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Assessment of Beach Access Paths on Dune Vegetation: Diversity, Abundance, and Cover

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ABSTRACT

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Coastal human populations are expanding and affecting plant communities, in particular dune systems. Coastal communities face risks from storm events, while coastal dune systems are heavily affected by human population and recreation pressures. Here, we evaluate the impacts of human disturbance (beach access paths) on vegetative cover and plant diversity in coastal dunes on the Isle of Palms, South Carolina. Transects were created in the foredune, middune, and backdune vegetation communities, and plots were placed 0, 1.5, 5, 10, and 20 m from a path to assess the impacts of three types of paths (public sand paths, private sand paths, and private wooden paths) at these distances on diversity, abundance, and measures of cover. Results indicate that beach access paths reduce biodiversity and density of beach dune vegetation. Sand paths contribute to greater reductions in vegetative cover than all wooden paths. Raised wooden paths compared to those at the sand surface have the least reduction in vegetation cover. Areas between closely spaced paths had reduced species richness and reduced percentage of vegetative cover compared to areas where paths were spaced at least 40 m apart. Dune vegetation plays a critical role in dune ecosystems by trapping and stabilizing sand. Areas of the dune that have reduced plant species diversity or lower levels of vegetation coverage are more prone to erosion and provide lower-quality habitat for other taxa. Current municipal regulations can be minimally altered to improve dune vegetation cover and richness while creating minimal inconvenience for beachfront homeowners and visitors.

ADDITIONAL INDEX WORDS: *Coastal dunes, coastal vegetation, beach access paths, urban ecology, human impact.*

INTRODUCTION

Dune vegetation plays a critical role in trapping and stabilizing dune sand and preventing coastal erosion (Hesp, 1991), particularly on barrier islands. This occurs in part through collection and germination of seeds, sand, and ramets in wrack and vegetation (Hinrichsen, 2011; Nordstrom, 2000). Areas of dunes that have less plant species diversity or lower levels of vegetative coverage are more prone to erosion and provide lower-quality habitat for other taxa (*e.g.*, Thompson and Schlacher, 2008). Both natural (Oosting, 1954) and human-induced disturbances disrupt facilitation interactions and lower species diversity in the dune vegetation community (Curr *et al.*, 2000; Franks, 2003; Hylgaard and Liddle, 1981). Human pressure on dune systems is caused by rapid real estate development, with its large rates of local human population growth and substantial increases in the use of beaches for recreation activities (Curr *et al.*, 2000). As human pressure on coastal systems increases, dune habitats shrink and are fragmented (Nordstrom, 2000), vegetation patterns change (Judd and Lonard, 1987), renourishment projects become more frequent (Nordstrom, 2008), and recreational dune traffic increases (Seeliger, 2003). Recreational beach use in particular can lead to trampling by humans, which has been established as degrading to dune vegetation (Curr *et al.*, 2000; Hylgaard and Liddle, 1981; Liddle and Greig-Smith, 1975a, b; Seeliger, 2003; Thompson and Schlacher, 2008; Williams, Randerson, and Sothern, 1997).

The natural environment of the maritime strand, including coastal dune habitat patches, is characterized by extremes (Oosting, 1954). Topography, wave action, wind, salt spray, sand burial, poor nutrient availability, fast-draining soil, full sun exposure, and high surface temperatures all contribute to the ecology of dunes (Ehrenfeld, 1990; Franks, 2003). The beaches of the SE United States consist of a barren sandy beach that extends from the low-tide line to the first low foredune. Behind this first ridge of dunes, there is an interdune depression characterized by herbaceous species. This depression is an interface in vegetation types between foredune communities and backdune communities (Stalter, 1975). The backdunes rise from the floor of the interdune depression, and the vegetation in this area is typically shrub and vine thickets, which become progressively taller as the distance from the open beach increases (Coker, 1905; Oosting, 1954; Stalter, 1975). Collectively, the foredune, middune, and backdune comprise the coastal dune system (Porcher and Rayner, 2001). Dune destabilization may be linked to decreases in percentage of plant cover, reduced seed banks, and less reproductive success of native plants. Thus, quantifying plant community diversity and species abundance in dunes and the impact of beach access paths provides data to evaluate the impacts of coastal development and recreational beach use on dune habitats and may inform management of these plant communities.

