Journal of Coastal Conservation 1: 41-50, 1995

An evaluation of the vegetation developed after artificially stabilizing South African coastal dunes with indigenous species

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Abstract. A total of 17 sites along the eastern Cape coastline, which had been established with indigenous species, were sampled to assess species composition and abundance. The areas sampled ranged from small blowout dunes of 1 ha, to extensive transverse dune fields of 134 ha; age at the time of sampling ranged from 2 to 20 yr. The total mean percentage cover and density, alpha diversity and importance values of all the species were calculated and used to describe each site. A TWINSPAN analysis grouped sites of similar localities, mainly on the basis of their species composition. A DECORANA plot revealed that axis 1 corresponded to the position of sites along the coastline rather than other factors, such as age. The variability in species composition was related more to the types of species used for stabilization, rather than the natural distribution of the indigenous dune vegetation. The species ordination showed a similar gradient, and it was possible from this analysis to determine which species were more commonly used and better suited for dune stabilization. It is concluded that successful stabilization can be achieved using indigenous species.

Keywords: Classification; Distribution; Drift sands; Management; Ordination.

Nomenclature: Gibbs Russell et al. (1987) for vascular plants.

Introduction

The stabilization or reclamation of mobile sands using vegetation, both within the coastal zone and elsewhere, is an important management tool which has been used in South Africa (Avis 1989; Stehle 1988), the United States (Jagschitz & Bell 1966; Davis 1975), Europe (Adriani & Terwindt 1974; Ranwell & Boar 1986; Skarregaard 1989), and elsewhere (for example Dougrameji & Kaul 1972; Zollner 1986; Craig 1985; Wendelken 1974). Although the process is relatively costly, it is effective and produces a natural and aesthetically pleasing barrier to mobile sands.

In South Africa large scale stabilization programmes are undertaken by Government agencies, mainly the Directorate of Forestry of the Department of Waters Affairs and Forestry. An ecological approach towards dune stabilization is now adopted, with a management plan being drafted for areas requiring stabilization, and only indigenous species are used (Avis 1989). This is important since coastal areas are geologically sensitive and in close dynamic equilibrium with the wave and wind regime. They are therefore prone to mismanagement (Rust 1988), and any serious human interference (such as dune stabilization) will be reflected by some adjustment to the beach profile. Thus, a clear understanding of the controlling environmental factors is imperative for correct management of an area.

The historical development of the techniques used for dune stabilization in South Africa were reviewed by Avis (1989). The technique used to stabilize the study sites sampled in this survey was as follows: The area is first covered with brushwood, at a density of about 650 m^{-3} ha^{-1}. From experiments this appeared to be the correct density (Stehle 1981). For larger sites, shadecloth fences were constructed also with 1 m-wide nylon shadecloth (40% shade) attached to poles placed at 1 m-intervals. Once the area had been temporarily stabilized with brushwood, vegetation was established by seeding and/or planting young indigenous plants. Seeds were sown at a density of 150 - 200 kg / ha, and sowing was repeated every year for 3-5 yr, due to the low germination rate of certain species (Lubke & Avis 1986). This technique was successful, and this basic principle of temporarily stabilizing the sand by packing it with brushwood or some other medium before planting or seeding is also used in many other parts of the world, such as Denmark (Skarregaard 1989), the Netherlands (Adriani & Terwindt 1974), and New Zealand (Wendelken 1974). The study by Sellery et al. (1983) highlighted the importance of this stage in the stabilization process, and Stanley & Watt (1990) showed that brush matting was superior to artificial liquid sprays.

Most literature on dune stabilization either describes the techniques used (Jagschitz & Bell 1966; Ranwell & Boar 1986; Skarregaard 1989) or discusses experimental investigations to improve existing, or develop new

