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Early development of vegetation in restored dune plant microhabitats on a nourished beach at Ocean City, New Jersey

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Abstract. Topography and vegetation of restored dunes on a developed barrier island were examined after a large-scale beach nourishment project. Restoration began in 1993 using sand-trapping fences and *Ammophila breviligulata* Fern. plantings. Subsequent growth of dunes was favored by installing new fences and suspending beach raking to accommodate nesting birds. Plant species richness, percent cover of vegetation, and height of *A. breviligulata* were sampled in 1999 on seven shore perpendicular transects in six dune microhabitats (backdune, primary crest, mid-foredune, swale, seaward-most fenced ridge, incipient dune on the backbeach).

A total of 26 plant taxa were found at all seven sites. Richness and percent cover were greatest in the backdune and crest, especially in locations that predated the 1992 nourishment. Richness was greater where fences enhanced stabilization. Fences initially compensate for time and space and allow vegetation to develop rapidly, but maintenance nourishment is required to protect against wave erosion and ensure long-term viability of habitat. An expanded environmental gradient is an option, where beach nourishment provides space for a species-rich crest and backdune to develop, while the incipient dune remains dynamic. Options where space is restricted include a dynamic, full-sized seaward section of a naturally functioning dune (truncated gradient) or a spatially restricted sampler of a wider natural dune (compressed gradient) maintained using fences. Expanded and truncated gradients may become self-sustaining and provide examples of natural cycles of change. Compressed gradients provide greater species richness and flood protection for the available space, but habitats are vulnerable to erosion, and resident views may be impaired.

Keywords: *Ammophila breviligulata*; Barrier island; Beach nourishment; Developed coast; Environmental gradient; Restoration; Sand fence; Species richness; Stabilization.

Introduction

Shorelines in developed areas are being converted to artifacts (Nordstrom 2000). Dunes are eliminated to facilitate construction, enhance access or create space for beach recreation, and beaches are mechanically cleaned to make them attractive. Coastal erosion and attempts to retain a fixed shoreline result in loss or truncation of beaches and dunes (Fig. 1). Beach nourishment operations can replace lost sediment, but nourishment is usually intended to protect buildings and provide recreation space, not to restore natural systems. If dunes are rebuilt, they are often low, narrow, and linear because they are designed to form a dike against wave attack and flooding and not to take up recreational beach space or interfere with views of the sea. The modified landscape usually lacks the topographical and biological diversity of natural coasts.

Allowing restored dunes to be functioning ecosystems rather than simply protective structures can help renew an appreciation for a dynamic natural landscape (Breton & Esteban 1995; Breton et al. 1996, 2000; Nordstrom 2000). Successful restoration in human altered environments requires adoption of a new symbiotic, sustainable relationship between society and nature to achieve diversity of landforms, species and ecosystems that are dynamic and natural as possible but compatible with human values (van der Maarel 1979; Westhoff 1985; Light & Higgs 1996; Pethick 1996; Jackson et al. 1995; Cox 1997; Naveh 1998; Barrett & Grizzle 1999; Minteer & Manning 1999; Katz 1999).

Large-scale beach nourishment operations provide sediments for dune building and space for dunes to form and survive. An initial step in increasing the number, size and usefulness of restored natural environments involves the determination of reference or target characteristics that are feasible given the temporal and spatial constraints (Falk 1990; Aronson et al. 1995; Hobbs & Norton 1996). Reference sites should not be so naturally favored that observed conditions are unachievable at

Fig. 1. Ocean City, New Jersey in 1984, just south of Site 7 (Fig. 2).

sites to be restored (White & Walker 1997; Ehrenfeld 2000). Research on feasible outcomes should evaluate whether the resulting landforms will approximate natural forms and identify advantages and drawbacks of alternative landforms and habitats.

This study identifies vegetation characteristics of restored dunes in the early years after beach nourishment. Microhabitats are evaluated along cross-shore transects at seven sites at Ocean City, New Jersey (Fig. 2). The emphasis is on plant species richness (i.e. diversity), percent cover (indicating sediment stability), and height of American beach grass (*Ammophila breviligulata* Fern.), because it is the initially-planted and presently-dominant species. These variables are evaluated relative to beach width and topography that affect sheltering from wind and wave run-up. Ocean City is the first location in New Jersey to receive a large, barrier island scale, Federal/State nourishment project of the kind that is being implemented along the critically-eroding ocean shoreline of the state. The fill was placed in 1992. Dune building began in 1993, so restoration potential can be evaluated over the 5 to 10-yr period when natural dunes reform on barrier islands after being eliminated by major storms (Hosier & Cleary 1977; Ritchie & Penland 1988). The time frame falls within the normal planning horizon of municipal officials and the period after restoration when resident attitudes and actions supporting or opposing the effects are most critical.

