How to Best Restore a Dune After Blowouts: An Assessment of Dune Accretion and Natural Flora Diversity at Island Beach State Park, NJ

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ABSTRACT

Prior to Superstorm Sandy, the importance of sand dunes had been overlooked in many coastal areas in the Northeast; however, given the storm's devastation, communities are now seeking ways to protect and/or restore their shorelines. Hence, they are focusing on the shore's natural defense system through sand dune maintenance. At Island Beach State Park (IBSP), some of the dunes were only eroded (historic dunes), whereas more northerly dunes were completely blownout (restoring dunes). To refortify the latter areas with dunes, the park installed continuous wood paling using two different patterns: straight and zigzag. I measured the weekly vertical accretion of these restoring dunes for 10 weeks by taking repetitive measurements using a rangefinder and clinometer. I found that zigzag fenced dunes increased over time at a much greater rate than straight fenced dunes, which showed only minute increases. Location (i.e. wind patterns, tides, and sediment supply) may be a factor that affected these growth rates, as there were differences in accretion by beach access. As a second element of this study, I took 1.5m core samples from atop historic dune crests and next to restoring dune fences. After sieving these samples, I found that there are differences in substrate composition between the two dune types. Lastly, I conducted random vegetation transect surveys along the historic dunes one meter inland from the crest. Using Simpson's Index, I found that the dunes were dominated by two plant species: native *A. breviligulata* and non-native invasive *C. kobomugi*. *C. kobomugi* is more dominant than *A. breviligulata* and reduces the diversity, density, and evenness of other plants in stands where it dominates. These results have many implications for coastal management and echo past findings that *C. kobomugi* negatively effects native dune flora composition.

INTRODUCTION

Dunes are an invaluable natural resource to coastal communities. Ecologically, they are used as habitat, incubation sites, and refuge areas for many migrants, shore birds, invertebrates, and mammals (USFWS 1993; Freestone and Nordstrom 2001; Saye et al. 2005). They also provide a number of essential ecosystem services, the most important being their role as a dynamic buffer to erosion. Sand dunes adsorb the destructive power of waves by physically blocking the upland areas during high tides and storms (Nordstrom and Jackson 2013). As a result, dunes are constantly eroding, but will continue to accrue if the beach has a positive sediment supply, and the dune has grasses and/or manmade structures that will trap windblown, aeolian, sand (Houser and Mathew 2011; Doody 2013). This unique "sand-sharing" active interchange of material between dune and beach makes dunes integral elements of a healthy coastal system (Saye et al. 2005; Doody 2013). However, despite their many invaluable roles in coastal management, prior to Superstorm Sandy in the fall of 2012, the importance of sand dunes had been overlooked in many shore communities in the Northeast.

New Jersey is home to the first, and now most developed and densely populated, coastline in the US (Seabrook 2013). According to the 2010 US Census, over 1.5 million people reside along the state's 130-mile stretch of coastline, despite the high storm risk and geographic instability of the area. However, these communities are not completely without defenses, as the NJ shore has a diverse array of protective infrastructures from town to town: jetties, groins, seawalls, and dune enrichment projects. These manmade structures protect upland areas during storms, but ultimately reduce the resiliency of the area by impeding the normal ebb and flow of littoral drift and ‘sand sharing’ (Cooper and Pethick 2005). A healthy and continuous dune system sustains the beach and vice versa thereby making that dune bound area more resilient to short-term storm damage and better sustained in the long-term (2005). When a storm hits the coast, damage is dependent on the height of the foredune relative to the elevation of the storm surge (Houser and Mathew 2011). Many NJ shore towns realized the symbiotic beach-dune relationship years ago and began fostering it, but many others overlooked its importance until after Superstorm Sandy.

Hindsight is truly 20/20, as towns that preserved and restored their dunes suffered millions of dollars less in damages from Sandy than towns that had not (Nuwer 2012). Over short distances, localized fluctuations in dune height and development can cause variable storm impact along a coast (Houser and Mathew 2011); this is magnified with increasing storm intensity. Due to the power of Sandy, many healthy dunes were blown-out and breached during the storm, such as Bradley Beach’s 15-ft dunes. However, acting like a dynamic defensive wall, the dunes prevented substantial damage before and after their collapse (Navarro 2012). Homeowners have long viewed dunes as a nuisance because they block their ocean view, thereby reducing the value of their property (Granatell 2013). However, Sandy has taught communites like these, such as Long Branch, New Jersey, that benefits of dunes outweigh the costs (Rosenberg 2013). Because of Sandy’s visible effects, dunes are now being viewed as invaluable commodities instead of property value plagues, and as such many communities are now working to restore and build up their dune defenses.

Because of the high use and human impact on beaches, dunes will not accrue naturally as they did years ago; therefore, we must aid in their accretion by providing a structure and or plants to catch windblown sand (Dahl and Woodard 1977; Doody 2013). Installing wood paling fences and/or planting dune-building grasses along the supra-tidal area are common methods used to help a dune accrue. To save on costs, coastal managers have attempted to use synthetic fabrics instead of wood fencing, but over time these deteriorate and cause the dune to collapse (Miller, Thetford, and Yager 2001). They have also experimented with fence configuration to see if different orientations and patterns increase accretion rates. However, some experiments found that patterns, such as spurred and zigzag fencing, did not accrue sand faster than traditional straight fencing parallel to the beach (Savage 1963; Miller et al. 2001). Whereas Mendelssohn et al. found that those other patterns initially accrued better than straight fencing, but after 3-years, straight fencing far exceeded all other patterns (1991). While there is debate over the cost-benefit of fencing patterns, all studies agree that there is no accretion without fencing.