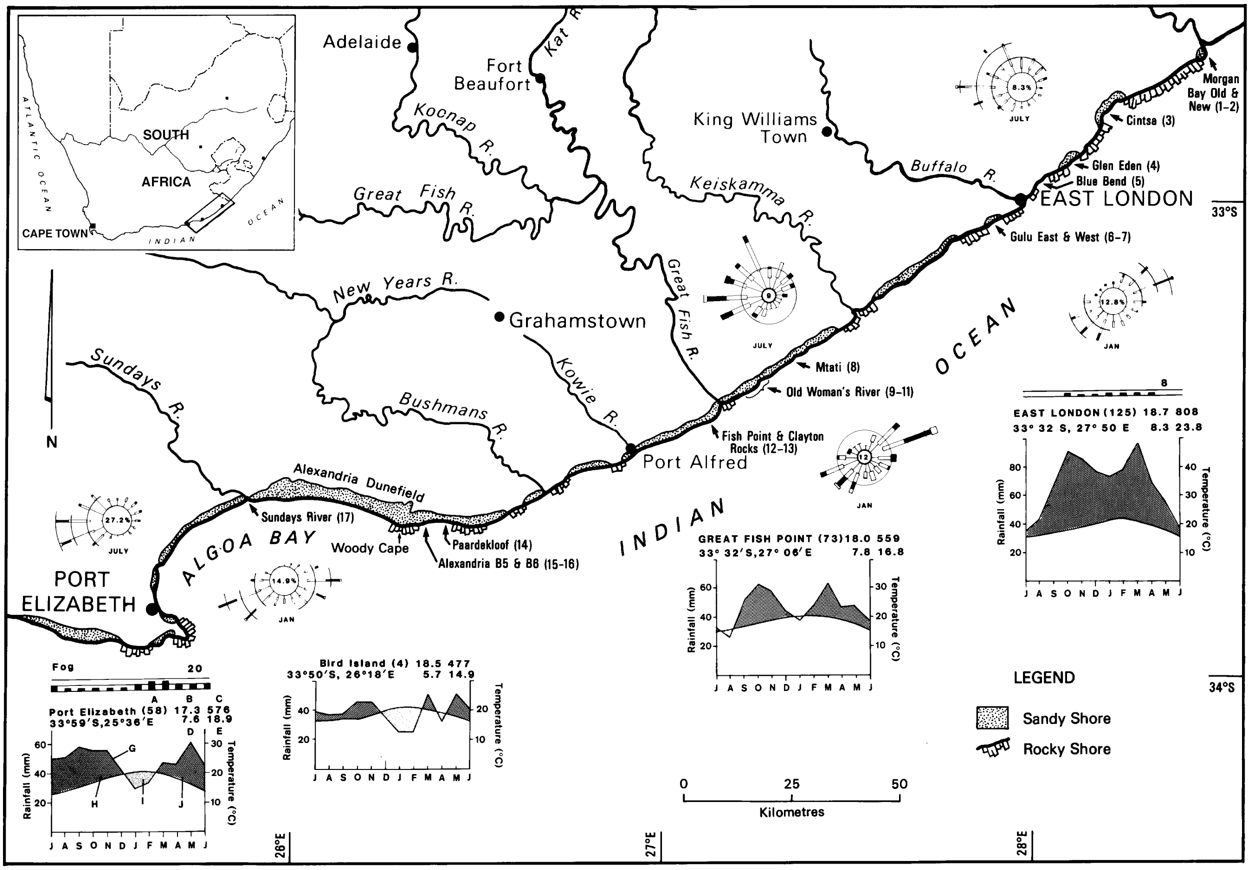

Fig. 1. Map of the coastline showing the location of the 17 stabilisation sites sampled, and climate diagrams (after Walter & Lieth 1967) for Port Elizabeth, Bird Island, Great Fish Point and East London. (A = elevation in m; B = mean annual temperature (°C); C = total annual precipitation (mm); D = mean diurnal range in temperature; E = mean annual temperature range; F = number of days with fog. Scale lines at 10 day intervals; G = rainfall curve; H = temperature curve; I = dry season; J = moist season. Wind rose for January (summer) and July are also shown for these locations.

techniques (Adriani & Terwindt 1974; Craig 1985; Stanley & Watt 1990). Few studies actually evaluate quantitatively the success of these programmes, exceptions being Hansen & Vestergaard (1984) and Zollner (1986). In South Africa no objective evaluation of dune stabilization programmes using indigenous vegetation have been undertaken; the present study presents for the first time the results of a quantitative assessment of stabilization sites in the Eastern Cape province of South Africa.

Study area

The 260 km of coastline east of the Sunday's River Mouth (33°43'S, 25°52'E) to the Kei River Mouth (32°43'S, 28°24'E) has about 200 km of sandy beaches. The coastline experiences a subtropical to temperate climate, with a bimodal rainfall and diverse flora (Fig. 1). Large sand dunes dominate from Sunday's River Mouth to the Keiskamma River Mouth (Fig. 1). Further east, the continental shelf becomes narrower and limited sand availability results in smaller dunefields. The sandy beaches are predominantly wave built and rest on low rocky platforms. Because they shelve gently, sand is usually exposed at low tide and may form dunes (Rust 1988). The variety of bare dune types formed include barchanoid, transverse, reversing, buttress barchanoid and longitudinal dunes. Vegetated dunes are mainly foredunes, retention ridges and various parabolic types (classification after Tinley 1985). The climax vegetation adjacent to the unvegetated transgressive dune fields is succulent thicket from Sundays River to Bushmans River, and from here to East London it is predominantly dune scrub or thicket with patches of forest (Table 1). North-east of East London, dune forest, best represented at Kei Mouth, becomes more common (Lubke & Avis in prep.).

Within this coastal area a total of 17 stabilization sites were sampled. Most of the stabilized dunes are

Table 1. Summary of the physiography, adjoining natural vegetation and five most dominant species (in order of decreasing importance) in each of the 17 stabilisation site samples. Life forms are given in brackets behind species names. F = forbs; C = creepers; S = shrubs; G = grasses; R = rushes and sedges; T = trees. For site locations see Fig. 1.