Methodology

Study area

Buildings in Ocean City are primarily single-family and multiple-unit houses (Fig. 1) with hotels and guest houses near the central business district (Fig. 2). The municipality is in the National Flood Insurance Program, and new structures must be built with the lowest floor above base flood elevation (3.05 m above mean sea level), but structures that pre-date the program are

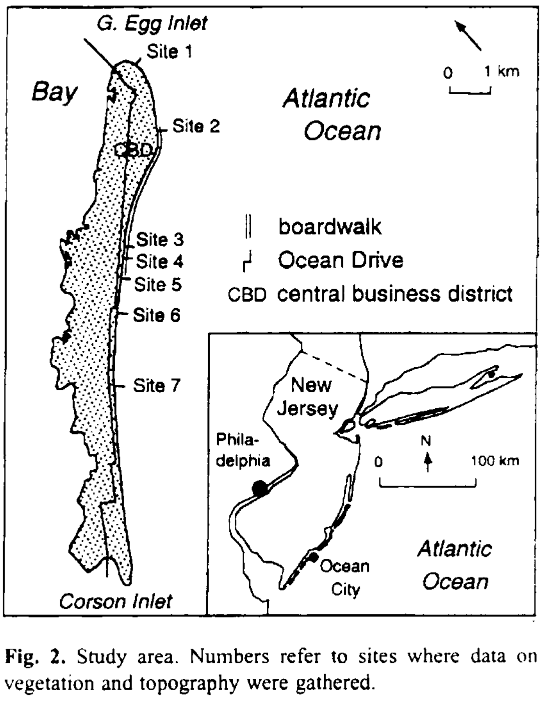

Fig. 2. Study area. Numbers refer to sites where data on vegetation and topography were gathered.

lower. Bulkheads, with an elevation of 3.4 to 3.9 m above mean sea level, front much of the shore. A 4.2-km long elevated wooden boardwalk runs seaward of the first row of buildings. The orientation of the boardwalk (Fig. 2) conforms to the backbeach, but the road network is linear, leading to termination of several north-south roads at the shoreline. Houses beyond these road termini are set farther back, providing space for a wider backdune.

Dominant winds are from the northwest. Average annual significant wave height is 0.82 m (Thompson 1977). Mean tidal range is 1.1 m (Anon. 1999). The northern shore terminates at Great Egg Inlet, and changes to the tidal channels and ebb delta at that inlet cause cycles of accretion and erosion at the northeastern tip of the island. Swell waves from the southeast transport sediment north; winter storm waves from the northeast transport sediment south. Net drift is to the south along the island south of Site 2 (Fig. 2) where the ebb delta does not provide shelter against winter storm waves. Natural beach sediments are fine sand (Anon. 1966).

The nourishment operation that preceded dune restoration was a Federal/State project, using 6.6 million m^3 of sediment dredged offshore of Great Egg Harbor Inlet (Anon. 1989). The initial fill was placed along 6.9 km of shore between Sites 1 and 7 (Fig. 2) in summer and fall of 1992. The zone of nourishment was extended south of Site 7 in 1995. Foredune building began early in 1993 at Sites 1 to 6 and 1995 at Site 7. The municipality placed two rows of sand-trapping fences 5 m apart and planted the space between with *Ammophila breviligulata*. The intent was to allow a dune to form by natural aeolian accretion, rather than by bulldozing as often occurs in New Jersey and other locations (e.g. Baye 1990). *A. breviligulata* is the only species the municipality planted. Plots were fertilized for two years after planting. Subsequent plantings occur annually as needed. None of the sites investigated in this study had recent plantings as was evident by the highly patchy vegetative cover.

The beach is privately owned in places, and the municipality had to obtain easements from property owners to build dunes. They obtained easements with the proviso that the dunes would become no higher than 0.9 m above bulkhead elevation, so residents could retain views of the sea. New sand fences are placed seaward of dunes, so dunes build seaward not upward (Fig. 3). Some sites have troughs landward of the dune crest, where sand is removed to minimize deposition on the boardwalk or private properties.

Beaches are raked during the recreational season, ending in September. Designation of nesting sites for piping plovers in some segments of beach resulted in prohibition of raking, leading to local colonization of the backbeach by plants and growth of incipient dunes that survived several winter storm seasons (Fig. 3). Beach managers avoid raking incipient dunes once established, so they can survive on the upper part of beaches that are normally raked.

Site descriptions

Transect lengths range from 87 m to 185 m (Fig. 4) and extend from the seaward-most static cultural feature that prevented dune formation landward of it (usually a bulkhead) to the active beach seaward of the berm crest. Sand fences and elevated boardwalks are not transect termini because they do not completely restrict aeolian transport, and dunes may form landward of them. Incipient dunes occur on all sites except Site 6. Sand

Fig. 3. Characteristics of the dune just north of Site 3 in November 1999, showing the dune crest (left), seaward-most fence (right) and incipient dune on the beach (far right).

