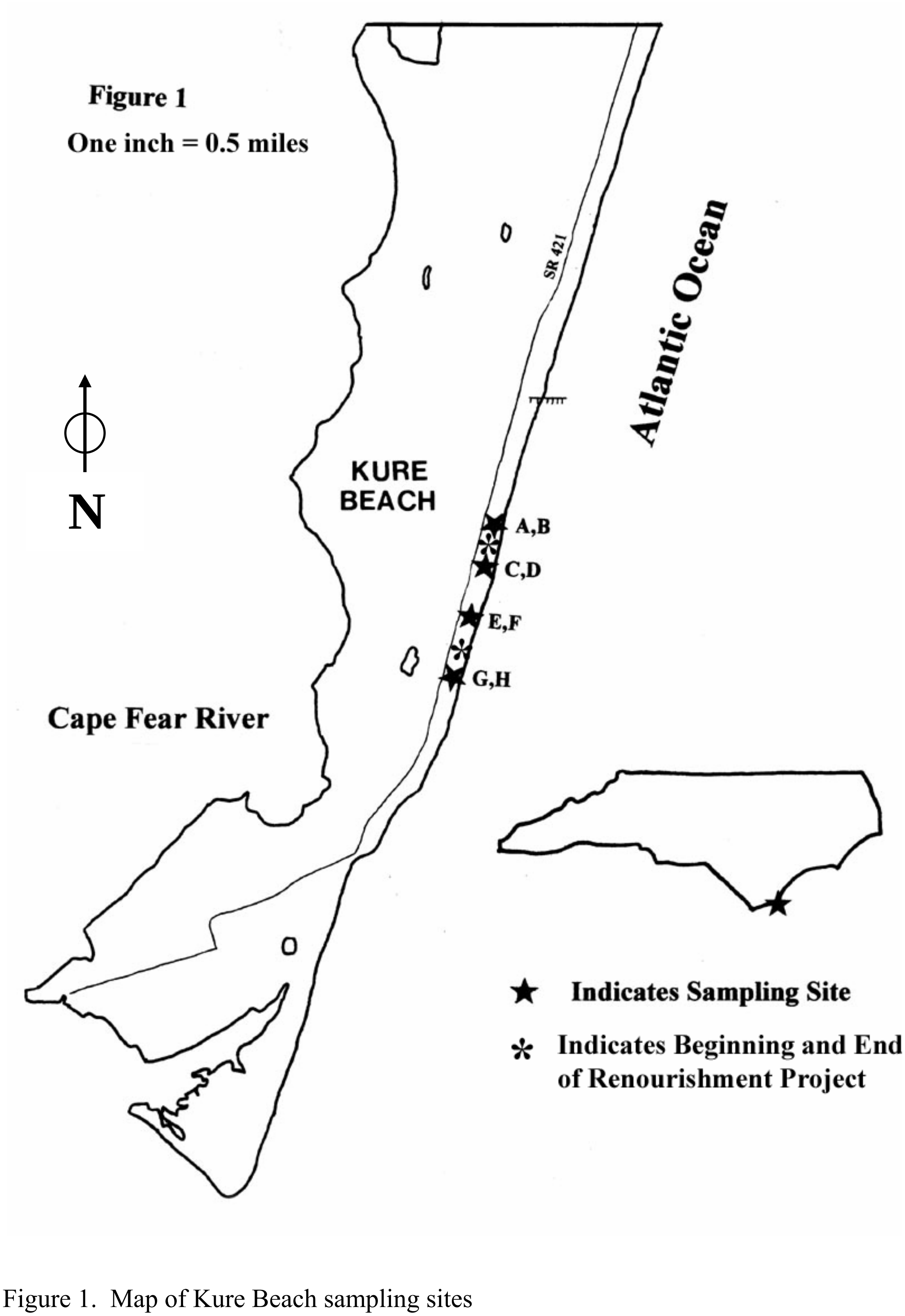


Figure 1. Map of Kure Beach sampling sites

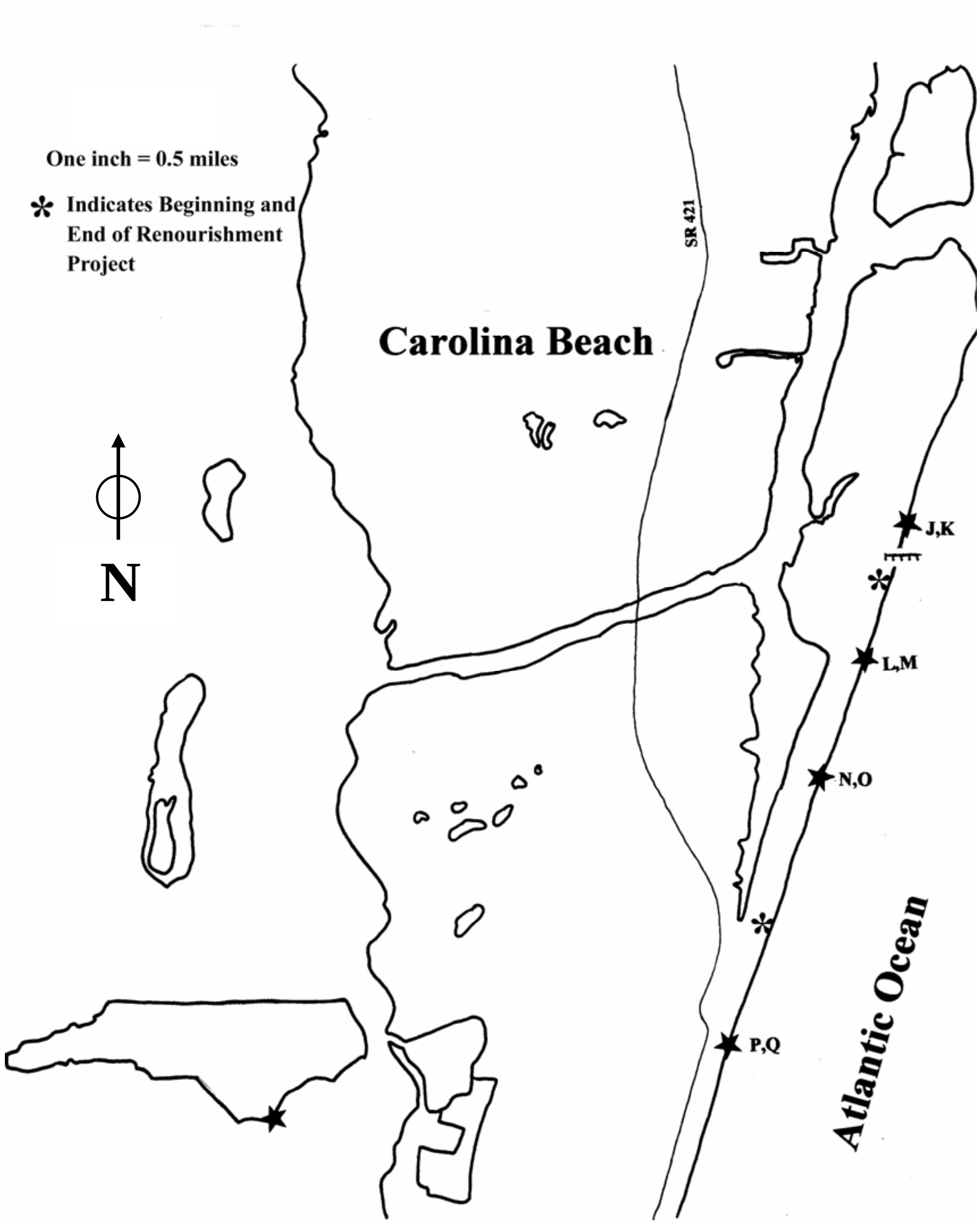


Figure 2. Map of Carolina Beach sampling sites

Sampling began three months prior to the renourishment project and concluded after one year. Samples were taken in the three months preceding the renourishment with the exception of February 2004. Samples were taken at two-week intervals through the renourishment period and in the two months following its completion. Subsequently, samples were taken at three-week intervals for a period of two months and then once a month through December 2004.