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Remnant patches of natural habitat within the urban fabric are important reservoirs of global biodiversity (*e.g.*, Dunn and Heneghan, 2011; Hinrichsen, 2011). In addition, the biodiversity in remnant fragments can provide important ecosystem services (Zedler, 2003), including ecological corridors that facilitate species movement and interaction (Hilty, Lidicker, and Merenlender, 2006) and protection of natural and built environments during storm events (Gornish and Miller, 2010). Further disturbance in these systems reduces their ability to act as intact habitats and provide such ecosystem services (Thompson and Schlacher, 2008). Natural disturbances in coastal dune systems occur during storms and very high tides (Stalter, 1975). Most of the world's human population lives in urban areas (Niemela *et al.*, 2011), and much of this increased urbanization is occurring along the world's coastlines (Small and Cohen, 2004). Human development impacts along coasts include increased habitat degradation, erosion, or loss (Nordstrom, 2008; Pilkey and Young, 2009) and in many areas increased seasonal pressure from tourism (Curr *et al.*, 2000; Seeliger, 2003). Anthropogenic disturbances to coastal dune systems include habitat fragmentation, introduction of novel species, large-scale habitat destruction and repurposing (Niemela *et al.*, 2011), trampling by humans and companion animals (Hylgaard and Liddle, 1981), and plant burial by sand loosened through trampling (Judd and Lonard, 1987). Previous studies of forest or meadow patches may not suffice to evaluate the influences of urbanization in urban-influenced coastal dune patches.

On Isle of Palms, South Carolina, beach access paths are either bare sand or are constructed of wood at varying heights above the sand. Paths constructed of sand are maintained clear by trampling and trimming. Paths constructed of wood are typically raised above the dunes and can have plants growing under them. Public paths are constructed at intervals that meet current city requirements for beach access and vary in usage, with high levels of recreational use in summer months (Curr *et al.*, 2000). Paths vary in width and distance from the next adjacent path. Here, we investigated the influence of beach access paths on the dune vegetation community. We asked the following questions: (1) Are there differences in ground cover and species richness, a measure of biodiversity, between plots adjacent to beach access paths and those farther from them? (2) Does plant diversity, abundance, or sand cover differ among the type of path construction or path density (distance between paths)? (3) Are threatened or invasive species found in the dune plant community, and are their locations associated with pathways? Urbanization impacts in a resort community, combined with increased storm intensity and frequency, make the protection and management of coastal systems including dune habitats a priority (Gornish and Miller, 2010; Miller, Cornish, and Buckley, 2010), both to maintain this ecological system and to protect stakeholder assets.

METHODS

The focus of this study was the ecological impacts of beach access paths as they cross through remnant coastal dune habitat. We investigated the influence of path design and frequency on the diversity and percentage of cover of dune plants. All beach access paths on the Isle of Palms were cataloged by path type (path characteristics including public or private) and by path material (wood or sand construction) to create groups that could be analyzed by these characteristics. The Isle of Palms is a developed Atlantic coastal barrier island with approximately 7 mi. of coastline. It is located 17 mi. north of Charleston, South Carolina, and has a residential population of 4583 according to the 2010 U.S. census.