Over time, by allowing vegetation to naturally accumulate or to physically plant vegetation, a dune becomes a functioning ecosystem as opposed to just a protective structure (Freestone and Nordstrom 2001). Mendelssohn et al. found that vegetation played little role in the initial accretion during the first 14-months of their fence study (1991). However, once a dune begins to build up, it can become relatively rich in species composition; this will further aid in their structural integrity (Freestone and Nordstrom 2001). The deep roots of dune stabilizing plants such as American Beachgrass (*A. breviligulata*) offer the dune structural support because the plant can generally grow at or greater than the rate of accretion (Wootton et al. 2005). Each dune grass species has a certain tolerance for burial, but in time many of these grasses can become completely buried, leaving bare spots that will not aid in accretion (Maun 1998). Burial combined with extremely low levels of water and nutrients, salinity, and erosion of substrate make the foredune a very stressful habitat for vegetation (Rees, Grubb, and Kelly 1996). However, native plants generally respond positively to this natural regime of disturbance, whereas large-scale disturbance events present an opportunity for non-native invasive species to capitalize (Hierro et al. 2006).

Sandy is an example of a large-scale disturbance that could exacerbate NJ’s ongoing issue of managing and reducing stands of non-native invasive Asiatic sand sedge (*Carex kobomugi*). Burkitt and Wootton found that disturbances might actually increase *C. kobomugi*’s ability to outcompete natives (2011). Furthermore, attempts to eradicate and remove the invasive, physically and chemically, have proved only somewhat successful (Wootton et al. 2003). Both *A. breviligulata* and *C. kobomugi* are effective dune stabilizers that build morphologically different dune structures. *A. breviligulata* creates taller and steeper while *C. kobomugi* creates shorter and more compact dunes (Lea and McLaughlin 2002; Wootton et al. 2005). However, since it’s introduction to NJ in 1929, the invasive has spread exponentially along the coast, subsequently reducing the density of native plants (Small 1954; Ishikawa and Kachi 1998; Wootton 2007). The more diverse an area is, in regards to functionally and species, the more resilient that system is to small and large-scale perturbations (Diaz and Cabido 2001; Reiss et al. 2009). Therefore, Sandy could have resounding aftereffects on the vegetation composition in washed out areas; this presents an opportunity for researchers like myself to conduct studies to prevent further damage (Theoharides and Dukes 2007).

Dune maintenance can be cumbersome, but their health is paramount to the protection of coastal communities. Therefore, in my study I will be measuring dune growth over time to see if different fence patterns accrue sand at different rates. I believe that zigzag fencing will accrue sand better than straight fencing because of the increased area and added angles for wind blown sand to catch on the fencing. Similarly, I believe that dunes that were not blownout (i.e. historic dunes) will not change over time; they will be in a state of dynamic equilibrium (Doody 2013). Looking at vegetation, I hypothesize that *A. breviligulata* and *C. kobomugi* will be the dominant dune species and there will be differences in plant compositions between the two types of stands; there will be less species richness, species diversity, and density of other dune species in *C. kobomugi* stands. I believe that there will be differences in the proportion of grain sizes found atop non-destroyed dunes and areas where dune fencing is being used. Issues related to coastal management are likely to become exacerbated in the years to come as global climate change continues to increase the frequency, severity, and unpredictability of hurricanes that would ravish the coast (Mann and Emanuel 2006; Miller et al. 2013). Sandy affords the opportunity not only to examine dune growth from a baseline, but also to examine how the vegetation responded to the storm so that better and more informed management decisions may be carried out in the future.

METHODS

***The Site*:** I collected my data along the coast of Island Beach State Park (IBSP) on the Barnegat Peninsula in Berkeley Township, Ocean County, NJ. The park is a barrier island that contains ≈10 miles of sandy beach shoreline along Barnegat Bay. The shoreline transitions into sand dunes, tidal marshes, and maritime forests and the park offers automobile beach access at four locations. I conducted my study along all of the beach accesses, A1-A23 (Figure 1).

Prior to Superstorm Sandy, the IBSP coast had been protected by largely continuous dunes; these dunes had been accruing for years. This is still the case in the South half of the park, A15 to A23, where the dunes in these areas, referred to as historic dunes, were eroded and pushed back, but not destroyed. Conversely, the North half of the park was blown out and there have been ongoing efforts to restore the dunes in those areas; these dunes, restoring dunes, are currently accruing aided by paling fences.

Along A7 and about 1.5-miles north and 1-mile south of the access, prior to the installment of fences, approximately 3000 recycled Christmas trees were placed on their sides end-to-end in trenches. The trees were placed in an undulating pattern to try to mimic the configuration of natural dunes. The trenches were dug approximately 1-foot deep and 1-foot wide using a forest fire break plow. This anchored the trees and prevented them from blowing all over the beach. The fencing was then installed in front of and in some places behind the tree mounds. Within a month the trees were completely covered and likely aided in initial accretion at these locations (Ray Bukowski, Park Manager, personal communication August 13, 2013). The fencing was installed during the winter of 2013, January-March, at beach level by the NJ Beach Buggy Association; storms that hit the park soon after these restoration efforts threatened to destroy the fences, but they were unscathed (Bukowski, personal communication August 9, 2013). The fencing is traditional wood lathe slatted fencing, commonly used for snow and or sand management. Twisted wire, 0.5 strands of 14-gauge, support 3/8" x ½" natural wood slats 4' tall and 50' in length. Along each access, the fencing is continuous and randomly varying in pattern, straight or zigzag.

***Data Collection*:** I collected data for 10 weeks, from June 4th to August 5th of 2013. John Wnek, Supervisor of Research and Science at the Marine Academy of Technology and Environmental Science, served as my advisor on this project. Together, we randomly selected points along the IBSP shoreline. Each access examined has at least two points associated with it. We picked data points by walking along the beach and marking points at approximately 1/3 and 2/3 the distance from the beginning of the access. To ensure collections were from the same locations each week, we marked the points with both GPS as well as labeled field flags. Ground truthing and core sampling was collected and analyzed from these points. Data collection was standardized to once a week on Monday or Tuesday mornings, weather permitting.