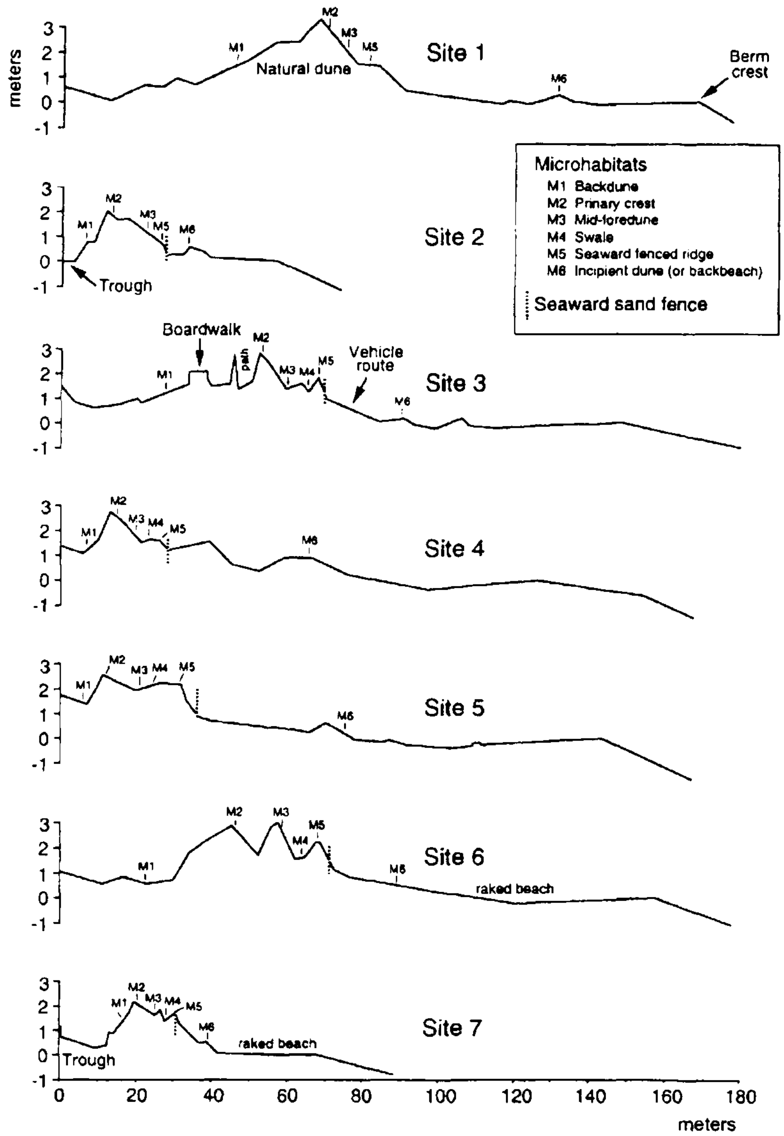

Fig. 4. Topographic profiles, showing microhabitats sampled. Landward end of Site 1 is at a patio deck; the end of Sites 2 and 4 are at the boardwalk (the unvegetated troughs are the effective landward limit of dune formation); the end of other sites is at a bulkhead.

fences are conspicuous at all sites except Site 1. Fences are responsible for much of the topographic variability, but the relationship between observed fences and topography is not always direct because some local peaks are the result of fences that are now buried.

Site 1 (Fig. 4) serves as an approximation of a natural control. The relatively wide beach was created through natural accretion at the inlet, and the beach is not raked. The dune has functioned naturally after burial of the initial two fences. The large dune size is attributed to exposure to the dominant northwesterly winds blowing across the wide beach. The backdune has two distinct plant communities. Woody vegetation dominates the landward half that existed prior to beach nourishment. The seaward half is contemporaneous with backdune locations in other dune sites created since 1993 and supports a grass-dominated community.

Site 2 is of interest because it has an intact well-vegetated dune ridge and incipient dune but is fronted by a narrow beach resulting from rapid erosion following nourishment. A trough that is maintained in an unvegetated state is the seaward-most static cultural feature. The boardwalk is just landward of the dune trough.

Site 3 provides the opportunity to assess the effects of an access path through the dune crest. This path is oriented south of shore-normal to restrict overwash from northeasterly storm waves (causing it to resemble a shore-parallel feature in Fig. 4), but it provides a conduit for aeolian transport, and the dune has migrated farther landward of the boardwalk than is usually allowed in developed areas. Incipient dunes formed on the beach where bird nests were observed, and raking and pedestrian use are prohibited. The incipient dunes are not contiguous to the managed dune because maintenance vehicles use the backbeach landward of the nest sites as a route for trash pickup. The access path and the unvegetated backbeach enhance sediment mobility.

Site 4 was selected because the incipient dunes seaward of the managed foredune are the largest in Ocean City, and they have a more complete vegetation cover than at Site 3 because maintenance vehicles do not use the backbeach. There is no path through the dune at this site, so comparison with Site 3 provides insight to the effect of suppressed aeolian transport.

Site 5 is 100 m south of the terminus of the boardwalk and was selected to document characteristics where the boardwalk does not preempt vegetation growth in the backdune. Incipient dunes occur seaward of the last fence because the beach is not raked. The backdune is landward of the pre-nourishment erosion line and was vegetated prior to the 1992 beach nourishment project.