At each sampling point, six cores were taken using a hand held polybutyrate corer with a diameter of 2.34 cm, and placed in separate 50ml centrifuge tubes. The volume of each sample was variable due to the dynamic wave environment and the resulting variability in subtidal grain size. However, when collected, each core reached at least the 15ml marking on the centrifuge tube into which it was transferred. This process ensured the sampling of the most likely environment for microalgae in the top few centimeters of the core (MacIntyre et al. 1996). After collection, the tubes were capped, placed in ice and frozen until chlorophyll *a* lab analys

Chlorophyll *a* was measured using a Turner Designs 10-AU Fluorometer according to Welschmeyer (1994). Analysis in the lab was completed in darkness to avoid light-induced degradation of the chlorophyll *a*. Samples were thawed in a water bath at room temperature and all water except for the last few milliliters was decanted to avoid diluting the acetone treatment. Once the samples were decanted, 20 ml of 100% acetone was added to each tube and each was shaken vigorously. Samples were then stored at -10 degrees C in darkness for 16-24 hours. Chlorophyll a concentration was calculated using the following formula:

mg chlorophyll *a* / m² = [reading μg/L acetone x {0.02L}] / [0.00041548 m² (area of the corer) x 1000μg/mg]

$$\text{mg chlorophyll } a / m^2 = [\text{reading } \mu g/L \text{ acetone} \times \{0.02L\}] / [0.00041548\ m^2 \text{ (area of the corer)} \times 1000 \mu g/mg]$$

Once analyzed for chlorophyll *a*, sediment samples were drained of acetone and dried in an oven at 50 °C for 24 hours. After drying, the six samples taken per elevation were combined and then analyzed for sediment size (modal and mean) and %<125 μm based on methods outlined in Folk (1980). Air temperature, water temperature and UV radiation levels were also monitored during the study in order to track environmental patterns not associated with beach renourishment. The Estuarine Research Reserve and NOAA collected these data hourly.

In order to determine if the methods used in this sampling scheme were sensitive enough to find differences in chlorophyll *a* data in the dataset it was necessary to determine the coefficient of variance (σ/μ). Thirty sub-samples were tested for variation to determine if the coefficient of variation for replicate sets was small enough to allow the sampling method to find differences in the data. For each sampling date, one elevation was drawn randomly to be evaluated. Values for the coefficient of variation ranged from 0.04 to 1.41 with a mean of 0.24. Most values (73.3%) were between 0.04 and 0.20 with only 3 values above 0.49 and only 1 above 1.0 (Microsoft Excel). These results show that the sensitivity of the sampling method was more than adequate to identify differences in chlorophyll *a* concentrations in this study (Sokal and Rohlf 2003).

Kure and Carolina Beach controls were compared to test for coherence and suitability as controls. This was determined using a mixed model ANOVA (SAS) that allowed the sampling sites to be modeled as repeated measures over time. Elevation, chlorophyll *a* response, treatment or control, and time were taken as factors influencing the response of chlorophyll *a*. A heterogeneous autoregressive error structure was used to allow variance to change over time. This structure also allowed observations closer in time to be modeled with higher correlation than those further away.

The number of samples taken in this study was very high. To determine if that amount of sampling effort was necessary a plot (SigmaPlot 2000) of variance versus sample size was created to determine at what sampling size variance began to plateau and further sampling was no longer useful. Sample size on the plot ranged from 3 (the lowest number used for variance calculations) to 12 (the greatest number of samples taken at any one elevation).

RESULTS

The final data set contained 4260 chlorophyll *a* measurements that covered two beaches, 8 sites, 16 transects, and 3 elevations. Chlorophyll *a* measurements ranged over two orders of magnitude, from 0.00 mg/m^2 to 14.88mg/m^2 with an overall mean of 3.53 mg/m^2 ($\sigma = 2.22$). Kure Beach averaged a chlorophyll *a* concentration of 2.98 mg/m^2 ($\sigma = 1.94$) over the course of the project while Carolina beach averaged 4.08mg/ m^2 ($\sigma = 2.33$). To meet the second objective of this project, chlorophyll *a* data were compiled to offer future studies of this kind a basis for comparison (Table 1, Table 2).

Immediately following the renourishment cycle, and for the succeeding two months, the northernmost Carolina Beach control, Site 1, was found to have significantly higher ($p<0.05$) chlorophyll *a* values than the southern most Carolina Beach control and the two Kure Beach controls at all 3 elevations from late March 2004 through early June 2004 (Figure 3). Site 1 was closest to and roughly 2500m down-current from the dredging site at Carolina Inlet (Figure 2). Because of its geographical proximity to the renourishment it is possible that dredge material from long shore transport impacted the site without direct placement of the material on the beach.

The southernmost Carolina Beach control site, Site 4, was not found to be significantly different from the two Kure Beach controls and was thus judged suitable for use as a control for

Carolina Beach	Site 1	Site 2	Site 3	Site 4
Chl a Mean (mg/m^2)	5.10	3.55	3.98	4.04
Chl a Standard Deviation	1.56	1.30	1.41	1.48
Chla Minimum (mg/m^2)	0.13	0.06	0.10	0.09
Chla Maximum (mg/m^2)	11.09	12.49	2.50	14.00
Chl a Median (mg/m^2)	4.94	2.21	13.54	3.30
			Grand Mean Chl *a* (mg/m^2)	4.08

Table 1. Benthic chlorophyll *a* data for each sampling site at Carolina Beach.

Kure Beach	Site 1	Site 2	Site 3	Site 4
Chl *a* Mean (mg/m^2)	3.08	3.09	3.27	2.66
Chl *a* Standard Deviation	1.22	1.21	1.15	1.01
Chl *a* Minimum (mg/m^2)	0.07	0.00	0.05	0.02
Chl *a* Maximum (mg/m^2)	9.84	13.54	13.54	9.41
Chl *a* Median (mg/m^2)	1.75	1.68	2.31	2.52
		Grand Mean Chl *a* (mg/m^2)		2.98

Table 2. Benthic chlorophyll *a* data for each sampling site at Kure Beach.

both treatment sites at Carolina Beach. Upon determination that the Site 1 control was significantly different from the other controls it was eliminated as a true control for that time frame but still used in some analyses for probative value. After late May 2004 the treatment and control sites at both beaches returned to a coherent pattern (Figure 3).

Chlorophyll *a* data were analyzed to determine if an overall temporal pattern associated with the beach renourishment event existed within the dataset but none was found. No significant periodicity was found in the data, and there was no consistent scale of temporal variability.

No seasonality pattern emerged from this analysis. A mixed model ANOVA (SAS) was used to compare chlorophyll *a* concentrations at control sites to adjacent treatment sites based on sampling dates. A total of eighty-four comparisons, with the p-value adjusted via the Sidak-Holm method (α=0.05) were made with only 1 significant difference found ($p = 0.0025$). The single difference was found in the swash zone of a treatment site at Carolina Beach in the late March/early April time frame. Chlorophyll *a* values in this paired comparison were found to be significantly higher in the treatment site than in the control site (Table 3).

Chlorophyll *a* differences between the two beaches also were analyzed through paired comparisons using the same model employed in the control-treatment analysis. Eighty-four paired comparisons were made and 6 significant differences were found within those comparisons. All 6 of the significant differences indicated that Carolina Beach had higher chlorophyll *a* concentrations than Kure Beach at comparable sampling times. Of those 6 differences, 3 (50%) had significantly higher chlorophyll *a* levels in control sites and 3 (50%) had significantly higher chlorophyll *a* levels in treatment sites (Table 4).