Dune Accretion & Vegetation: By laying at the toe of the dune at ground level, I used a range finder to measure the length of the dune's hypotenuse, from toe to crest; from this same spot I used a clinometer to get the angle of the slope (Shafer, 1996). I measured the slope at this initial point, as well as 3.5m to the left and right. Averaging these three angles accounts for the variability in dunes height and development over short distances

(Houser and Mathew, 2011). I took these measurements weekly from restoring dune points, straight and zigzag fenced, and every four weeks from historic dune points, as these remain relatively stable over time (Millington et al. 2009). Using trigonometry I calculated dune height:

$$\text{Dune height} = \text{Sin}(\text{Angle}_{AVG}) \times \text{length}$$

I conducted vegetation surveys along 5m of contiguous transects using a $1m^2$ PVC quadrant, such that a each survey area was 5x1m (Schlacher et al. 2008). On historic dunes, I took the surveys atop the dune 1m from the crest. On restoring dunes, I took surveys 1m behind the fencing and on the dune face, along the distance from the far left and far right angle measurements. Using a field guide, I identified and quantified plant species by counting stems (Silberhorn, 1999). I considered each culm to be a separate stem/plant (Burkitt and Wootton, 2011). Vegetation surveys from A15 to A23, historic area, were taken once during the study, both at survey points and randomly along the dune tops. All surveys were at least 5m apart. At restoring dune points, I quantified vegetation weekly.

Dune Cores: I collected sand cores from both historic and restoring dunes. Cores were taken 1m from the edge of historic dune crests whereas at restoring dunes I took cores next to the fencing. I used a standard metal coring device to extrude an unmixed and continuous sediment core to 1.5m depth (Glew and Smol 2002). Prior to desiccation in a drying oven, I shook up each core so that a sample would be an accurate representation of the proportion of sand types at each location. Using an RX-29 Ro-Tap cascade shaker, I sieved each 100g sample for a standardized 5-minutes, as increasing the time increases the effectiveness in fragmenting the particles because of added energy (Diaz-Zorita et al. 2007). I sieved samples using eight different US Standard Sieve Mesh Sizes, mesh #25 (0.71mm, ϕ0.5), #35 (0.50mm, ϕ1.0), #45 (0.35mm, ϕ1.5), #60 (0.25mm, ϕ2.0), #70 (0.21mm, ϕ2.25), #100 (0.149mm, ϕ2.75), #140 (0.105mm, ϕ3.25), and the bottom pan (<0.105mm, ϕ>3.25). These sorted the samples into silts and coarse, medium, fine, and very fine sands (Folk, 1980).

Statistics Analysis**:** I performed my data analysis using the statistical program JMP 9.0. I performed a regression of growth over time for historic, straight, and zigzag dunes to infer if there was significant growth. I also performed regressions on starting heights by access to see if a height gradient exists along the park. To look at the potential effect of location, I used Analysis of Variance (ANOVA) in conjunction with student's t-tests to compare the growth of straight fenced dune heights by beach access, holding time constant. I analyzed starting heights with a combination of t-tests, 2-way ANOVA, Tukey HSD, and regression analysis. I also performed a 2-way ANOVA to see if there was an effect between initial dune height and growth rate and further analyzed straight fences. To analyze the cores I used Student's T-tests. I compared zigzag and straight means and then lumped the two patterns' data together to compare the grain size between the historic and all restoring dunes. For both of these comparisons, the grain sizes were simplified to coarse (mesh #25 and #35), medium (mesh #45 and #60), fine (mesh #70 and #100), and very fine/silt (mesh #140 and smaller). For all vegetation surveys, I averaged the number of stems of each species in the 5x1m plot to compare the average vegetation in a 1m^2 transect. To determine the similarity of the vegetation found at different accesses I grouped A23-20, A19-18, and A15-14 and used Jaccard's Index:

$$\text{Jaccard's Index} = \frac{j}{r_1 + r_2 + j} \times 100$$

Where j is the number of species in common between the two sites and r represents the species unique to each site respectively. To infer a value for species diversity I analyzed the vegetation transects using Simpson's Index. I first calculated L, which is a measure of dominance:

$$L = \sum n_i(n_i - 1) / N(N-1)$$

I considered a survey area as having a dominant species if L>0.5 and inferred the dominant species by looking over my raw data to determine which species had the greatest abundance. Using dominance, I calculated Simpson's Diversity (D_S=1-L) and evenness (E_S= D_S/ D_{SMax}). I compared these values, as well as species richness, total stems, and species' densities using t-tests.

RESULTS

Of IBSP's 23 total accesses, I was able to collect data from 19; A16, A17, and A22 were roped off for terrapin nesting and Sandy heavily scarped A2 and A3 such that they were inaccessible. I collected from a total of 43 dune points. Of these 43 points, 19 are historic, for which data was collected 4-times, 14 from A13-A23 and 3 from A0/A1. At access 13 one enters a unique transition zone; the area was blown out and is being restored, but is also sprinkled with lone standing dune hills that survived while the dunes next to them were entirely destroyed. Two points at A13 are historic and one is restoring.

The 24 other restoring points are along A4-A12. There was more straight fence than zigzag throughout the park. The zigzag fencing and points were concentrated at A6/7, with one in A13. To eliminate crowding among points I did not quantify the growth of the short stretches of straight fence that were in between zigzag points. Therefore, straight fence points were at A4-5 and A8-12. The average distance between restoring points was 109.57m (SD=80.99m) with the maximum, minimum, and median distance between points at 370m, 40m, and 80m, respectively. I collected data 10-wks for all 15 straight fence points and of the 9 total zigzag, I collected six for 10-wks and three additionally added points for 7-wks.