No.	Stabilisation site	Dune type	Aspect	Slope	Natural vegetation	Dominant species	Comments
1	Morgan Bay new area	Parabolic and buttress barchanoid	SSW	Steep	*Mimuspos*/ *Sideroxylon* Forest	*Carpobrotus edulis* (C); *Mariscus conjestus* (G); *Gazana rigens* (F); *Cynanchum natalitium* (C); *Senecio elegans* (F).	Close to river mouth
2	Morgan Bay old area	Parabolic blow-out	SW	Moderate	as above	*Ficinia aphylla* (G); *Anthospermum littoreum* (F); *Metalasia muricata* (S); *Carpobrotus edulis* (C); *Passerina rigida* (S)	Immediately behind above site
3	Cintsa	Eroded mature foredune	SE	Steep	*Mimusops caffra* forest	*Chrysanthemoides monilifera* (S); *Cynanchum natilitium* (C); *Passerina rigida* (S); *Brachylaena discolor* (C); *Ipomoeae pes-caprae* (C)	Edge of site eroded by high tide
4	Glen Eden	Edge of transverse dune	SE	Flat	Dune scrub	*Stenotaphrum secundatum* (G); *Rhoicissus digitata* (C); *Oplisminus hirtillus* (F); *Digitata eriantha* (G); *Casuarina equisitifolia* (T)	Small area close to forest
5	Blue Bend	Parabolic blow-out	E	Moderate to steep	*Brachylaena discolor*/ *Mimusops*	*Helichrysum praecinctum* (F); *Chrysanthemoides monilifera* (S); *Carpobrotus edulis* (C);*Rhus crenata* (S); *Cynanchum natilitium* (C)	Active blowout recently stabilized
6	Gulu East	Parabolic; foredune; buttress barchanoid	SW	Moderate to steep	As above	*Passerina rigida* (S); *Casuarina equisitifolia* (T); *Senecio litorosus* (F); *Ehrharta villosa* (G); *Metalasia muricata* (S)	East of Gulu River
7	Gulu West	As above	S	As above	As above	*Passerina rigida* (S); *Casuarina equisitifolia* (T); *Chrysanthemoides monilifera* (S); *Senecio litorosus* (F); *Metalasia muricata* (S)	West of Gulu River
8	Mtati	Buttress barchanoid and transverse	S, SE	Steep	*Brachylaena discolor; Mimusops caffra; Sidero-xylon inerme* dominated dune thicket	*Ehrharta villosa* (G); *Stoebe plumosa* (S); *Myrica cordifolia* (S); *Silene primulifolia* (F)	West of Mtati River
9	Old Woman's River East	Parabolic blow-out	E, SE	Moderate	As above	*Ehrharta villosa* (G); *Passerina rigida* (S); *Chrysanthemoides monilifera* (S); *Polycarena cuneifolia* (F); *Silene primulifolia* (F)	Blowout above aeolionite ridge
10	Old Woman's River Middle	Parabolic and buttress barchanoid	E, SE	Moderate to steep	As above	*Stoebe plumosa* (S); *Ehrharta plumosa* (S); *Helichrysum praecinctum* (F); *Carpobrotus edulis* (C); *Polycarena cuneifolia* (F)	Active blowout area in the forest
11	Old Woman's River West	Parabolic and buttress barchanoid	E, SE	Steep	As above	*Carpobrotus edulis* (C); *Chrysanthemoides monilifera* (S); *Passerina rigida* (S); *Heteroptilis suffruticosa* (F); *Silene primulifolia* (F)	Active erosion of stabilisation area
12	Fish Point	Transverse reversing buttress barchanoid and parabolic	SE	Flat/Steep	As above but invaded by *Acacia cyclops*	*Ehrharta villosa* (G); *Stoebe plumosa* (S); *Stipagrostis zeyheri* (G); *Myrica cordifolia* (S); *Rhus crenata* (S)	East side older than west
13	Clayton's Rocks	as above	SE	Flat/Steep	As above	*Stoebe plumosa* (S); *Myrica cordifolia* (S); *Ehrharta villosa* (G); *Metalasia muricata* (S); *Scirpus nododus* (R)	Immediately west and joined to Fish Point
14	Paardekloof B7 and B8	Transverse and barchanoid	S to SW	Moderate to steep	Sparse dune thicket with patches of dune fynbos	*Ehrharta villosa* (G); *Helichrysum praecinctum* (F); *Silene primulifolia* (F); *Chrysanthemoides monilifera* (S); *Stoebe plumosa* (S)	Large expanse of unvegetated dune field surrounds site
15	Alexandria B5 compartment	Transverse barchanoid and parabolic	S to SW	Moderate to steep	As above	*Ehrharta villosa* (G); *Senecio litorosus* (F); *Helichrysum praecinctum* (F); *Silene primulifolia* (F); *Stoebe plumosa* (S)	Edge of thicket far from high water mark
16	Alexandria B6 compartment	Transverse	S to SW	Moderate to steep	As above	*Silene primulifolia* (F); *Ehrharta villosa* (G); *Chrysanthemoides monilifera* (S); *Ammophila arenaria* (G); *Senecio litorosus* (F)	As above. Has test plot using *Myrica cordifolia*
17	Sunday's River mouth slack	Dune hollow	S	Flat	Kaffrarian thicket	*Helichrysum argenteum* (F); *Ficinia aphylla* (G); *Helichrysum praecinctum* (F); *Gazania rigens* (F); *Myrica cordifolia* (S)	Behind large artificial foredune