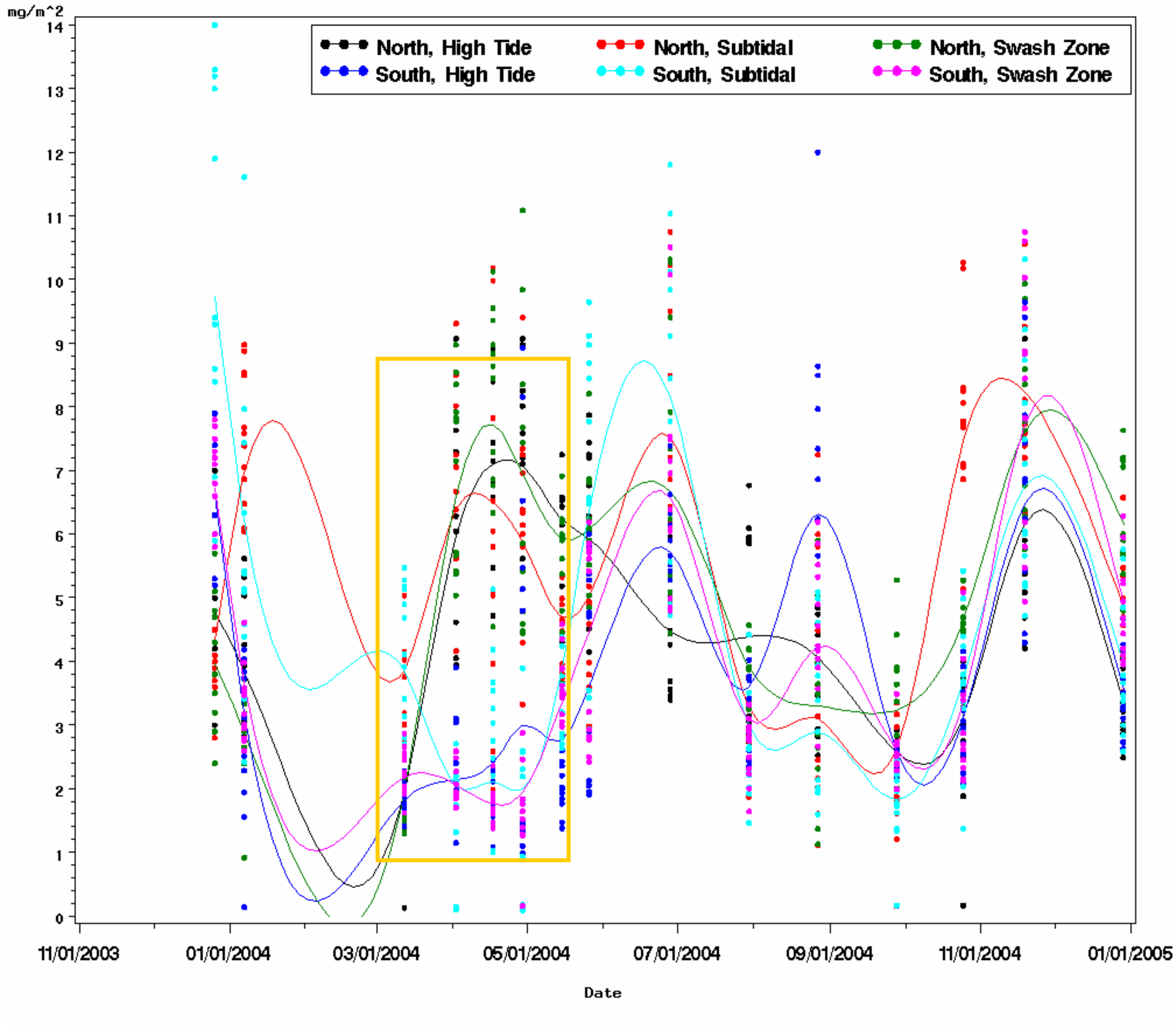


Figure 3. Mean chlorophyll *a* concentrations by elevation at Carolina Beach control Sites (Site 1- north (anomalous), Site 4- south)
Yellow box indicates time-frame when chlorophyll a concentrations at the two control sites were significantly different from one another

Beach	Date	Elevation	Est.	Original t-statistic	Unadjusted p-value	Sidak Adjusted p-value
Carolina	**Late March/Early April**	**Subtidal**	**-5.597**	**-4.2127**	**0.000030**	**0.002498**

Table 3. Significant paired comparison of chlorophyll *a* concentrations by elevation and comparable sampling time between treatments (Control-Treatment).

Date	Treat.	Elevation	Est.	Original t-statistic	Unadjusted p-value	Sidak Adjusted p-value
August	**C**	**High Tide**	**3.2520**	**3.709785**	**0.000230**	**0.018230**
Mid April	**T**	**Swash**	**3.8435**	**3.631248**	**0.000310**	**0.024212**
Late Dec./Early Jan.	**C**	**Subtidal**	**5.7558**	**4.748711**	**0.000003**	**0.000218**
Early March	**C**	**Subtidal**	**3.9372**	**5.941080**	**0.000000**	**0.000000**
Early March	**T**	**Subtidal**	**3.2164**	**7.918592**	**0.000000**	**0.000000**
Late March/Early April	**T**	**Subtidal**	**4.2066**	**3.988727**	**0.000076**	**0.006140**

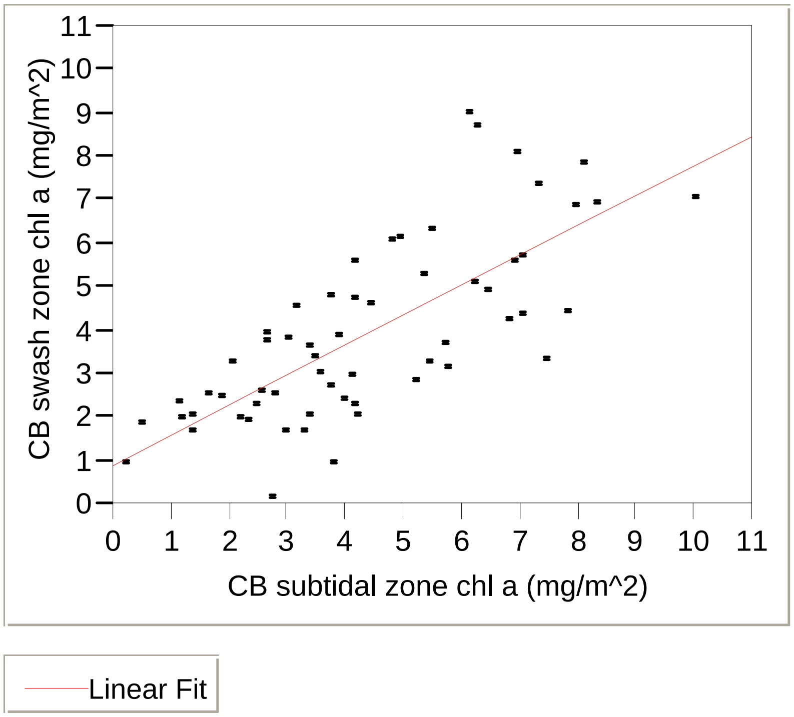
Table 4. Significant paired comparisons of chlorophyll *a* concentrations by elevation and comparable sampling time between beaches (Carolina-Kure).

Differences in chlorophyll *a* concentrations among elevations at identical sites were explored graphically (SigmaPlot 2000) and statistically (JMP 4.0) to determine correlation. Though graphically the concentrations of chlorophyll *a* at the different elevations on the beach seemed to follow similar patterns, when compared statistically they were not the same (slope was not equal to 1). Ninety-five percent confidence intervals around the calculated slope values included 1.0 for only the Kure Beach subtidal zone/swash zone comparison although two other comparisons had slopes + 95% confidence interval values close to 1.0 (0.99 for the Kure Beach high tide zone and swash zone comparison and 0.98 for the Carolina Beach swash zone and high tide zone comparison). All comparisons did show high correlation (>0.51) however, which indicates that the different elevations on the beach co-varied and chlorophyll *a* concentrations at one elevation increased proportionally with the chlorophyll *a* concentrations at other elevations (Figures 4-9).