Dune Accretion Results: At accesses A9-A12, the toes of the restoring dunes were frequently driven on from week to week. The historic dunes did not change over time ($F_{1, 81}$=0.22; p=0.64), nor did the straight fenced dunes ($F_{1, 148}$=0.81; p=0.37), but zigzag fences showed an increase in accretion over time ($F_{1, 75}$=11.81; p<0.001) (Figure 2). There was no effect of initial dune height on growth rate ($F_{1, 22}$=0.52; p=0.48). However, straight fences began at a greater starting height than zigzag *(t*(21)=-2.28, *p*<.05). Location did not have an effect on starting heights of the straight fences (ANOVA; $F_{6, 8}$=2.28; p=.14). However, there exists a gradient where overall starting height increases going north to south along the park's accesses ($F_{1, 31}$=45.91; p<0.0001); looking specifically at straight fence starting heights, they increase in this north to south direction as well ($F_{1, 13}$=6.03; p<0.03). Similarly, there were differences in accretion along the park's coast by access in straight fenced area (ANOVA; $F_{6, 143}$=15.83; p<.0001); dune height appears to increase as one goes further south (Figure 3). Zigzag points were located too close together, A6-8, to infer a location effect. The straight fence dunes in A8 were the only dunes that were almost completely covered (less than 6" of paling exposed). Of 25 restoring dunes, 3 of 8 (37.5%) zigzag and 10 of 15 straight fence points (66.7%) had plants grow in during the study. However, it was not uncommon for plants present one week to be gone the next. The first zigzag point to acquire plants was at week-2, whereas no straight fence points acquired plants until week-7, with the most new plants springing up in week-8. Sea rocket (*Cakile edentula*) was the most common pioneer plant and seems largely opportunistic, followed by seaside spurge (*Euphorbia polygonifolia*), and *A. breviligulata*.

Sand Cores: There were no differences in dune substrate composition between zigzag and straight fence dunes. However, comparing all restoring dunes in general to historic, there were differences in composition. Restoring dunes are composed of a greater percentage of coarse sand than historic dunes ($t(31)=2.82$, $p=.009$). The two dune types did not differ in proportion of medium sands. Historic dunes are composed of more fine sand ($t(31)=-8.28$, $p<.0001$) and very fine sand/silts ($t(31)=-9.71$, $p<.0001$) (Figure 4).

Vegetation Transect Results: A total of 11 different species were encountered during this study. American Beachgrass was present in 59 of 63 or 93.6% of vegetation survey areas. Of those 63 areas, 35 (56.5%) were dominated by *A. breviligulata*, 19 (30.6%) were dominated by *C. kobomugi*, one (1.6%) was dominated by Beach Pea (*Lathyris japonicus*), and eight (12.9%) did not have a dominant species. *A. breviligulata* averaged $35.52 \pm 2.36/m^2$ with a minimum of $0/m^2$ and max of $56.8/m^2$, whereas *C. kobomugi* averaged $133.5 \pm 6.9/m^2$ with a minimum of $0/m^2$ and max of $205.4/m^2$. Of the 35 *A. breviligulata* dominated areas, only 4 had *C. kobomugi* present whereas *A. breviligulata* was present in 15 of the 19 *C. kobomugi* dominated stands. Besides *A. breviligulata* and *C. kobomugi*, other common plants encountered were seaside goldenrod (*Solidago sempervirens*) and sea rocket. Other plants that were encountered less frequently were dusty Miller (*Jacobaea maritime*), beach pea, Virginia creeper (*Parthenocissus quinquefolia*), seaside spurge, poison ivy (*Toxicodendron radicans*), and two species that I was unable to confidently identify. Species richness was generally low in all of these areas, varying from 1-6 species, with a median of 3 species and mean of 3.29 ± 0.97 per 5x1m survey area. The accesses were very similar in their vegetation compositions, 60% similarity between A23-20 and A19-18, 77.8% similarity between A23-20 and A15-14, and 69.4% similarity between A15-14 and A19-18. The plants were often very patchily distributed and I noticed that the edges where *C. kobomugi* dominated patches and *A. breviligulata* dominated patches met had very distinct borders (Image 1 & 2).

Of the 55 plots with dominant species, there were differences between *A. breviligulata* and *C. kobomugi* dominated plots (Table 1 & Image 3). *C. kobomugi* is more dominant than *A. breviligulata. C. kobomugi* dominated plots had greater total plants/transect, lower diversity, evenness, and lower average density of other plants. The distribution of plots dominated by *A. breviligulata* and *C. kobomugi*, respectively, did not differ by access (N=54; $R^2_{10}=.018$; $p=.36$) (Figure 5 & 6).

	A. breviligulata dominant plot (mean ± SE), N=35	*C. kobomugi* dominant plot (mean ± SE), N=19	Student's T-test N=55
Total $stems_{AVG}$	39.39 ± 2.34	139.42 ± 6.84	t=-13.84, p<.0001*
Dominant $Plant_{AVG}$	33.52 ± 2.36	133.5 ± 6.9	t=-13.72, p<.0001*
A. breviligulata	35.52 ± 2.36	4.53 ± 1.09	t=11.14, p<.0001*
C. kobomugi	0.53 ± 0.3	133.5 ± 6.9	t=-19.26, p<.0001*
S. sempervirens	3.76 ± 0.53	0.26 ± 0.12	t=6.39, p<.0001*
C. edentula	0.93 ± 0.19	0.92 ± 0.27	t=0.05, p=.96
Diversity (D_S)	0.27 ± 0.03	0.08 ± 0.02	t=6.19, p<.0001*
Evenness (E_S)	0.51 ± 0.02	0.39 ± 0.00	t=6.13, p<.0001*
Dominance (I)	0.73 ± 0.03	0.92 ± 0.02	t=-6.19, p<.0001*
Species Richness	3.2 ± 0.15	3.1 ± 0.25	t=0.32, p=.75

(Table 1): Comparisons among *A. breviligulata* and *C. kobomugi* dominated plots.