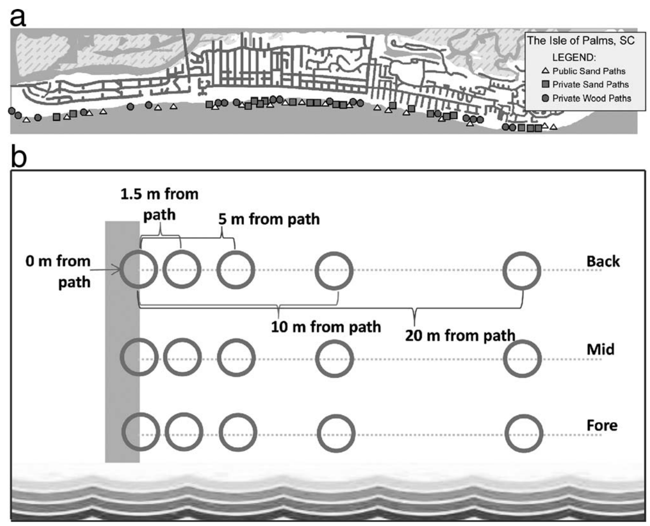

Figure 1. (a) Location of selected paths. Public paths are noted by dotted lines, and almost all oceanfront properties have defined paths that are not shown on this map. Squares, triangles, and circles indicate paths randomly selected for this study. (b) Location of a survey block relative to a path. The rectangle on the left side of the figure represents the path selected for survey, and the waves at the bottom represent the open beach and ocean. Rings indicate survey plot locations within the block. Three parallel transects were established to span the foredune, middune, and backdune areas with survey plots 0, 1.5, 5, 10, and 20 m from the selected path. Some randomly selected paths were not 40 m from the adjacent paths on one or both sides. When there was not at least 40 m between paths, transects were truncated to ensure that plots were not located closer to adjacent paths than indicated by the distance of the plot from the selected path. This was done to ensure that plots located at 10 or 20 m were not influenced by adjacent paths.

Fieldwork

To select field plots, all beach access paths on the Isle of Palms as of August 31, 2012, were cataloged and identified as private sand paths, public sand paths, private wooden paths, or paths that changed material between cresting the backdune and cresting the foredune. We categorized and counted paths using the most current Google maps satellite imagery on that date and following previously published methodologies (Curr *et al.*, 2000; Seeliger, 2003). Paths that changed material between the backdune and the foredune crests were removed from further consideration. From the set of 433 paths spanning the dune system from the developed area to the west to the open beach, we used a random number generator to randomly selected 20 paths in each of the three path-type categories (public sand, private sand, and private wood paths; Figure 1a). Paths transected the dune system from the backdune to the beach. For each path, we created a survey block (Figure 1b).

Each block was defined by a transect parallel to the beach and perpendicular to the path. At each survey block, we recorded the type of path (public sand paths, private sand paths, and private wooden paths), distance to neighboring paths, path width, and path height (for wooden paths only). Because dunes are dynamic systems, we considered height a potentially important covariate, because the path may contribute to shading or maintenance of intact vegetation.

Following the random selection of paths, we employed within each block a stratified systematic sampling design to account for the known vegetation variation in the backdune, middune, and foredune. Backdunes and foredunes are known to be most influenced by wave action (foredune) and human disturbance (backdune) (Curr *et al.*, 2000; Nordstrom, 2000). Within each block, we placed a series of three transects; one along the backdune, one at the middune, and one at the foredune (Figure 1b). A series of five survey plots per transect were located 0, 1.5, 5, 10, and 20 m from the path (Figure 1b), totaling 726 survey plots across the 60 sample path locations. We retained all paths in our random selection, yet some did not reach a distance of 40 m apart, resulting in an incomplete design. This protocol was adapted from methods used by Thompson and Schlacher (2008) and Seeliger (2003). We delineated survey plots using a 91.4-cm-diameter hoop (0.66 m^2). In each plot, we noted all species present, counting the number of stems per species. We employed a modified Daubenmire cover-class (Daubenmire, 1959) approach by life form and abiotic features important in coastal dunes and recorded the percentage of cover in 5% increments in six cover classes: sand, debris, grass, herb, shrub, and vine cover. We defined the abiotic cover class as the combination of the sand and debris classes, while the biotic cover class totaled the percentage of cover of grasses, herbs, shrubs, and vines—the dominant life forms in the dune system.

Statistical Analyses

To assess whether we adequately surveyed the dune plant community in each area of the dunes (backdunes, middunes, and foredunes), we employed rarefaction (species accumulation curves). We evaluated our sampling *via* Mau Tau and Chao2 and then analyzed singletons (a species found in only one survey plot) and doubletons (a species found in only two survey plots) using EstimateS (Colwell, 2013). We employed Mau Tau and Chao2 because of their different statistical strengths. The Mao Tau sample–based rarefaction curve is a richness estimate that resamples plots 50 times to yield the expected mean number of individuals at each sampling level (species observed, or Sobs). The Chao2 estimate has low bias and robust methods to examine richness extrapolated from the sampled data and thus create an estimate of actual richness for incident data (Colwell and Coddington, 1994; Peterson and Slade, 1998; Scarff *et al.*, 2003; Walter and Martin, 2001). If the foredune, middune, and backdune rarefaction curves all leveled off, or if the middune rarefaction curve plateaus and the backdune and foredune curves are influenced by singletons or doubletons, we considered sampling sufficient (Figure 2).