either parabolic blowouts or buttress barchanoids, and only in the larger sites are transverse dunes and foredunes found (Table 1). Due to the configuration of the coastline, most sites face south or south-east, but in log spiral Algoa Bay the aspect changes to south-west. (Fig. 1). Most dunes have steep (> 30 %) or moderate (15-30%) slopes, with only a few flat areas (Table 1).

Methods

A pilot survey revealed that cover and density were the best plant abundance measures to use. These two parameters were visually assessed for all species at each site in 1-m^2 sampling quadrats placed at random. The number of samples taken depended on the size of the site (Table 2). Bulk soil samples from the surface layer were taken from the centre of every fifth quadrat, and sealed in plastic packets for later laboratory analysis. Soil reaction was determined by measuring the pH of 20 grams of soil placed in 50 ml deionized water for 1 hr, using a DDS 200 Ph/Conductivity meter. For conductivity, the solution was left to stand for 24 hr, reagitated and filtered. Conductivity was measured with the same instrument using a conductivity probe. Percentage organic matter content was estimated as the loss on combustion of air-dried soil placed in a muffle furnace for 8 hr at 450 °C. The position of each quadrat was recorded on a sketch map of the area, and notes made on the aspect and slope of dunes, the latter being determined with an Abney level.

Initially, the cover values for each of the 17 sites were analysed separately using TWINSPAN and Detrended Correspondence Analysis (Hill 1979a,b), but this was found to be unreliable due to the sparse vegetation cover and low density of individuals at certain sites. The importance value for each species which was based on three measures of abundance (cover, density and frequency) was calculated for each species at each site. These data were then combined into a single data set, which was re-analysed by TWINSPAN to determine the synecological relationships between species and to see if the sites were distinct enough to be separated on the basis of their floristic composition. An ordination using DECORANA was undertaken to elucidate the major factors controlling the distribution of species along the coastline.

Data on individual sites was expressed better when the following information was calculated and compared with the observed results: total mean percentage cover; total mean density; total number of species; Simpson's diversity (*l*) and dominance (Ds); mean soil pH, conductivity and organic matter content (Table 2).

Results

Description of the stabilization sites

A review of the Forestry records provided insight into the amount of work undertaken at each stabilization site. Unfortunately, detailed records for many of the sites, particularly the smaller areas in the East London district had not been kept. However, detailed records were kept for the Gulu, Mtati, Fish River/Clayton Rocks and Old Woman's River sites. This lack of detail at

Table 2. Edaphic and floristic properties at 17 stabilisation sites sampled from the east (left of table) to the west (see Fig. 1). (Note that soil data at Paardekloof, Alexandria B5 and B6 and are lacking.)

Stabilisation site	Morgan's Bay		Cintsa	Glen	Blue	Gulu		Mtati	Old Woman's River			Fish	Clayton	Paarde-	Alexandria		Sunday's
	New	Old		Eden	Bend	East	West		East	Mid	West	Point	Rocks	kloof	B5	B6	River Mouth
Stabilisation number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Size (ha)	1.3	1.2	1.0	3	5	25	40	57	6.2	7.5	?	134	--	40	--	16.5	12
Sample size	60	45	20	17	40	154	270	404	70	191	150	400	420	245	160	150	55
Year started	1982	'70	'78	'73	'80	'65	'65	'77	'68	'68	'68	'68	'68	'77	'78	'78	'81
Age (at time of sampling)	2	15	17	12	5	20	20	8	17	17	17	17	17	8	7	7	4
Mean pH	8.99	8.88	9.05	--	9.15	7.91	7.90	7.96	7.96	7.53	7.78	7.95	7.61	--	--	--	8.04
± S.E.	± 0.064	± 0.131	± 0.003		± 0.036	± 0.091	± 0.062	± 0.055	± 0.005	± 0.085	± 0.170	± 0.085	± 0.15				± 0.108
Mean conductivity	128	136	132	--	116	85	104	83	98	133	146	103	134	--	--	--	167
µS cm^{-1} ± S.E.	± 13.5	± 6.69	± 15.38		± ± 2.27	± 5.99	± 8.42	± 4.04	± 15.4	± 31.0	± 9.1	± 8.36	± 23.9				± 39.7
% organic matter	0.58	0.97	0.93	--	0.41	0.97	1.01	0.97	0.96	0.93	0.89	0.97	1.12	--	--	--	1.1
Species richness	17	34	6	22	19	33	37	37	23	31	32	40	40	35	42	21	15
Simpson's diversity	0.871	0.912	0.696	0.925	0.843	0.902	0.915	0.814	0.628	0.872	0.910	0.822	0.889	0.831	0.810	0.622	0.846
Simpson's dominance	0.128	0.087	0.304	0.075	0.157	0.098	0.085	0.186	0.372	0.128	0.089	0.178	0.111	0.169	0.190	0.378	0.153
Mean total % cover	8.08	52.24	36.9	51.6	19.1	27.0	34.3	18.46	14.52	12.46	13.51	25.23	22.64	21.91	17.01	16.58	12.55
Mean total density	5.72	11.21	3.44	6.98	8.57	3.70	4.05	3.81	5.01	4.00	3.95	3.36	3.63	6.95	4.78	7.08	5.71