DISCUSSION

The results of this study have many applications and implications for coastal management and restoration. The IBSP historic dunes appear to be in a state of dynamic equilibrium, as opposed to positive or negative, sediment supply at the park during my time of study (Doody 2013). Both zigzag and straight fenced dunes increased over time, with minimal if any assistance from plants. However, this increase was only significant for zigzag fencing. Zigzag may accrue sand faster because of its increased area and angles of fencing to catch the wind blown sand. The current number of studies quantifying the effectiveness of fencing restorations is lacking. These findings are consistent with Mendelssohn et al. that zigzag and spurred patterns, and in the first 3-years, accrued better than traditional straight fencing (1991). Whereas, Miller et al. 2001 and Savage 1963 found that these other patterns did not accrue sand faster than straight fencing. It is hard to compare my study to others, as they collected for a longer time, but collected less data: Mendelson et al. collected once a year for 4-years (1991); Savage collected four times a year for one year (1963); and Miller et al. collected twice a year for four years (2001). My study is more comprehensive in regards to documenting accretion, as it is the first fence study to monitor weekly dune growth during a full season.

There were differences in the starting height and morphology of restoring dunes. Increasing accretion, starting heights, and decreasing Sandy damage as one goes further South at IBSP may be a result of decreased anthropogenic effects from less recreational use at accesses further into the park (Houser and Mathew 2011). Although the straight dunes began at a higher initial starting point than the zigzag fences, this did not affect growth rate. This starting height discrepancy could be attributed to any one or a combination of four explanations: (1) abiotic factors that would vary along a beach, i.e. wind direction, wind speed, sediment size, and tidal fluctuations, could create localized accretion differences (Houser and Mathew 2011); (2) this difference may be an anomalie, as Saye et al. found that dune morphology frequently changes over time and does not always reflect beach morphology (2005); (3) small sample size may be driving this difference; and (4) storms that occurred during the winter very shortly after the fences were installed could have affected areas differently such that more southerly accesses received more sand during this time; explanation four seems plausible, as overall starting height increased going north to south along the park's accesses. Lastly, anecdotal evidence based on personal observation suggests zigzag dunes appear to have collected a greater volume of mounded sand, whereas straight fences formed more of a ramp (Ruz and Anthony 2008).

Anthropogenic disturbances may be altering the effectiveness of the fences in high recreational-use accesses. The results of the cores are surprising as coarser sand is less transportable by wind. Coarse sand could have been transported to restoring dunes by the cars that frequently drive on the beach along dune toes. Increased wind speeds and tidal fluctuations from the storms that occurred soon after the fences were installed could have also transported these larger particles, as was the case with Hurricane's Dennis and Katrina (Houser and Hamilton 2009). It is not surprising that historic dunes had more fine and very fine sands/silts. The cores were only taken down to 1.5m and this top layer of historic dunes would be expected to be largely aeolian sand. By walking along the beach to collect my data I encountered numerous forms of human disturbance that could and should be avoided: walking along and up dunes, trampling fencing, driving on dunes, and ignoring the existence of a dune (Image 4).

It is possible that the average person associates a dune, with a tall, largely sloped, and highly vegetated area, but people may not realize that the slants in front fencing are premature dunes. They likely think the fence is to keep them out of the area behind the fences. This disconnect needs to be bridged through education. There is currently a lack of signs and information along the dunes and signage has proved effective in similar situations (Gomez-Pina et al. 2002). Installing easily understood signs that make it clear that the restoring dunes are indeed dunes might help remedy this problem (Image 4). Similarly, A15 is roped off and marked with signs for terrapin nesting and people seem to respect the string boundary (Image 6). Using string to create a protective boundary at the toe of restoring dunes may also be an option to keep beach-goers on the beach, but off the dunes. There could be opposition to this as people may feel their beach space is being reduced; however, on a micro-scale it would be inexpensive, take minimal labor, and it could greatly increase the effectiveness of the fences and on a macro-scale increase the beach's resiliency for future storms. These are issues that should be addressed to increase the effectiveness of the fencing.

In some areas of the park the fences are almost covered and need to be reinstalled to continue being effective. Once a fence is covered, if it is not lifted or additional fences added atop the old, then the accumulation rates are not sustained and eventually diminish (Dahl and Woodard 1977; Mendelsohn et al. 1991); thus, one would potentially lose the progress, and investment of time and money spent on the initial installation. Vegetation is another viable option as a tool for accretion. It can be as effective as fencing and has the advantage of continuing to accumulate and grow vertically in time with the dune (Miller et al. 2001). New fences should be reinstalled or lifted once old fences fill to approximately two-thirds of their height (Savage and Woodhouse 1969). As previously mentioned, the fences at IBSP are currently near, at, or past this mark. These fences need to be reinstalled and/or fortified with plants to continue the dunes' increase in both size and stability.

The vegetation findings of this study corroborate that *C. kobomugi* invasions are still an ongoing issue at IBSP post-Sandy. *C. kobomugi* populations have been increasing exponentially at IBSP by at least 300% since 1985 (Wootton et al. 2005). Similar to other studies, my results show that *C. kobomugi* is more dominant than and reduce the ratio of native *A. breviligulata* (Small 1954). The average stems of the two dominants plant varied greatly with *C. kobomugi* having much greater density in a plot. The lack of diversity and space between plants in these plots could result in a reduced number of microhabitats for macro-invertebrates. Interestingly, the mean number of stems of *C. kobomugi* in general and when it is the dominant species in a stand is the same. This suggests that *C. kobomugi* is either the dominant species, or generally not present. With respect to dune integrity it is better to have 'a' species as opposed to no species (Dahl and Woodard 1977); both *C. kobomugi* and *A. breviligulata* are effective dune-stabilizers because of their deep sand-binding root systems (Wootton et al. 2005). Furthermore, the average stems per m^2 fall within the range found by Wootton and her constituents in previous studies (Wootton et al. 2005; Wootton 2007; Burkitt and Wootton 2011). *C. kobomugi* stands are expanding by several meters in diameter every year and should be contained, but there is currently no entirely effective method of doing so (Wooton, Halsey, and Rella 2006).