Species richness, percentage of cover, and stem count analyses were performed using SAS (SAS Institute, 2014). Graphical representations were performed in R (R Core Team,

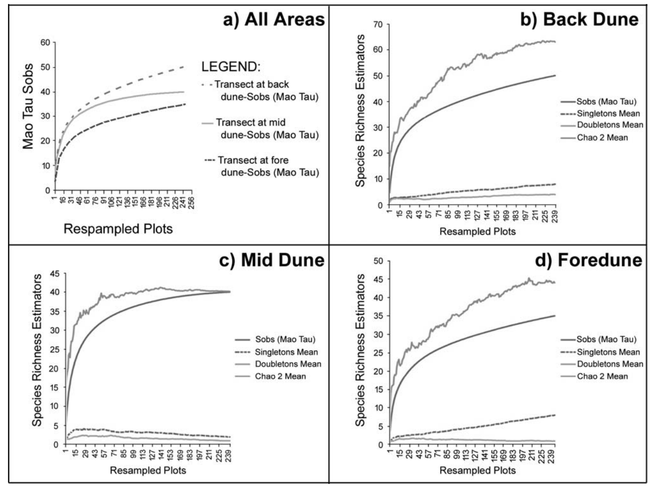

Figure 2. (a) Species accumulation curves (Sobs) for each transect (EstimateS), employing the Mao Tau statistic for number of Sobs for backdune (wide dashed line), middune (solid line), and foredune (tight dashed line) area transects. (b) Species accumulation curve, singletons and doubletons, for the backdune area (EstimateS), employing Chao2 (solid line), Mau Tau (Sobs; wide dashed line), singleton (small dashed line), and doubleton (large dashed line) estimates to ascertain sample completeness and richness. Singletons species are found in only one plot within the sample, and doubletons are species found in only two plots within the sample. Chao2 is an asymptotic richness estimator that is robust to samples containing singletons and doubletons. (c) Species accumulation curve, singletons and doubletons, for the middune area. (d) Species accumulation curve, singletons and doubletons, for the foredune.

2013). Mixed-model analyses of variance (ANOVAs; PROC MIXED) were performed to examine whether there were significant differences among path types, location within the dunes and distance from the path in species richness, percentage of cover, and stem abundance. When main effects were found to be significant, we performed Tukey post hoc tests to evaluate which levels of a factor differed. When considering wooden path height, we defined two groups: (1) raised wooden paths (those at least 0.7 m above the dune) and (2) those at the sand surface. Based on examination of distribution of height, these were two natural groupings. We employed a mixed-model ANOVA that included the two categories of path height: raised ($n = 18$) and less than 0.7 m above the surface ($n = 42$).

RESULTS

Characteristics of beach access paths were important indicators of beach access path impact on the dune vegetation community on the Isle of Palms. Our data allowed us to compare impacts at set distances from a path. Later, we describe in detail the changes in percentage of cover and species richness with the distance from a path. We also explore differing impacts of path material on diversity and abundance. We examine specifically the differences between path type and distance with percentage of vegetative cover. Finally, we outline how path type (public or private) and the distance between paths contribute to the overall impact of beach access paths on dune vegetation.

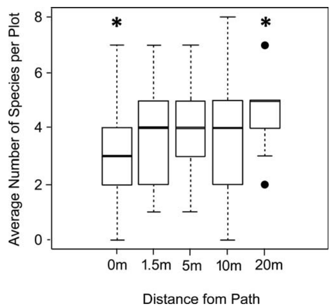

Figure 3. Average number of species at each distance from the path (horizontal line). Dots in the graph indicate extreme outliers. Whiskers indicate maximum and minimum values within 1.5 times the interquartile range from first and third quartiles. The upper bound of the box represents the 75th percentile or third quartile. The bold line within the box indicates the 50th percentile, median, or second quartile. The lower bound of the box represents the 25th percentile or first quartile.

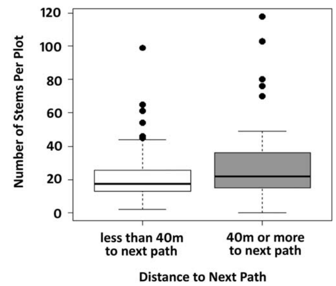

Figure 4. Number of stems per plot for 10-m plots. All areas of the dune are incorporated, and paths are categorized as transects that include 20-m plots (gray box) and transects that do not (white box). Any transect that does not have 20-m plots was in an area where the adjacent path was closer than 40 m to the surveyed path. ($F_{1,1139} = 2.108$, $p < 0.005$). See Figure 2 for boxplot definitions.