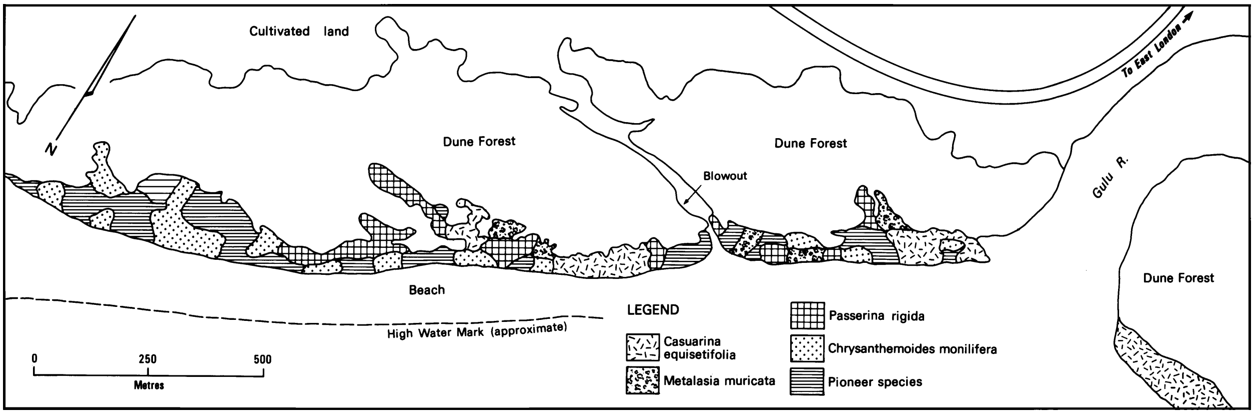

Fig. 2. Map showing the vegetation of the Gulu West stabilization sites. Note the patches of *Casuarina equisetifolia*.

certain sites made the interpretation of the floristic data, and the evaluation of the success of stabilization more difficult. From this review of the records it was found that brushwood fences were constructed before the area was packed with brushwood. This activity took place each year, until the area had been temporarily stabilized. The sowing of seeds or planting of seedlings was undertaken less regularly, being limited by the availability of seeds or a large enough area previously packed with brushwood. Older sites required maintenance in the form of brushwood repacking, but this was only undertaken at the larger sites.

Table 1 provides a summary of the physiography and natural vegetation in the vicinity of each site. The five most dominant species in each stabilization site are also listed. Dominance was based on the results of the quantitative assessment of cover and density of all species at each site. In Table 2 the edaphic and floristic properties of the sites are summarised.

The older site at Morgan Bay is situated in a hollow in the coastal forest, and due to its age, it was mostly dominated by woody species such as *Metalasia muricata.* The younger site was dominated by the succulent creeper, *Carpobrotus edulis* and by *Mariscus congestus*, a sedge common along this stretch of the coastline. At the Cintsa Bay site a steep south-east facing slope was stabilized to prevent collapse. Here, Simpson's diversity was the lowest recorded, with only six species found (Table 2). The Glen Eden site is situated immediately north-east of a car park, and was stabilized with Australian beefwood, *Casuarina equisetifolia* and the alien shrub *Acacia cyclops*. Despite the allelopathic and inhibitory effects reported in the literature for the former species (Benge 1982), the highest species diversity was recorded at this site, although species richness was not very high (Table 2). At Blue Bend, 1 km north-east of East London (Fig. 1), a parabolic dune was stabilized to prevent the blowout encroaching onto adjoining residential land. Simpson's diversity was relatively high, and woody species such as *Rhus crenata* and *Chrysanthemoides monilifera* dominated (Table 1).