A. breviligulata fosters greater diversity and species evenness, whereas *C. kobomugi* reduces the density of other plants by crowding them out (Wootton 2005; Burkitt and Wootton 2011). *C. kobomugi'*s reduction of these factors may ultimately weaken the resiliency, both as a working habitat and protective structure, of areas where it takes hold (Diaz and Cabido 2001; Lea and McLaughlin 2002; Reiss et al. 2009). Furthermore, the reduction of native plants could have resounding effects on other organisms, such as the endangered Monarch butterfly (*Danaus plexippus*), which rely on the nectar of *S. sempervirens* during their migrations (Snell 2010). However, despite the invasive's dominance, a square meter can rarely be found without *A. breviligulata* present-only 4 of 63 stands (Small 1954). Physical and chemical attempts to eradicate *C. kobomugi* only proved somewhat effective and costly (Wootton 2003; Wootton, Halsey, and Rella 2006). I suggest that for now, management of already established stands and prevention of further spread on washed out areas should be a higher prioirty than erradication (Theoharides and Dukes 2007).

CONCLUSION

The main findings of this study are in regards to fence restorations and *C. kobomugi*'s presence at IBSP. My results suggest that different fence orientations cause varying accretion rates. Zigzag fencing appears more effective in the initial baseline period than traditional straight fencing. If more fencing were installed, then further monitoring would be needed to see if this pattern persists in other seasons with changing winds and conditions. Regarding vegetation post-Sandy, the non-native invasive *C. kobomugi* is still an issue at IBSP. My findings echo the results of previous studies that *C. kobomugi* is a more dominant species than *A. breviligulata* and outcompetes native plants, subsequently reducing diversity, evenness, and the density of natives. Other factors that were not considered in this study are spatial arrangements of vegetation as they relate to interspecific competition, winds, and the possible effect of sandbar locations. More research should be done to shed light on if there are specific morphological and physiological factors that allow *C. kobomugi* to outcompete and replace *A. breviligulata* in vegetation stands. Superstorm Sandy afforded the opportunity to observe how biotic and abiotic factors responded to a large-scale perturbation. Therefore, the results of this study have many implications for coastal administration as climate change makes the Northeast more vulnerable to storms of this magnitude; they should be considered in decision making for current and future projects in order to make more informed management decisions.

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(Image 1): The low densly packed plant coming from the back of the dune is *C. kobomugi*. The taller plant in the front of the dune is *A. breviligulata*. This large *C. kobomugi* stand is pressuring the *A. brevigulata* dominated area in the front as well as the sides.

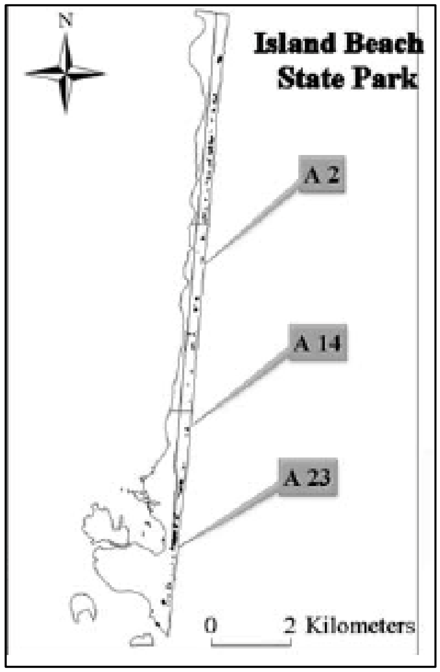
(Image 2): Notice the stark line between the *C. kobomugi* stand and *A. breviligulata* dominated area. There is likely high competition for space and dominance at the areas where the two species overlap.

(Image 3): *A. breviligulata* dominated stand (L) vs. a *C. kobomugi* stand (R)

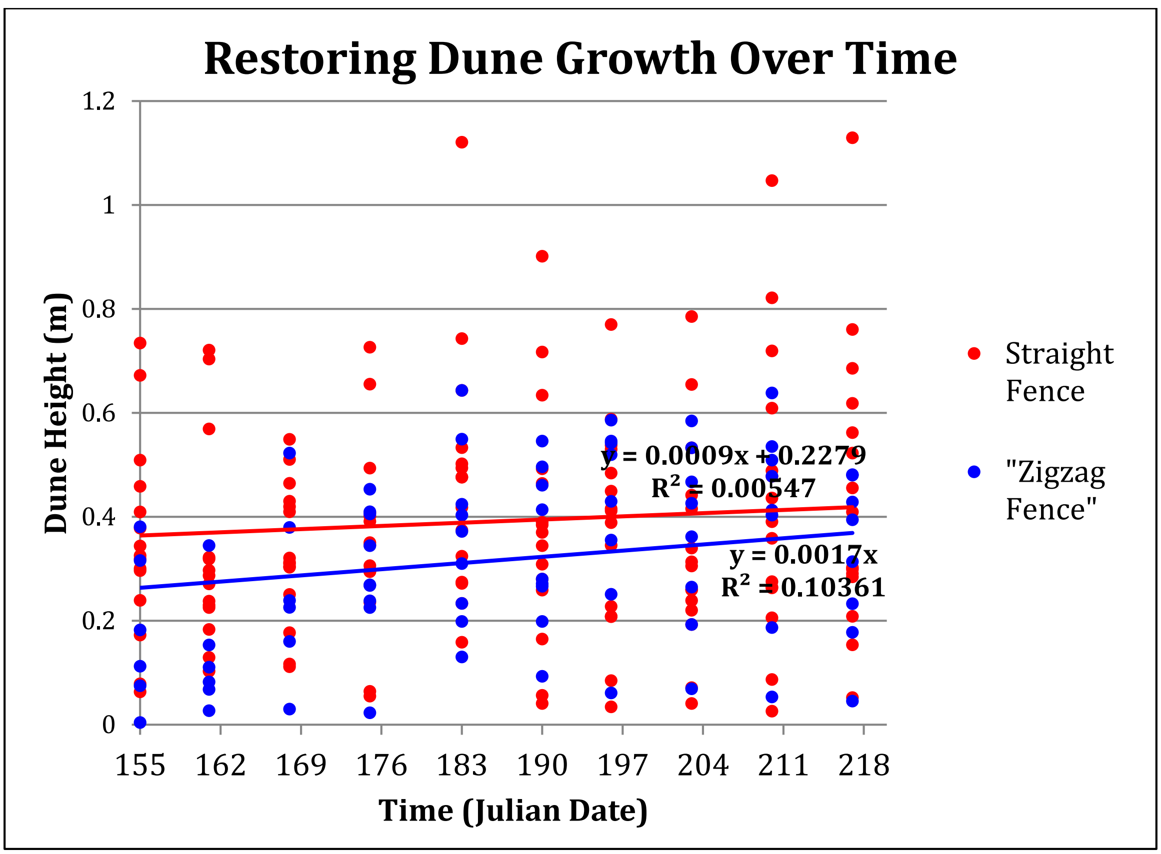
(Image 4): Examples of the types of human disturbance encountered along the restoring areas of IBSP.