Species Richness

Overall, we identified 57 species, with eight singletons, six doubletons, and five tripletons, across all 726 sample points. In the backdune, there were 50 species, with 13 singletons and five doubletons. Species occurring most frequently in the backdune area were *Uniola paniculata* (53.3% of plots), *Strophostyles helvola* (48.3% of plots), *Smilax* spp. (37.5% of plots), *Oenothera drummondii* (35.8% of plots), and *Hydrocotyle bonariensis* (32.5% of plots). In the middune, 40 species were found. The species found in most survey plots in the middune transects were *U. paniculata* (60.2% of plots), *S. helvola* (57.7% of plots), *H. bonariensis* (51.5% of plots), *O. drummondii* (42.7% of plots), and *Heterotheca subaxillaris* (34.4% of plots). There were two singletons and five doubletons. The foredune had 35 species. The species found in the greatest number of foredune survey plots were *U. paniculata* (58.8% of plots), *H. bonariensis* (56.7% of plots), *S. helvola* (46.1% of plots), and *Panicum amarum* (29.0% of plots). There were nine singletons and three doubletons (see Purvis, 2013, for a full species list). Species richness varied significantly among the distance from path classes ($F_{4,726} = 3.27$, $p = 0.011$) in a mixed-effect ANOVA that accounted for path width, path type, and location within the dune structure and where mean number of species per plot was highest at the 20-m distance (Figure 3). There was greater observed variation at 0- and 10-m plots and the least variation at 20-m plots with a few outlying observations.

Percentage of Cover and Distance from Paths

The density of abiotic and vegetative cover varied with proximity to the paths. Using mixed-effect ANOVAs that consider path width, path type, and location within the dune structure, we examined the percentage of sand cover, as well as the percentage of cover of biotic and abiotic cover classes. We found that plots differed significantly in percentage of cover at different distance classes ($F_{4,726} = 37.37$, $p < 0.001$) such that those plots adjacent to the path had significantly more sand cover compared to plots located farther away. There was a greater percentage of sand cover from 0 m (60% average sand cover, where 50% of the plot was located in the path, which shows impact from trampling both in the path and in sand cover adjacent to the path) to plots at 1.5 m (6.3% average sand cover), perhaps attributable to edge effects. Analyses adjusted for the amount of the sample unit by path trampling uncovered similar patterns with distance (not shown). Plots at 5, 10, and 20 m showed a decrease in the average percentage of sand cover, with plots at 5 m containing an average sand cover of 18.1%, plots at 10 m containing an average sand cover of 9.7%, and plots at 20 m containing an average sand cover of 0.3%.

Path Density

Mean stem count, representing total plant abundance, varied significantly with the distance between paths, although considerable variation was observed at each distance (Figure 4). In a mixed-effect ANOVA, accounting for path type and location within the dune structure, we detected significantly lower stem counts in plots located 10 m from the sampled path when paths are less than 40 m apart ($F_{1,1139} = 2.108$, $p < 0.005$; Figure 4) than we found in plots 10 m from the sampled path when paths were greater than 40 m apart. We specifically chose to contrast 10-m plots, because plots at 10 m from the path were included in the survey at all path densities.

Path Type and Vegetation Density

Using mixed-effect ANOVAs that accounted for location within the dune structure (foredune, middune, and backdune) and path width on percentage of sand cover and vegetation density in the 0-m plots for each path type, we found that the percentage of sand cover was significantly lower adjacent to wooden paths than it was adjacent to both private and public sand paths analyzed separately ($F_{2,179} = 4.89$, $p < 0.009$; Figure 5a) and combined ($F_{1,178} = 9.08$, $p < 0.0030$; Figure 5b). Wooden paths also vary in mean height above the sand surface (Figures 6a and b). Wooden paths that were more than 0.7 m off of the sand surface had a lower average percentage of sand cover adjacent to the path compared to paths that were less than 0.7 m from the sand surface ($F_{1,59} = 16.52$, $p < 0.0002$; Figure 6c, which documents both mean and variation). Increases in percentage of sand cover occur concurrently with decreases in percentage of vegetative cover. The relationship is clear;