Site 6 is 100 m south of the point where the shore front road (Ocean Drive) turns landward (Fig. 2), and the houses are farther back from the dune crest than at other sites. The backdune environment pre-dates the 1992 nourishment. The backbeach is raked, and incipient dunes have not established.

Site 7 was selected because dune building was initiated 2 yr later, providing insight to differences in growth over 4 vs 6 yr. The site has an undeveloped lot with residential houses on either side, and it has a wide graded and unvegetated shore-parallel trough that is maintained between the landward bulkhead and the foredune. The beach is raked.

Sampling methods

Species richness, percent cover of vegetation, and height of *A. breviligulata* were sampled September to November 1999 using 1 m x 1 m quadrats in six dune microhabitats along seven representative shore perpendicular transects (Fig. 2). Topography was measured at breaks in slope in October 1999 using a level and transit. The microhabitats are similar to topographic site types or habitats used in other studies (Moreno-Casasola 1986; Doing 1985) and are defined topographically because of the significance of sheltering on wind stress, salt spray, and blowing sand.

Microhabitat 1 (sampling location M1, Fig. 4) represents the backdune and was sampled halfway between the seaward-most static cultural feature and the primary (highest landward) dune crest. The backdune at Site 1 is so wide that the landward vegetation is not an achievable restoration outcome on spatially-restricted developed sites. Accordingly, M1 at Site 1 was sampled no farther landward of the crest than the equivalent sampling point at the widest backdune on a developed site (Site 6). Microhabitat 2 (M2) represents the primary dune crest and was sampled just seaward (1 to 2 m) of the highest point. Microhabitat 3 (M3) is half the distance from the primary crest to the top of the seaward-most dune ridge that was maintained by sand fences. Microhabitat 4 (M4) is in the swale landward of the seaward-most fenced ridge, and Microhabitat 5 (M5) is on the top of that ridge. There is no swale at Sites 1 and 2 and no sampling location M4 for those transects; quadrats designated M5 were sampled at a location comparable to the crest of the seaward-most fenced ridge at other sites. Microhabitat 6 (M6) is within an incipient (embryonic or pioneer) dune. The beach at Site 6 was sampled where it was believed that incipient dunes would have formed if the beach were not raked. Aerial photographs (1: 9600 scale) from 1986 were used to identify vegetation growth that predated the 1992 nourishment project. These areas include M1 on Site 5 and M1 and M2 on Site 6.

One quadrat in each microhabitat was sampled on the transect line, with a replicate quadrat sampled on each side at random distances up to 10 m, yielding 120 quadrats (40 microhabitats x 3 replicates). Richness is the number of species observed in quadrats. Percent cover of vegetation is classified in 20% ranges (0% - 20%, 21%-40%, etc) and ranked 1 to 5. Height of *A. breviligulata* is the average height where it was most dense in each quadrat. Data were analyzed using two-way ANOVA and Bonferroni/Dunn (all means) mean comparison at 0.05 significance level. Species richness, percent cover of vegetation, and average height of *A. breviligulata* were the dependent variables. Categories were site, microhabitat, and microhabitat within a site.

Table 1. Species list for study sites. N means microhabitat was not sampled at that site.

Site	1						2						3						4						5						6						7					
Microhabitat	1	2	3	N	5	6	1	2	3	N	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Achillea millefolium																									X																	
Ammophila breviligulata	X	X	X		X	X	X	X	X		X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X	X			
Anaphalis margaritacea																															X											
Baccharis halimifolia																									X						X											
Cakile edentula												X			X			X																X								
Cenchrus tribuloides							X		X													X																				
Cyperus spp.																															X											
Euphorbia polygonifolia								X	X		X				X				X		X	X	X			X						X										
Heterotheca subaxillaris								X																																		
Lechea spp.								X					X						X	X					X						X		X									
Lichen																															X	X										
Mollugo verticillata											X																															
Moss																															X											
Mushroom			X				X	X																			X										X					
Oenothera spp.																									X																	
Panicum amarum			X																						X			X			X	X	X									
Parthenocissus quinquefolia																									X																	
Salsola kali																		X						X										X								
Schizachyrium scoparium																																	X									
Solidago sempervirens																									X						X	X										
Spartina patens	X																			X											X	X										
Taraxacum officinale																															X	X	X									
Triplasis purpurea							X	X					X						X																							
Xanthium strumarium											X	X																														
Other: Rosette																									X						X											
Other: Seedling								X												X					X		X				X		X	X								

Results

Ecological findings

A total of 26 plant taxa were found at the seven sites (Table 1). Summarized vegetation characteristics (Table 2) reveal that richness is greatest in Site 6, with most species in the two microhabitats that predate the 1992 nourishment. The next greatest average richness is at Site 2. Site 7, where the dune is more recent, had the lowest average richness value, but Site 1, the highest and most naturally-functioning dune, has richness values that are not statistically different. Mean height of

Table 2. Summary statistics, per quadrat, for vegetation data by site.