(Image 5): Examples of the type of sign that might catch a beach-goer's eye as well as inform them where they should keep off.

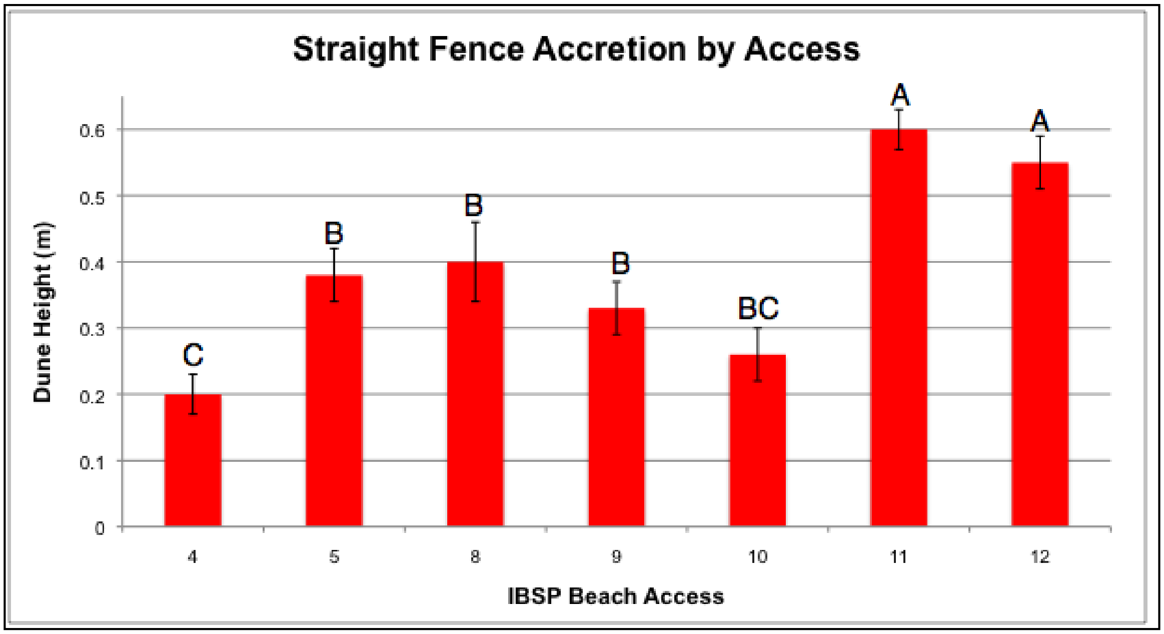
(Image 6): An example of an area in A15 that is strung off for terrapin nesting. This access sees less human traffic than the restoring areas, but notice the lack of footprints behind the string.



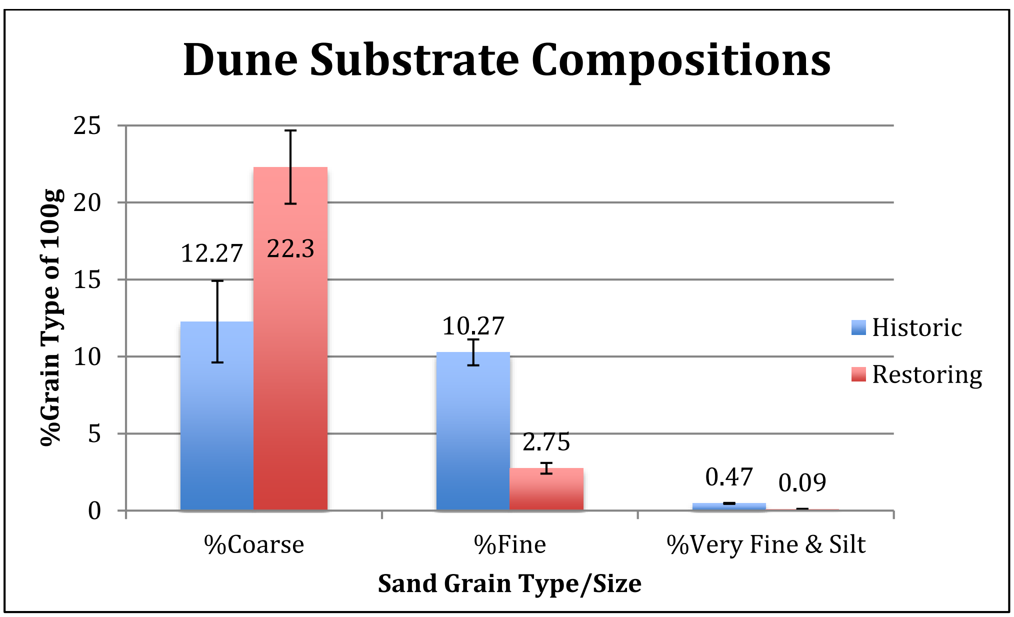
(Figure 1): A map of IBSP with beginning, middle, and end accesses labeled. This map was taken from Wooton et al. 2005.