Grain Size

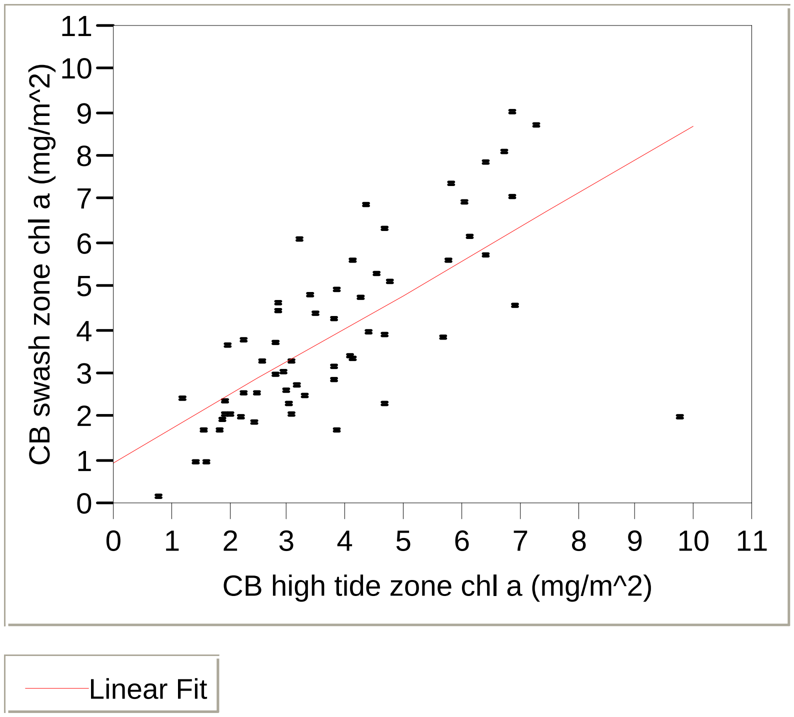
Two hundred and seventy-nine grain size analyses were conducted on the sediment collected in the subtidal zone of the two beaches. Grain size ranged from less than 0.63mm to greater than 2mm, the larger grains usually composed of shell hash. The mean grain size for Carolina Beach samples before renourishment was 0.3mm (σ =0.08) while post-renourishment the mean grain size was 0.44mm (σ =0.50). The mean grain size in samples taken at Kure Beach prior to renourishment was 0.68mm (σ =0.25) and following renourishment the average grain size was 0.48mm (σ = 0.46). A one- way ANOVA (Microsoft Excel) was run to determine if differences between pre-renourishment sediment grain size and post-renourishment sediment grain size at Kure and Carolina Beaches were significant ($p< 0.05$). Differences between pre- and post-

Figure 4. Bivariate fit of CB swash chl *a* (mg/m^2) by CB subtidal chl *a* (mg/m^2)



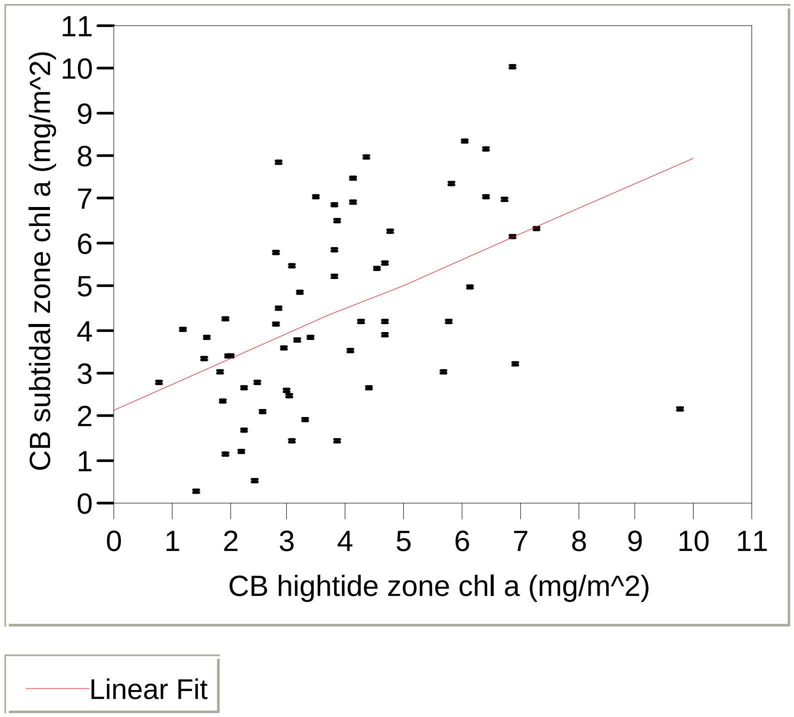
CB swash chl *a* (mg/m^2) = 0.907 + 0.687 CB subtidal chl *a* (mg/m^2)
(r^2= 0.23, p<0.0001), (95% C.I. 0.69 ± 0.16)

Figure 5. Bivariate fit of CB swash chl *a* (mg/m^2) by CB high tide chl *a* (mg/m^2)



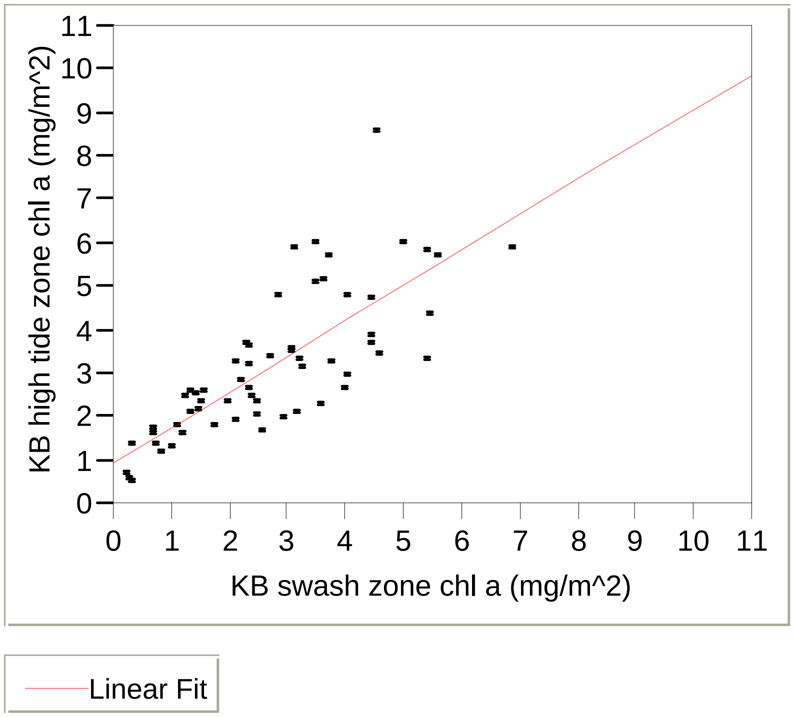
CB swash chl *a* (mg/m^2) = 0.930 + 0.778 CB high tide chl *a* (mg/m^2)
(r^2= 0.48, p<0.0001), (95% C.I. 0.78 ± 0.2)

Figure 6. Bivariate fit of CB subtidal chl *a* (mg/m²) by CB high tide chl *a* (mg/m²)