Site	Richness No. species		Percent cover (20% categories)		*A. breviligulata* height (m)	
	mean	SD	mean	SD	mean	SD
1	1.17	0.39	2.33	1.56	0.64	0.16
2	2.53	1.19	1.87	1.25	0.59	0.10
3	1.13	0.84	1.88	1.46	0.61	0.25
4	1.78	1.06	2.28	1.53	0.66	0.09
5	2.17	2.04	1.94	1.70	0.57	0.17
6	4.92	2.88	3.17	1.64	0.61	0.13
7	1.00	0.54	1.00	.00	0.66	0.12

A. breviligulata is similar at all sites. It is most variable at Site 3, where topography is variable and human activity is increased. Percent cover is greatest at Site 6, where microhabitats M1 and M2 predate nourishment.

The ANOVA revealed that richness and percent cover were significantly different among sites, microhabitats and microhabitats in sites (Table 3). Heights of *A. breviligulata* were significantly different among microhabitats and microhabitats in sites but not between sites (Table 3). Ten site pairs are statistically different using richness as the dependent variable. Site 6, with more species, is statistically different from all other sites. The other site pairs with significantly different richness values are Site 2 with Sites 1, 3 and 7 and Site 5 with Site 7. Site 5 is the only other site that had a microhabitat (M1) that predates the nourishment. Site 1 is only statistically different from Sites 2 and 6. That Site 2 is not statistically different from Site 5, indicates that greater width of beach and dune (Figs. 3 and 4) may not affect richness over a 6-yr period.

Five site pairs are significantly different using percent cover of vegetation as the dependent variable. These are Site 6 with Sites 2, 3, and 7 and Site 7 with Sites 1 and 4. No sites are statistically different using *A. breviligulata* height as the dependent variable (Table 3).

Mean richness and cover for all sites generally

Table 3. Results of ANOVA of plant microhabitat attributes against location.

Dependent variable	Location	df	*F*-value	Significance
Richness	Sites	6	26.796	0.0001
	Microhabitats	5	13.276	0.0001
	Site microhabitat	21	5.525	0.0001
Percent cover	Sites	6	6.830	0.0001
	Microhabitats	5	16.201	0.0001
	Site microhabitat	21	2.333	0.0058
Height *Ammophila breviligulata*	Sites	6	1.090	0.3795
	Microhabitats	5	5.022	0.0007
	Site microhabitat	21	2.465	0.0036

decrease seaward (Fig. 5). In terms of richness, the backdune (M1) is significantly greater than all other microhabitats and the dune crest (M2) is significantly greater than the seaward-most ridge (M5). The backdune and crest (M1 and M2) have significantly greater percent cover than all other microhabitats but are not significantly different from each other. *A. breviligulata* height (Fig. 5) is least on the seaward-most ridge (M5), where recent vegetation growth has not kept pace with rapid deposition, and greatest on the crest (M2). The crest (M2) is statistically different from the swale and seaward-most ridge (M4 and M5) in terms of *A. breviligulata* height.

The backdune (M1) of Sites 5 and 6 and the dune crest (M2) of Site 6, which pre-date the nourishment, have much greater richness than other locations (Fig. 6A). Mean richness in the backdune at Site 5 (6.33 species) greatly exceeds the value for the adjacent post-nourishment microhabitat on the dune crest (1.33). Richness at each site is greatest in the backdune (M1), except at Site 2, where the dune crest (M2) has nearly twice the richness (4.33 versus 2.33).

Percent cover at Site 7 is low at all microhabitats (Fig. 6B). Percent cover is low at Site 2, except at the crest. Microhabitats at Sites 5 and 6 that pre-date nourishment have the greatest percent cover. Mean height of *A. breviligulata* within each microhabitat on each site differs little, except at Site 3 where heights in the backdune (M1) and swale (M4) are less than half the heights on the more stable crest (M2) and mid-foredune (M3).

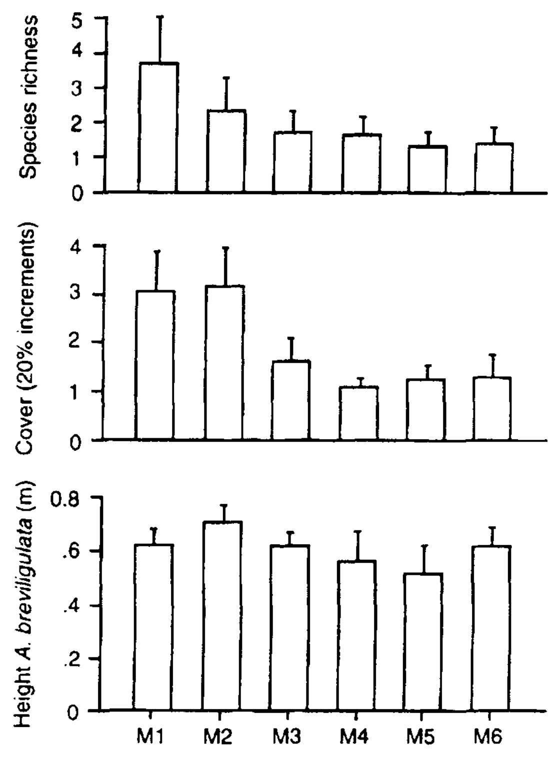

Fig. 5. Mean richness, percent cover and height of *Ammophila breviligulata* for each microhabitat on all sites. Error bars represent 95% confidence level.