The Gulu River mouth, 20 km south-west of East London (Fig. 1), has a sandy beach backed by foredunes, parabolic dunes and buttress barchanoid dunes. The mobile sands from these dunes were thought to be responsible for silting up the river, and to prevent further siltation a stabilization programme was initiated in 1965. This area was initially seeded with indigenous species and *Acacia cyclops* was planted, but later this alien species was removed. In 1975 over 6000 *Casuarina equisetifolia* trees were planted. This alien species was selected due to its non-invasive and rapid growth rate. Indigenous shrubs such as *Rhus crenata* and *Passerina rigida* were planted or seeded together with pioneer species, and at the time of sampling a number of distinct plant communities were recognised (Fig. 2). Since stabilization began closest to the river mouth the vegetation furthest west was younger and therefore colonised by pioneer species. In other areas woody species such as *P. rigida, Metalasia muricata* and *Chrysanthemoides monilifera* were planted and became dominant (Fig. 2 and Table 1). Total mean cover was high when compared to other sites, and Simpson's diversity was also high, possibly indicating that indigenous species are establishing naturally (Table 2).

The Mtati, Old Woman's River and Fish Point/ Clayton Rocks sites all experience a similar climate (Fig. 1). At the Mtati site, stabilized to prevent sand being blown on the coastal road, a total of 37 species were recorded. Simpson's diversity was slightly below average (Table 2), due to the dominance of *Ehrharta villosa* and *Stoebe plumosa* (Table 1), which were sown and planted extensively (Avis 1992). Three sites near Old Woman's River were stabilized (Fig. 1), and all had steep slopes with active blow-outs and buttress barchanoid dunes at the base. Species diversity was lower at Old Woman's River East (Table 2), due to the overall dominance by Pipegrass (*Ehrharta villosa*). Other common species are given in Table 1. The Fish Point and Clayton Rocks sites are located a few km west of the Great Fish River (Fig. 1). Species richness for the two areas is identical, but Simpson's diversity is lower at Fish Point, due to the dominance of *Ehrharta villosa* (Tables 1, 2).

No large areas stabilized with indigenous vegetation are found between the previous site and the Bushman's River (Fig. 1), but a large number of sites occur west of this area in the Alexandria dunefield. The Paardekloof site is situated east of Woody Cape (Fig. 1) and has a relatively high species richness (Table 2), despite being dominated by *Ehrharta villosa* (Table 1). However, species richness and Simpson's diversity is far greater in areas B5 and B6. Area B6 also has a lower diversity due to the significant dominance by *Silene primuliflora*. At Sunday's River the total mean cover and density was high for this young area (Table 2), which occurred in an interdune hollow (Table 1).

Classification and ordination of stabilization sites

Multivariate analysis of the importance value data for all species in the 17 sites resulted in a classification (Fig. 3) and ordination (Fig. 4) of the stabilization sites. The first division separated sites 2 and 4 (Morgan Old and Glen Eden), both with high diversity and cover values (Table 2), from the remainder. The Glen Eden site contained many ground cover species usually associated with forests, and the Morgan Bay Old site was dominated by woody shrubs and trees which were not common elsewhere. The second division separated the three sites found north east of the Buffalo River (sites 1, 3, and 5) into a distinct group (Fig. 3). These sites were stabilized within a few years of each other (Table 2), and are therefore of similar age. Although the diversity and species richness were lower, and the cover higher at Cintsa (Table 2), the species composition of these three sites was similar as they have the same climatic regime (Fig. 1).

The sites in the Alexandria area near Woody Cape (Fig. 1; sites 14-17) were separated into a distinct group at level three. Sites in this group do not have similar diversity and species richness values, despite being of comparable age and having similar cover values (Table 2). They are therefore grouped according to their species composition, which is similar, with species such as *Ehrharta villosa*, *Silene primuliflora* and *Helichrysum praecinctum* being common (Table 1).

Level 4 separated Clayton Rocks (13) and Fish Point (12) from the remaining sites. Species richness and total mean cover are high, but total mean density is relatively low (Table 2). As these two sites are close together, they share a number of species, but the abundance of species