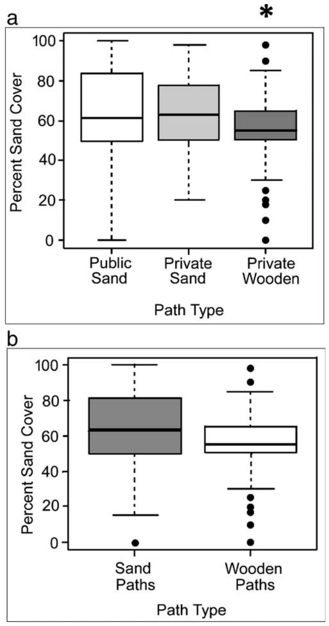

Figure 5. (a) Percentage of sand cover adjacent to each path type ($F_{2,179}$ = 4.89, $p < 0.009$). (b) Percentage of sand cover adjacent to sand and wooden paths ($F_{1,178}$ = 9.08, $p < 0.0030$). See Figure 2 for boxplot definitions.

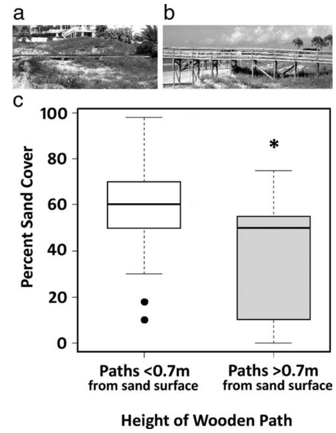

Figure 6. (a) Wooden path near the sand surface. (b) Raised wooden path (defined as at least 0.7 m off of the sand surface). (c) Paths farther from the sand surface show a lower percentage of sand cover at 0 m. See Figure 2 for boxplot definitions.

however, because it is possible to have more than 100% vegetation cover, analyzing sand cover provides a picture of exposed versus unexposed areas of dune sand.

DISCUSSION

Beach dunes are often part of a recreational access system for humans along the coast. The dunes on Isle of Palms, South Carolina contain 433 beach access paths on approximately 7 mi. of barrier island coastline. As the local human population increases, and the island is further developed, the impacts of these paths on coastal dune ecology will intensify. Here, we demonstrate how beach access paths affect the abundance, diversity, and biotic cover of dune vegetation directly adjacent to and at greater distances from the paths. The type of path and the density of paths affect the dune vegetation community through reduction in vegetative cover and species richness.

Species Richness, Biodiversity, and Distance from Paths

Broadly, foredune areas have lower species richness, while areas in the backdune have greater species richness (Monserrat, Celsi, and Fontana, 2012; Porcher and Rayner, 2001), a pattern confirmed in our dataset. Plots adjacent to paths had increased sand cover and reduced vegetative cover for all path types in comparison to those farther from human-constructed paths. Reductions in vegetation caused by trampling and windblown sand increase the area of dunes that are susceptible to erosion and wave action by extending exposure of sand (Nordstrom, 2000). The average number of species per plot was significantly higher at plots 20 m from a path than at other distances; plots 20 m from a path contained an average of five species, while plots adjacent to (0 m from) paths contained an average of only three species, demonstrating that lower diversity is associated with beach paths. The average number of stems per plot was higher for plots in areas where there were more than 40 m between paths. Together, our estimates of biodiversity and vegetation coverage suggest that management regulations that allowed fewer paths at greater distances from one another would improve species richness and likely resilience in the dune vegetation community (see also Nordstrom, 2000).

Path Density

Path density was investigated in plots to ascertain its influences on overall vegetation cover. We found a higher number of stems per plot in transects where paths were more than 40 m apart. The vegetation density, estimated *via* stem counts, decreased as the number of paths per unit area (path density) increased. This trend indicates higher vegetation cover and greater dune stability in areas with lower path densities. Because vegetation stabilizes sand dunes, as the vegetation cover decreases, the dunes become more susceptible to erosion from wind and water (Curr *et al.*, 2000; Judd *et al.*, 2008; Monserrat, Celsi, and Fontana, 2012).