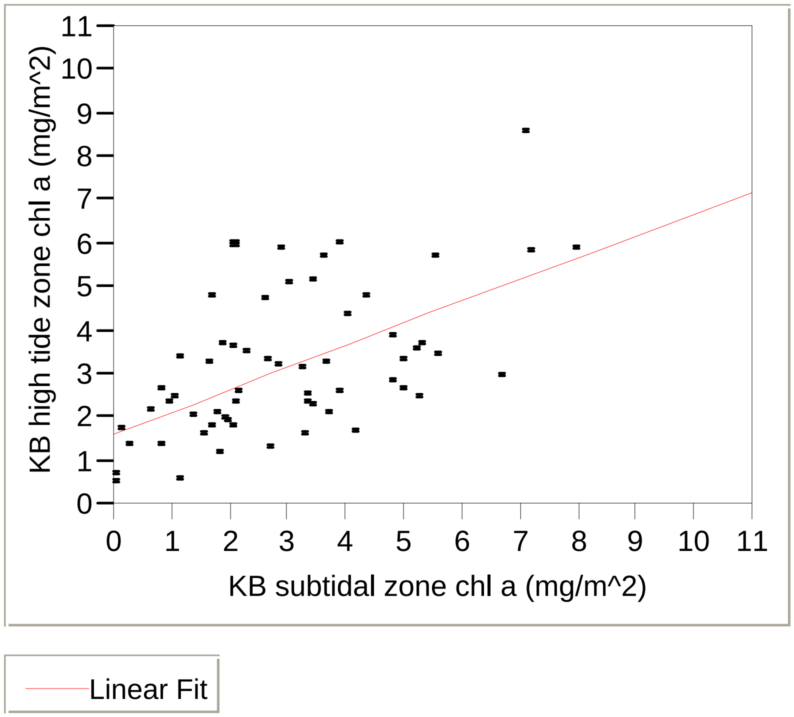
CB subtidal chl *a* (mg/m^2) = 2.168+ 0.579 CB high tide chl *a* (mg/m^2) (r^2= 0.55, p<0.0001), (95% C.I. 0.58 ± 0.28)

Figure 7. Bivariate fit of KB high tide chl *a* (mg/m^2) by KB swash chl *a* (mg/m^2)



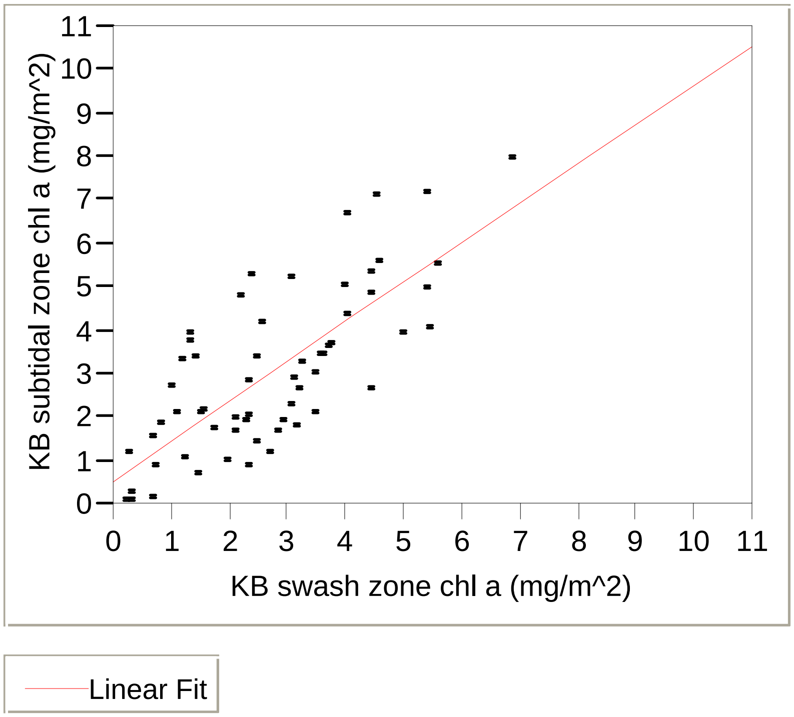
KB high tide chl *a* (mg/m^2) = 0.921 + 0.815 KB swash chl *a* (mg/m^2)
(r^2= 0.59, p<0.0001), (95% C.I. 0.81 ± 0.18)

Figure 8. Bivariate fit of KB high tide chl *a* (mg/m^2) by KB subtidal chl *a* (mg/m^2)



KB high tide chl *a* (mg/m^2) = 1.625 + 0.506 KB subtidal chl *a* (mg/m^2)
(r^2= 0.33, $p<0.0001$), (95% C.I. 0.51 ± 0.18)

Figure 9. Bivariate fit of KB subtidal chl *a* (mg/m^2) by KB swash chl *a* (mg/m^2)



KB subtidal chl *a* (mg/m^2) = 0.531 + 0.912 KB swash chl *a* (mg/m^2)
(r^2= 0.58, $p<0.001$), (95% C.I. 0.91 ± 0.2)

renourishment mean grain sizes were not significant at either beach (Kure, df = 137, p = 0.10; Carolina, df = 137, p = 0.19).

The grain size data set for this study was plotted (SigmaPlot 2000) for visual assessment and was found to be highly skewed, and heterogeneous (Figure 10). Because the data violated two of the assumptions required for parametric tests, Spearman's rho (JMP 4.0), a non-parametric test, was used to determine correlation between chlorophyll *a* concentration and grain size. The negative relationship between the two parameters was highly significant (correlation coefficient= -0.5152, p<0.0001).

Variance may have obscured differences in the chlorophyll *a* data owing to renourishment effects, so it was essential to identify and partition variance among beaches, sites, and elevations. SAS was used to compute the residual sums of squares variance associated with each parameter so that sources of the variance could be quantified (Table 5) and visualized (Figures 11-12).

Figure 11 partitions residual variance, pooled over time, across beach and elevation combinations. Both sampling transects from each site are represented for a more accurate illustration of the sources of variation. Kure Beach shows a gradual increase in total variance from the high tide zone (H) to the swash zone (I) to the subtidal zone (S). Values are slightly higher in the treatment sites (20.5% of total variance versus 17.5% in the control sites). The subtidal zone at the control sites shows 2.1 times as much variance as the swash zone and 4.2 times as much variance as the high tide zone. The treatment sites also show the most variance in the subtidal but do not show the same dramatic difference between elevations as seen in the control sites (2 times higher than the high tide zone and 1.4 times higher than the swash zone).