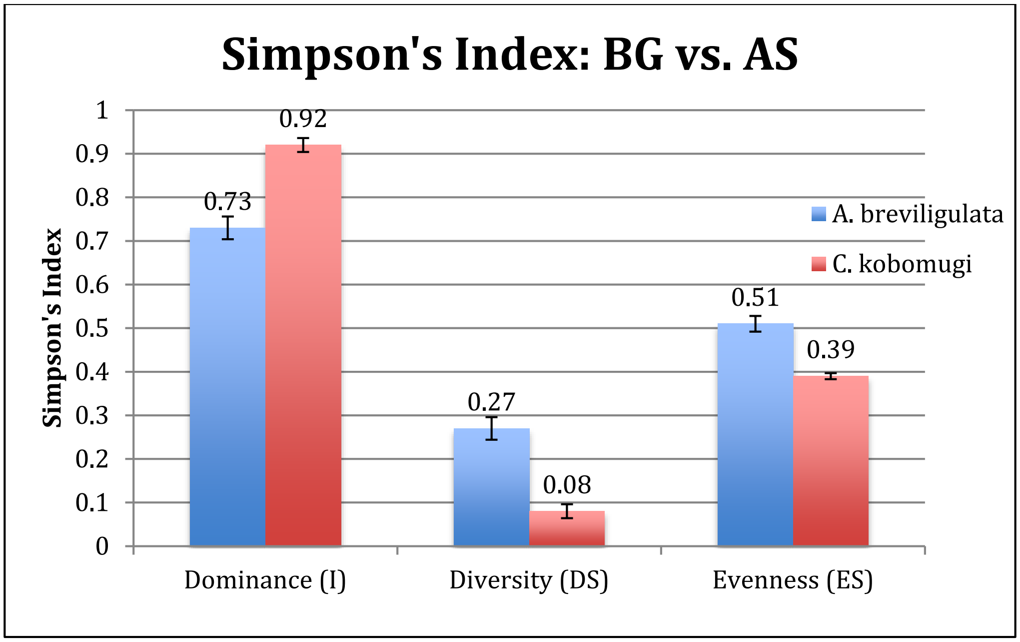
(Figure 2): Straight fenced dunes increased over time, but not significantly ($F_{1,148}$=0.81; p=0.37), whereas zigzag fences significantly increased ($F_{1,75}$=11.81; p<0.001).



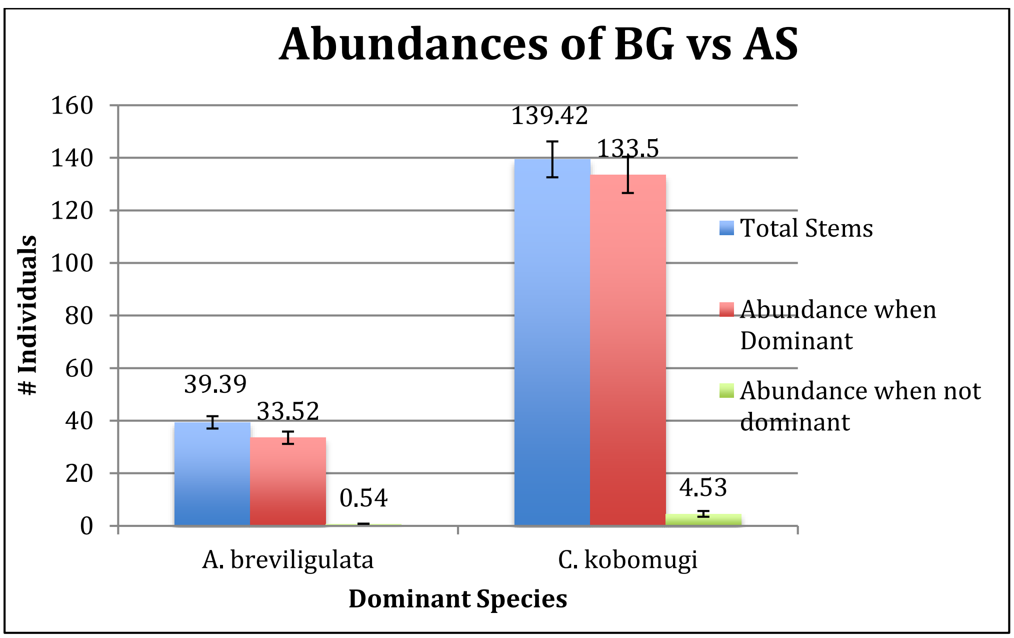
(Figure 3): Dune height varied by access, with the greatest sizes furthest South in A11 and A12 and the smallest dunes fartehst North is A4. Bars denoted by different letters are statictically significnalty different (ANOVA; $F_{6, 143}$=15.83; p<.0001)



(Figure 4): There were no differences in medium sand, but historic dunes have greater fine (*t*=-8.28, *p*<.0001) & very fine/silts (*t*=-9.71, *p*<.0001) than restoring dunes. Restoring dunes have a greater proportion of coarse sands (*t*=2.82, *p*=.009).



(Figure 5): 55 of 63 surveys were dominated by a speceis, *A. breviligulata* for 35 and *C. kobomugi* for 19. *C. kobomugi* is more dominant and *A. breviligulata* plots are more even in density of other plants and have greater diversity.



(Figure 6): *C. kobomugi* is more abundant than *A. breviligulata* in all stands where it is present as the dominant species or non-dominant.