Discussion

Sediment mobility

Disturbance is considered the driving influence on coastal dune community composition and richness, especially in the strand and foredune (Keddy 1981; Moreno-Casasola 1986; Ehrenfeld 1990). Fewer species can tolerate the stresses and great sand mobility, and richness is diminished in the least stabilized portions of a gradient (Moreno-Casasola 1986). Low richness at Site 1 (Table 2) may be due to high rates of sediment mobility. Beach width is an important control on aeolian transport, with rates greatly increased on wide beaches (Davidson-Arnott & Law 1990; van der Wal 1998; Jackson & Nordstrom 1999). The wide beach and lack of fences at Site 1 contribute to instability of the dune. The implication is that greater interplay of natural processes leading to greater foredune height on a wide beach and dune profile does not favor species richness over management that favors ongoing use of sand fences, at least in the time frame examined here.

Low richness at Site 3 may be attributed to relatively great sediment mobility due to the access path through the dune ridge and the unvegetated vehicle route landward of the incipient dune (Fig. 4). Reduced richness and percent cover at Site 7 may occur because the dune is 2 years younger, but sediment mobility may be a factor. Reworking of the deflated surface of a nourished beach increases the exposure of fine-grained sediments

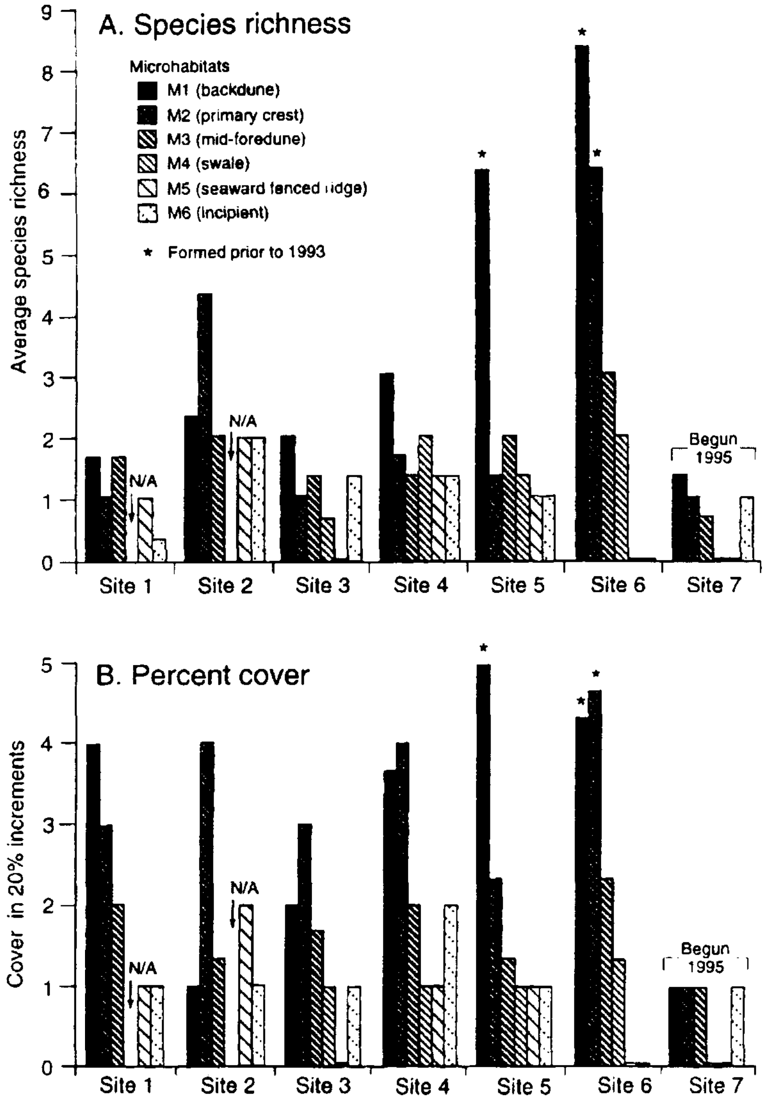

Fig. 6. Species richness (A) and percent cover of vegetation (B) for each microhabitat (mean of three quadrats) at each site. Percent cover is depicted as zero where no vegetation was observed in any replicate samples of a microhabitat.