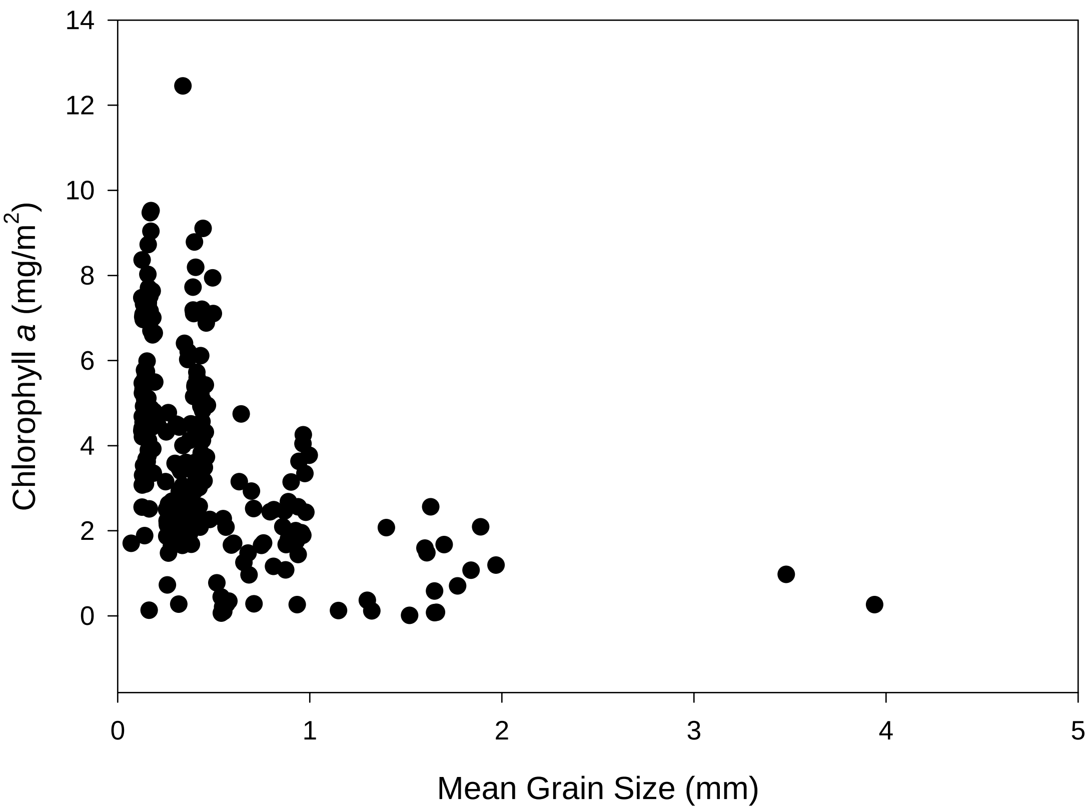


Figure 10. Chlorophyll *a* versus mean grain size

Site	Carolina Beach			Kure Beach			**Total**
	H	I	S	H	I	S	
C1	1.81	1.83	2.67	0.77	0.53	3.61	**11.22**
C2	1.16	1.28	2.67	0.67	1.89	3.76	**11.43**
C3	3.24	3.02	3.84	0.67	0.77	1.53	**13.07**
C4	3.17	2.62	6.56	0.70	0.75	1.89	**15.69**
T1	1.72	2.91	3.47	2.52	3.30	2.40	**16.32**
T2	0.94	1.0	2.87	0.69	1.80	3.61	**10.91**
T3	2.43	1.09	4.14	0.79	0.91	1.89	**11.25**
T4	3.46	2.0	2.11	0.62	0.64	1.28	**10.11**
Total	**17.93**	**15.75**	**28.33**	**7.43**	**10.59**	**19.97**	