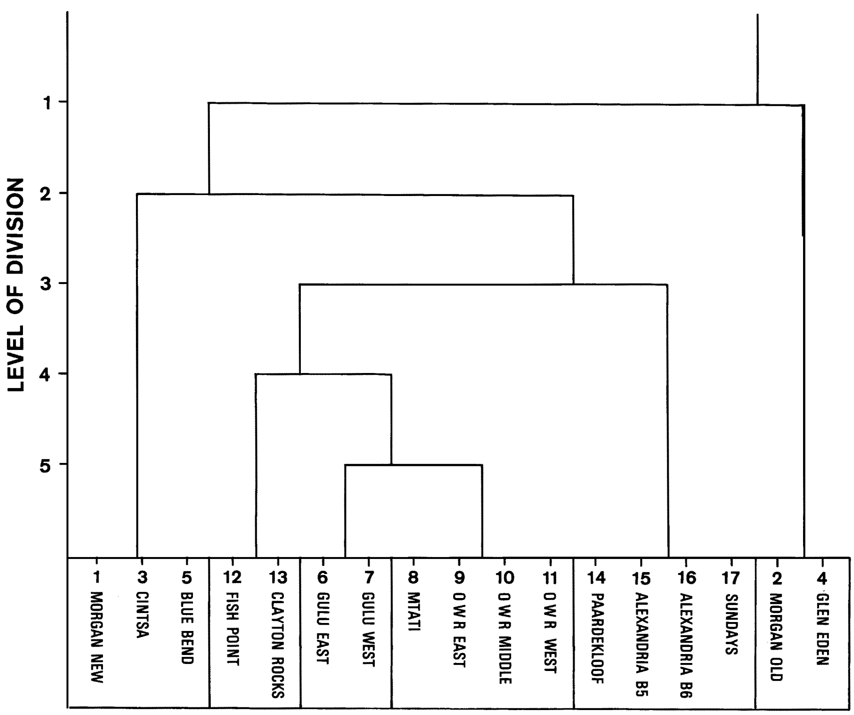

Fig. 3. Dendrogram showing the classification of the 17 stabilisation sites, based on floristic composition.

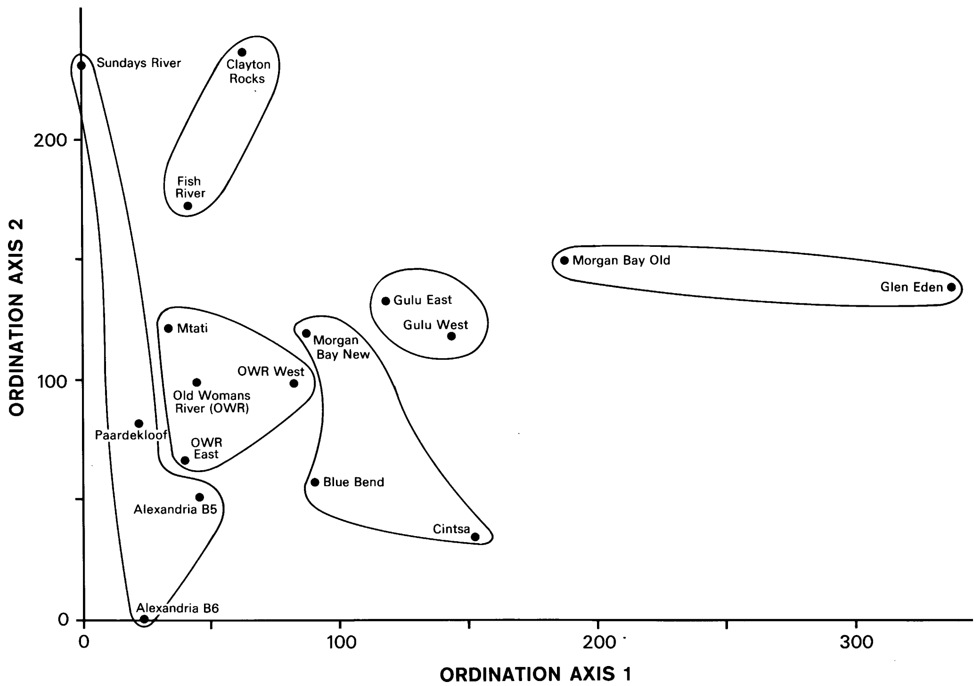

Fig. 4. Ordination of the 17 stabilisation sites using Detrended Correspondence Analysis, showing sites grouped on the basis of the TWINSPAN classification (Fig. 3).

usually common in other sites, such as *Carpobrotus edulis* and *Passerina rigida*, is low. The final two groups were separated at level five. The Gulu sites have a predominance of *Casuarina equisetifolia* and *Senecio litorosus*, both uncommon in most other areas (Table 1). Species richness, diversity and density values are similar for these groups, but the Old Woman's River and Mtati sites have a lower total mean cover and are dominated by *Ehrharta villosa*.

Most of the groups defined by TWINSPAN consist of sites found in similar regions of the coastline. This became even more clear using Detrended Correspondence Analysis (Fig. 4). It appeared that axis 1 corresponded to the position of sites along the coastline rather than other factors, such as age, percentage cover or size. Most of the sites in the East London region appear to the right of value 100 on axis 1, and are more scattered along axis 1 than those to the left of this value (Fig. 4). This may indicate a greater variability between these sites, which range from those dominated by woody species (Glen Eden and Morgan Bay Old) to those dominated by pioneer species (Blue Bend and Morgan Bay New). However, west of the Keiskamma River, roughly corresponding to value 100 on axis 1 (Fig. 4), sites are more closely grouped. This is in spite of the fact that they are spread over a greater length of coastline (Fig. 1). It therefore appears that differences in species composition account for much of the variability within the stabilization sites. These differences may not necessarily relate to the natural distribution of the indigenous dune vegetation, and appear to be more dependent on the types of species which were planted at the various sites. For example, the greater difference noted along axis 2 for sites in the Alexandria and Bathurst region is related to the species composition of these sites. The Clayton Rocks and Sunday's River sites both contain typical dune slack species, whereas Alexandria B5 and B6 and Old Woman's River East contain species more typical of the larger stabilization areas (*Ehrharta villosa* and *Silene primuliflora*), despite the fact that they are found in different regions of the coastline (Fig. 1).