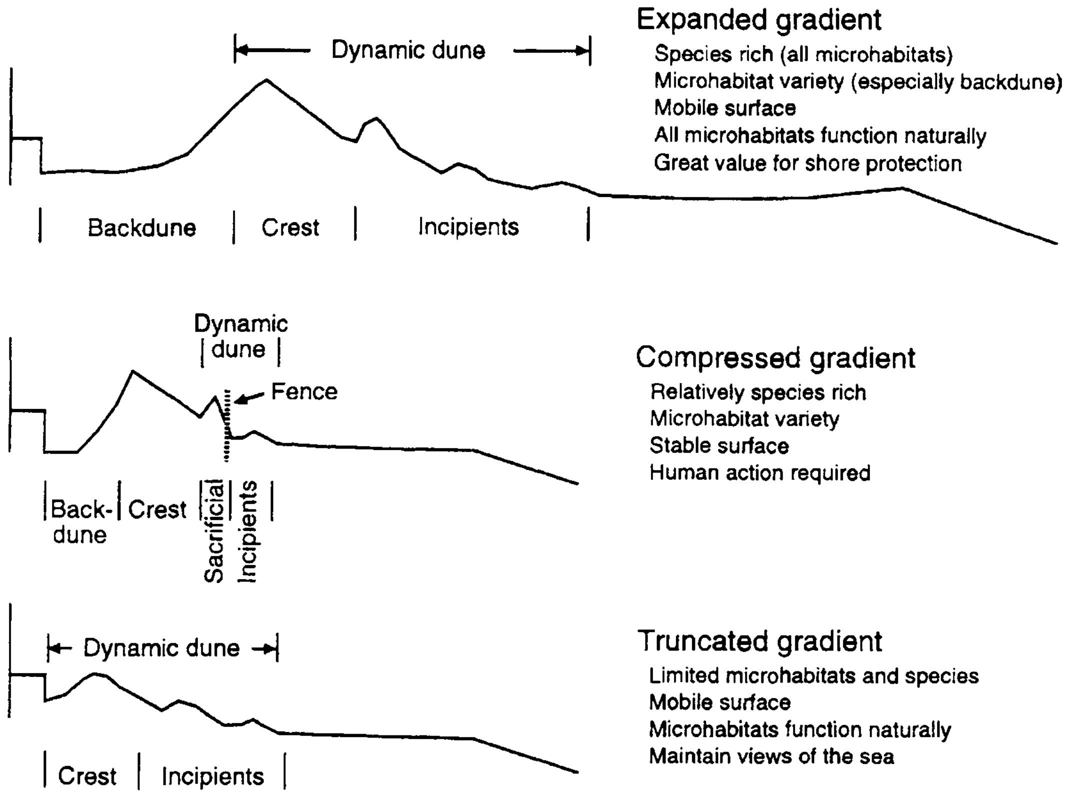

Fig. 7. Categories of restoration outcomes for dunes on a developed coast.

and enhances aeolian transport (van der Wal 1998). Raking of the beach at Site 7 may have enhanced sediment transport during onshore winds. Channeling of wind through the gap in the line of houses and entrainment of sand from the bare trough during the dominant offshore winds also contribute to sediment mobility at this site. Raking of the backbeach at Site 6 has contributed to a high rate of deposition at the seaward-most ridge (M5) that has been too rapid and recent for new vegetation to colonize, but the accretion there has prevented excessive sedimentation of the well-vegetated landward microhabitats.

Sediment mobility may be considered good or bad, depending on rate of deposition, age and size of the dune system, species of vegetation that is of greatest management interest and the status of that vegetation (de Rooij-van der Goes et al. 1997; Maun 1998; Rhind & Jones 1999). It is important to determine the specific context in which the degree of mobility is evaluated. In this case, it is desirable to have a reduced rate of sediment transport in the dune close to the backbeach in order to favor growth of backdune species that enhance the image of the dune as an aesthetic resource as well as a protection structure.

Microhabitat locations and dune width

There is a close interaction between species richness and vegetation cover, and increasing plant cover instigates the stabilization process (Moreno-Casasola 1986). These correlations are reflected in the cross-shore trends of richness and plant cover that decrease in the seaward direction (Fig. 5). Continued use of sand fences seaward of dunes enhances stabilization by reducing sedimentation from the beach. Dunes of a developed coast are usually restricted to a much narrower space than natural dunes, and the dune zone corresponds only to the dynamic seaward section of a natural environmental gradient. Therefore, the backdune and crest microhabitats of artificially restored and fenced dunes are important in providing the relatively stable environment, increased plant cover and increased richness that may not otherwise form in the space available.

Sites 2 and 4 formed over the same time period, using similar fencing, planting and raking practices, and they have similar richness values but conspicuously different widths of beach and dune. Thus a compressed (artificially narrow) environmental gradient (Site 2) appears to offer a viable alternative to a wider beach if maximizing richness is the goal. The significance of beach width as a limit to transport of sand during onshore winds is most pronounced in the first tens of meters close to the water (Jackson & Nordstrom 1999; van der Wal 1998), and it is possible that richness at Site 2 is favored by the reduced rate of transport from the narrow beach.