Table 5. Percentage of variance found among beach, site, and elevation

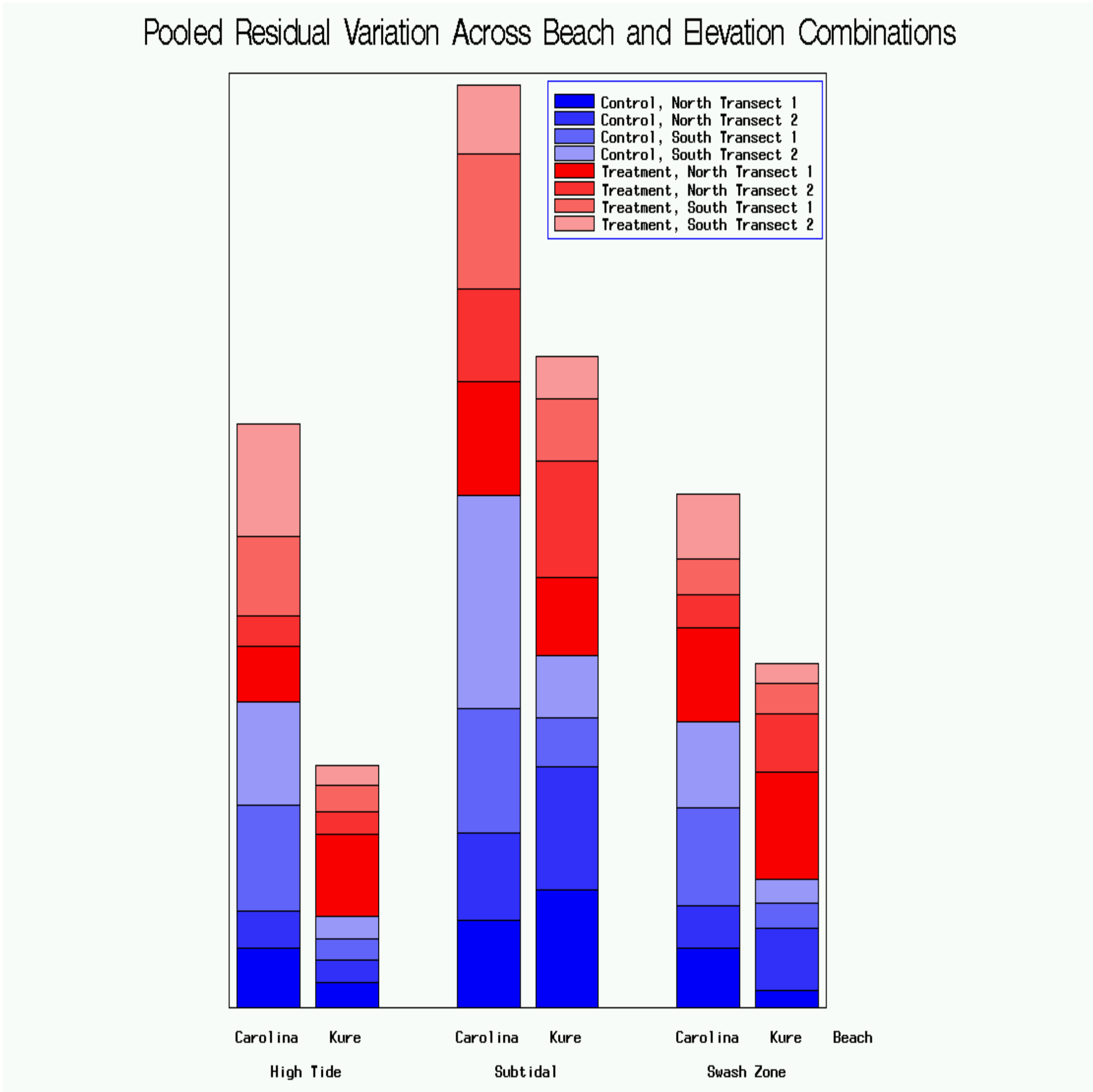


Figure 11. Pooled residual variation across beach and elevation combinations

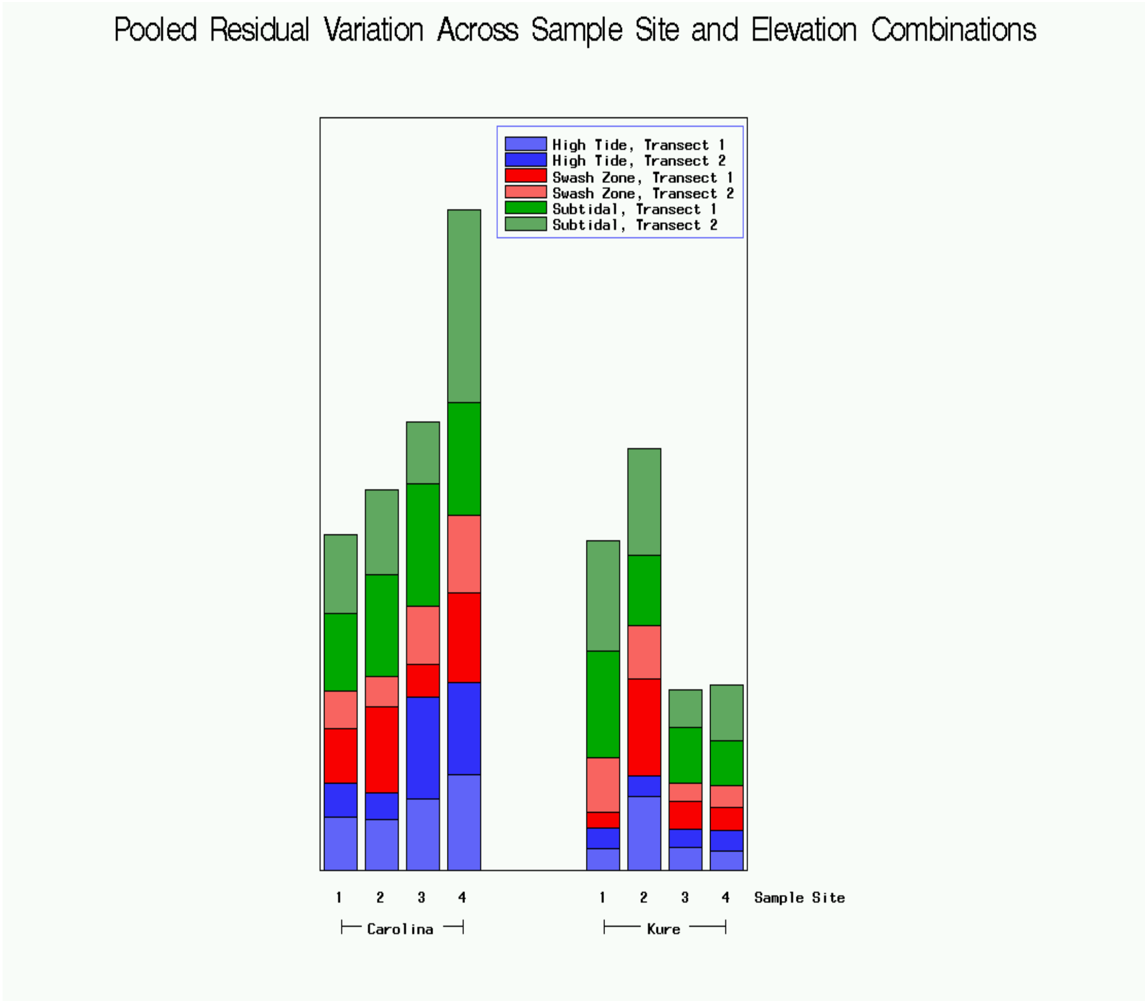


Figure 12. Pooled residual variation across sample site and elevation combinations

Carolina Beach shows slightly higher variance overall in the high tide zone than the swash zone but variance in the subtidal is far greater than the other two sampling zones. Both treatment and control show higher variance in the subtidal zone than any other elevation and the swash zone shows the least. Variance is slightly higher in the control sites (33.9% of total variance versus 28.1% in the treatment sites). High variance in this portion of the beach is likely due not only to the variability of the environment but also to the inherent difficulty in sampling such a high energy zone.

Figure 12 illustrates the partitioning of variance pooled across sample site and elevation combinations. This figure most effectively illustrates the variation among sites along the beach. Kure Beach shows less variance overall and higher variance in the two northernmost sites compared to the two southernmost sites. Carolina Beach shows increasing variance from north to south and a higher average variance overall.

Sites and elevations for the variance versus sample size plot were chosen at random to determine to amount of sampling effort necessary for future studies. The plot indicated at that at 4 samples, the variance begins to level off (Figure 13). For future studies, four samples per elevation would be an acceptable sampling effort. Any sample number greater than 4 would be unnecessary effort.

DISCUSSION

The null hypothesis regarding renourishment effect for this project was that no significant differences were expected in chlorophyll *a* concentrations at the beach renourishment projects at Kure and Carolina Beach versus the established controls. Other studies of population changes around beach renourishment including Gorzelany and Nelson (1987)

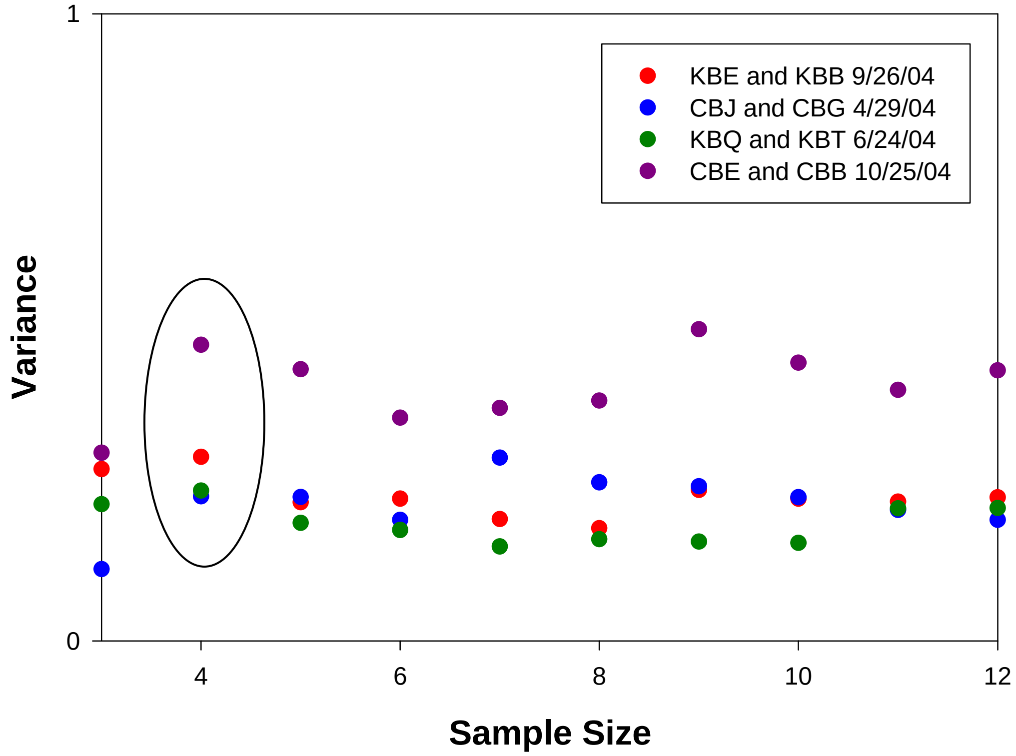


Figure 13. Variance versus sample size – Black oval indicates first peak in variance

and Wilber et al. (2003) have reported little to no significant negative impact on faunal communities. Gorzelany and Nelson studied the impact on species density and community composition of benthic communities in the near-shore zone after renourishment in Florida. Wilber focused on the response of surf zone fish to a renourishment project in New Jersey. Though neither author found significantly lower population densities following their respective renourishment projects, changes in community structure did occur with surf fish. A sharp contrast exists between these groups and benthic microalgae. Organisms such as polychaetes, amphipods, fish and even bivalves are capable of migrating out of an area that is disturbed and returning once the disturbance has passed. These faunal organisms, unlike primary producers such as benthic microalgae, are not directly dependent on sunlight and are not impacted by the same metabolic limitations microalgae face in a burial or displacement event. Because benthic microalgae are a primary source of food for organisms looking to return to a disturbed area, monitoring their response to renourishment becomes an important issue both environmentally and ecologically.

The physical properties inherent in beach renourishment also supported expectations for a drop in chlorophyll *a* concentrations. Forces imposed on benthic microalgae through the dredging and piping of sediment to the renourishment site included increased water pressure, hydrostatic forces, friction, collisions among sand grains and abrasion. Benthic microalgae native to the renourished beach were buried under meters of sand and were thought to stand little chance of survival. These conditions would be fatal to most vegetative cells. The limited motility of benthic microalgae (Krom 1991) coupled with their dependence on sunlight to metabolize and reproduce lowered expectations for their survival after renourishment events.

Elevation was included in the design of this study because it was necessary to evaluate its importance as a variable in the sampling scheme. The different elevations on the beach are exposed to different physical forces from wave action and storm events as well as varying degrees of UV radiation. Different responses from the benthic microalgae could be expected under these varying circumstances. Correlations of chlorophyll *a* among elevations are strong, linear, but not all at a 1:1 ratio. Therefore, sampling at any consistent elevation of the covariated elevations is a good proxy for the others and will reduce the number of samples needed in future studies.

The range of chlorophyll *a* data in this study covered 2 orders of magnitude. Though the average concentrations found on the open beach were low compared to estuaries and other marine habitats (3-4 mg/m^2 versus up to 200 mg/m^2 (Panasik 2003)) the methods and design used in this study were sensitive enough to detect a significant effect if one was present (average coefficient of variability = 0.12). Panasik (2003) reported marked increases in chlorophyll *a* concentrations after the application of dredged material in a North Carolina estuary. The chlorophyll *a* concentrations in her study showed rapid increases over a short period of time after the application of the dredge material. This study of renourishment on Kure and Carolina Beach did not have the same findings. Though Panasik's study had characteristics similar to that of a beach renourishment study, including the transport of foreign sediment and the burial of native communities, the estuary is a dramatically different environment and does not experience the same high-energy forces as the open beach.