Path Type and Vegetation Density

Previously, work on the effects of paths on plant diversity or animal diversity has focused on the direct effects of trampling (Curr *et al.*, 2000; Seeliger, 2003; Thompson and Schlacher, 2008). Comparison of wooden raised paths to sand paths sheds some light on this issue in a dune habitat. Directly adjacent to wooden paths, we found a lower percentage of sand cover when compared to areas adjacent sand paths. The design of the study allowed a comparison of both path types (public and private) and path material (sand and wood). Public and private sand paths were not significantly different from one another in terms of percentage of cover or species richness. This pattern indicates that path material or construction history is a more important factor in ecological impact than path width or amount of path traffic, assuming that public paths receive more traffic than private paths (Curr *et al*., 2000; personal observations). Our data cannot differentiate whether the wooden path has a psychological influence that encourages human visitors to remain entirely on the path or is related to other factors, such as blowing sand from sand paths covering adjacent vegetation. Furthermore, sand paths and other access points create a break in the line of foredunes, thereby promoting flooding on the interdune areas during very high tides and storm events, which causes erosion and increases soil salinity (Martin, 1959). With the tendency of beach access paths to delineate a line from the first roadway through the dune system to the open beach, storm waters are given easy access to the interdune and backdune areas (Hesp, 2002). This action leads to the erosion and eventual landward retreat of the dune system (Hesp, 2002), indicating that disruptions to the dune system that result in reduced vegetation and breaks of the foredunes can have a significant impact on the long-term health and stability of the dune system (Hesp, 2002; Martin, 1959). Vegetated dunes tend to be more stable and therefore more resilient to disturbance events (Nordstrom, 2000).

While the presence of access paths is not the only cause of blowouts, which are breaks in the line of protective foredunes, Martin (1959) was among the first to boldly state that there is always a blowout where sand paths cross the foredunes because of the break they create in the profile of the foredune (confirmed by personal observation and Nordstrom, 2008). This pattern suggests that regulations requiring raised wooden paths could decrease the likelihood of foredune breaches during high tides and storm events, reducing the human impacts of dune dynamics. Our data indicate that management regimes where paths were constructed from wood and raised above the sand surface would positively influence the dune vegetation community and overall vegetative cover of the dunes.

CONCLUSION

The current regulations of many SE U.S. beaches, and of Isle of Palms, South Carolina, in particular, allow each beachfront property owner to create a path extending from the backyard to the open beach. For Isle of Palms, permits are required for the construction of wooden paths but not for the creation of sand paths (Isle of Palms, 2013). Other regulations require the placement of public access paths at distances of ⅛ or ¼ mi., based on parking and other amenities that facilitate public access, when state monies are used for beach restoration or renourishment projects (South Carolina Legislature, 2013), and these are all sand paths. South Carolina's Office of Ocean and Coastal Resource Management implements its retreat policies through the use of a management zone that uses the mean high-tide line to establish a minimum setback from the open beach at a distance behind the primary dune structure, determined by the average 40-year erosion rate. As coastlines along the U.S. Atlantic seaboard endure increased storm frequency and intensity, the political battle over retreat and dune management policies is heating up (Bartelme, 2013; Jones, 2013; Malone, 2012; Parry, 2013; Schwirtz, 2013). Such policies may be an important consideration as municipalities and ecologists examine the potential effects of predicted sea level rise and additional climate change impacts on local plant communities (Pilkey and Young, 2009). The two primary points of view are represented by government agencies that are attempting to manage the beach in ways that benefit the community and by the private landowners who are trying to protect their specific properties. While the issue of retreat may not be easy to resolve, both of these groups can find common ground through the protection of existing dune systems (Purvis, 2013).

Based on the ecological findings of this study, two important recommendations for modifications can be made in beach access path practices. The first is to require neighboring homeowners to share a common path rather than create and maintain separate paths. This should reduce the density of paths through the dune system, thus reducing fragmentation. Given the decrease in vegetation cover and species richness when paths are closely spaced, this change could make significant improvements in the resilience of existing and restored dune systems. The second alteration could be to allow only raised wooden beach access paths for private residences. This change would create a dune system with fewer breaks in the foredune, reducing opportunities for storm events and high tides to breach the foredune and maintaining higher levels of vegetative cover and diversity. Wooden beach access paths should also encourage more continuous vegetation across the dunes, minimizing open sand cover and thus providing more overall protection during storms.

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