Similarity in richness of Sites 2 and 4 does not mean that dune size is unimportant in achieving restoration goals. The linear, single-crested dune at Site 2 retains the look of an engineered sand dike, albeit one with diverse vegetation, whereas the dune at Site 4 more closely approximates a natural dune field and may convey a better image of the environmental heritage that was lost through development. The protective value of a restored dune must also be included in evaluating the significance of gradient width. The narrow beach at Site 2 may have contributed to richness in the backdune and crest microhabitats, but this compressed system is more vulnerable to wave erosion during storms. Site 4 has three dune ridges that protect the vegetation in the backdune areas, although they do not increase species richness over this time frame.

Temporal aspects

Greater richness in backdune microhabitats that originated prior to 1993 indicates that dunes on a developed coast can become relatively rich in composition if they are allowed to persist. These results underscore the future advantage of maintaining a wide beach and large dune through maintenance nourishment to reduce vulnerability to erosion by storm waves. The linear shape and small size of the dune at Site 2 may present an image of a sacrificial structure built for protection of buildings and human infrastructure, but the vegetation indicates that the dune is a resource in its own right that requires protection through renourishment.

Management choices

General restoration goals for human altered areas include: (1) using active management to obtain a desired characteristic; (2) re-establishing nature as the principal process control; or (3) restoring functions rather than restoring original conditions with all former species present. The first goal creates a desired image quickly, whereas the second and third goals lead to a self-sustaining system requiring minimum human intervention (Jackson et al. 1995; Palmer et al. 1997; White & Walker 1997). Success in achieving these goals on a developed coast is determined by the space available for dunes to form. Considering the results at Ocean City, three general types of restoration outcomes appear appropriate (Fig. 7): (1) an expanded dune gradient (based on Sites 1, 4 and 6); (2) a compressed gradient (based on Site 2); and (3) a truncated gradient (based on incipient dunes at Sites 3 and 4 and dunes observed in other developed municipalities in New Jersey where sand fences are not placed on the backbeach).

An expanded gradient may be an achievable outcome where beach nourishment provides and maintains space for a species-rich stable crest and backdune to develop, while the backbeach/incipient dune system remains dynamic. Judicious use of sand fences may hasten development of landward environments, but it may be desirable to refrain from use of fences to ensure a fully natural trajectory. Comparison of richness and percent cover at sites subject to pedestrian and vehicular traffic (Site 3) with dunes of comparable width and age that lack these impacts (Site 4) indicates that minimizing human-induced sediment mobility may also hasten development of habitats on expanded dune gradients.

An issue that must be resolved where beach space is more critical than at Ocean City is whether the desired landscape image should be the dynamic but full-sized seaward section of a naturally functioning dune (truncated environmental gradient) or a spatially restricted sampler of a wider transect of a natural dune (compressed environmental gradient), enhanced using fences or plantings. Both kinds of dunes have value in the New Jersey context. Truncated gradients with full-sized naturally functioning seaward microhabitats provide: (1) the kind of beach nesting birds would use as habitat (Melvin et al. 1991); (2) seed sources for pioneer species that have value as food for fauna (Amos & Amos 1985; Andre et al. 1994); and (3) examples of the cycles of growth and destruction that underscore the dynamic nature of natural coastal environments (Nordstrom et al. 2000). Compressed gradients provide: (1) greater species richness for a given space; (2) a view of nature that contains more variety than would otherwise be available; (3) greater protection against wave overwash, flooding, and wind-blown sand. The diverse vegetation on a compressed gradient may provide local stakeholders a more aesthetically pleasing landscape and a more reassuring image of geomorphic stability than is provided by a truncated gradient, but the increase in dune crest height required for stability may restrict resident views. Active management can create the specific image desired in a compressed gradient quickly, but this kind of dune must be maintained by human efforts on a narrow beach where wave erosion or aeolian transport contribute to dune instability. This kind of target state, where humans are considered part of nature in restoring and maintaining an ecosystem, may be more accurately defined as rehabilitation rather than restoration (Callicott et al. 1999). Expanded gradients and truncated gradients may be self-sustaining, and they accurately depict wild nature, but they may not be allowed to develop as fully natural systems in developed areas because of competing needs for the space and the present preference of local managers for landform stability.

Conclusions

This evaluation of plant species richness, percent cover, and height of *Ammophila breviligulata* on dunes built using sand fences and vegetation plantings over 4 to 6 yr indicates that:

• Both natural and human-induced sediment mobility may reduce species richness or delay development of vegetation in the crest and backdune habitats.

• Greater interplay of natural processes does not favor species richness over management using sand fences, and a narrow dune can have comparable richness to a wider dune if fences are used to overcome space restrictions.

• Increase in richness in the backdune and crest over time underscores the advantage of using maintenance nourishment to protect these microhabitats.

• Restoration outcomes where space is critical may be a naturally-functioning truncated gradient or a compressed and artificially-maintained gradient with increased species richness and greater protection against wind-blown sand, wave overwash and flooding.

• An expanded gradient with species-rich crest and backdune and large incipient dune is an appropriate goal where wide beaches can be maintained by maintenance nourishment.

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