A predictable overall seasonal or temporal pattern in the chlorophyll *a* data was expected but not found. Standard statistical time series procedures need to sample over 5 complete cycles to identify such patterns. Sampling in this study was only conducted over one year and though the data showed expected seasonal chlorophyll *a* highs in the spring and lows in the late winter, a cyclic model could not be fit statistically to the overall data.

There were patterns within the individual elevation data, however, that led to surprising conclusions. Though it was expected that chlorophyll *a* concentrations would be diminished by the beach renourishment project, the data indicate that little difference existed between treatment and control sites before or after renourishment. Variability within the data existed but beach renourishment was not a demonstrable cause. Paired comparison analysis yielded no results that would indicate renourishment as a source of variation.

Paired comparisons of chlorophyll *a* concentrations between beaches were analyzed and 6 significant differences were found between Carolina and Kure Beach at comparable sampling times. Three of the 6 differences were found in sampling times before the renourishment project began, so it is difficult to say that the renourishment project itself made a significant difference in the concentration of chlorophyll *a* on either beach. Of the 3 remaining differences that were found in the post-renourishment time period, 2 were found between treatment sites and 1 was found between control sites. All 6 significant differences, both before renourishment and after, showed higher chlorophyll *a* levels at Carolina Beach. From these data it may be concluded that Carolina Beach has higher ambient chlorophyll *a* levels than Kure beach but due to the limited number of differences found in the most conservative analysis it would be premature to determine that the beaches are different from one another in any consistent way.

The overall pattern from these data and that of the control-treatment analysis strongly indicate that beach renourishment has very little overall effect on chlorophyll *a* concentrations and the net growth of benthic microalgae in this open beach environment.

Grain Size

Cahoon et al. (1999) reported a relationship between chlorophyll *a* concentrations and sand grain size in tidal estuaries in southeastern North Carolina. That study found that medium to fine grained sands had higher concentrations of chlorophyll *a* than sediments with high percentages of sediments <125μm. This study also revealed a relationship between grain size and chlorophyll *a* concentrations. However, I found that on the open beach there is a negative relationship between grain size and chlorophyll *a*; as mean grain size on the open beach increased, chlorophyll *a* concentrations decreased. On Carolina and Kure Beach more chlorophyll *a* was measured in samples that had average grain sizes in the medium to fine sand grain range than those samples with larger average grain sizes. Smaller grain sizes allow for greater surface area for benthic microalgae to colonize per volume of sediment. Shell hash, the substance representing most of the larger grain sizes in this study, tends to be much smoother than the quartz sand grains primarily found on beaches located in the southeastern United States. The smooth texture of the shell hash is not a favorable surface for benthic microalgae and the larger fragments have proportionally less surface area per unit weight and volume. Quartz is a much coarser, textured material and offers crevices that afford microalgae more protection from predators and abrasion.

One further consideration regarding the suitability of shell hash on renourished beaches is the opaque nature of the sediment. As previously mentioned, the primary sediment type on the beaches of southeastern North Carolina is quartz, a mineral that is more transparent than shell hash; allowing more sunlight through the grain than shell hash and also facilitating the scattering of light. Too much shell has on a beach could very well limit the amount of light filtered into the lower millimeters of the photic zone and thus potentially reduce the potential of primary producers in that zone.

Average grain size has proven not to be the only factor that controls the concentration of chlorophyll *a* on the open beach, yet the relationship between chlorophyll *a* concentration and grain size cannot be ignored. The selection of suitable renourishment material therefore becomes that much more important in the planning and execution of any beach renourishment project. It is well established that sediment that is too small and can be easily winnowed away by wave action fails to serve any beach renourishment project well. However, sediment that is too large or too heavily composed of shell hash may damage the recovery potential of benthic microalgae after a renourishment event.

Variance

Variance within this dataset became a variable in its own right. There were noteworthy differences between the variance found at Kure Beach and that found at Carolina Beach. Carolina showed more variance in all comparisons to Kure Beach with the exception of Site 2 which was higher for Kure than it was for Carolina Beach. At every elevation Carolina Beach had higher variance than Kure Beach at both control and treatment sites. The mechanism(s) behind the higher levels at Carolina Beach is unknown. The two beaches are geologically similar; both are east southeast facing barrier islands on the southeastern coast of North Carolina and are subject to similar, if not identical, winds, seasonal changes and storm events. Both beaches have a history of renourishment and have comparable grain sizes and sediment composition. The two beaches are not separated by any physical boundary other than name and municipality. Kure Beach has a rocky outcropping at its southernmost point that is unmatched at

Carolina Beach. The variance analysis shows the second lowest levels in the site closest to the outcropping (Site 4). Anecdotally, Carolina Beach appears to be a steeper beach than Kure, a topographical difference that might influence the stability of the benthic microalgae on the beach and therefore the variance of the collected data. However, without significant differences in chlorophyll *a* concentrations or any other indicators of heterogeneous environments, any inference that the two beaches are different is merely speculative. Differences in the beaches can therefore not explain differences in the amount of variance found between the two beaches.

Despite the fact that an equal number of samples was taken at each elevation at each site, the variance in the data was not uniform in quality or quantity over the course of the study. As a pilot study, partitioning sources of variance when sampling the open beach for chlorophyll *a* became a primary goal. Most of the variance among elevations was found in the subtidal zone, and this comes as no surprise. The subtidal zone on the open beach is subject to the movement of wave action, bottom currents, and burrowing faunal activity. The sediments in this zone are constantly shifting and settling, making it difficult for benthic microalgae to stay in once place for any period of time. This movement leads to sampling problems and patchiness issues above and beyond what is normally associated with benthic microalgae.

Conclusions: Future Studies

The most obvious conclusion drawn from this study is the lack on impact beach renourishment had on benthic microalgal communities. The results of this project are compelling in their lucidity. However, it is important to remember that the two beaches sampled over the course of the project were representative of only one type of habitat in one geographical location. The results from this study cannot be universally applied to all renourished beaches nor can they represent any other time frame than the one sampled.

The experimental design of this study set out to sample all obvious variables. By partitioning variance in the data it is possible to hone the design for future endeavors. The most variance found in this study was among sampling sites not elevations. Sampling effort should therefore be directed towards increasing the number of sites along the beach (sites being defined as sampling locations far enough apart so as to be statistically independent of each other) rather than multiple transects within one site. Sampling across one elevation (though not in the subtidal where the most variance among elevations was found) in a large array or box scheme would also help to stabilize the mean and reduce variance. Future studies may also remove transect sampling as well as elevation sampling from within each site to reduce the amount of time spent and the number of samples pulled at any one site. The sampling effort in this study was found to be greater than what future studies will need to minimize variance. Four samples per elevation will be sufficient for an accurate representation of the benthic microalgal community without wasting time or resources.

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BIOGRAPHICAL SKETCH

Erin S. Carey was born on January 25, 1977 in Brattleboro, Vermont. She graduated from the University of North Carolina Wilmington in 1999 with a B.S in Environmental Science. After graduation, Ms. Carey worked with The Nature Conservancy on the seasonal fire crew and as a field technician in endangered species surveys before turning to water quality analysis and assessment. She entered the Masters of Science program in Marine Science at the University of North Carolina Wilmington in January of 2004 where she worked under the guidance of Dr. L.B. Cahoon. During her time as a graduate student Erin was awarded a Nation Science Foundation GK-12 Teaching Fellowship which afforded her the opportunity to teach science to 6th graders in the local middle schools.

Ms. Carey graduated in December of 2005 and plans to pursue a career in coastal management.