The species composition at each site will depend on what was planted, and this anthropogenic effect complicates data interpretation, particularly since planting records are sometimes very brief. Other factors which may affect the position of sites in the ordination include total percentage cover and diversity, as both factors appear to increase slightly from left to right. Unfortunately, the gradients controlling axes 1 and 2 are too complex to elucidate, due to the variation in species used in the stabilization processes. This is compounded by the complexity of the natural dune vegetation in this region.

The ordination of the species groups defined by TWINSPAN is not very clear (Fig. 5). However, there appears to be a gradient along axis 1 with less common

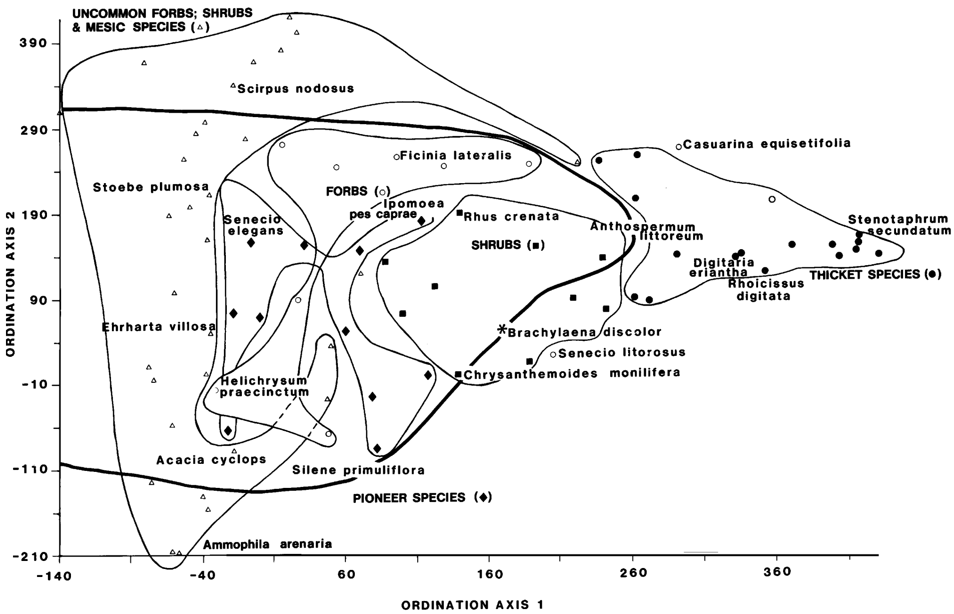

Fig. 5. Ordination of the species recorded in all stabilization sites, using Detrended Correspondence Analysis. The species groups are based on the TWINSPAN classification. Δ = uncommon forbs and shrubs; ◆ = pioneer species; ○ = forbs; ■ = shrubs; ● = thicket species.

species naturally associated with thickets on the extreme right of Fig. 5. Shrubs occur to the left of these thicket species, and groups of forbs and pioneer species are found in the middle (Fig. 5). The large group on the extreme left consists of a mixture of shrubs, less common forbs and mesic species usually found in dune slacks. Axis 1 suggests a successional gradient, with species of early succession stages on the left to those of thicket communities to the right (Lubke & Avis 1988). The variation along axes 1 and 2 may also be related to the range of habitats or, in this study, the number of stabilization sites in which particular species occurred. Species outside the bold line of Fig. 5 were restricted to a few stabilization sites, whereas species found within the bold line were widespread, more commonly used and most suitable for dune stabilization.

Discussion

The TWINSPAN analysis separated sites on the basis of their species composition, with factors such as cover and diversity being less important. These groups could be related to their position along the coastline. For example, Morgan Bay, Cintsa and Blue Bend sites were all grouped together (Fig. 3), as these three sites all occur north-east of East London (Fig 1). The ordination of the sites showed this more clearly (Fig. 4), indicating that species composition, followed by location along the coastline were the two most important variables responsible for this gradient. However, these two factors are closely related, since various sectors of the coastline are managed by different forest offices. Sites from Gulu north-east to Kei Mouth fall under East London; sites 8-13 (Mtati to Clayton Rocks) fall under Bathurst; and the rest under Alexandria (Fig. 1). Therefore, the species composition of the stabilized sites does not correspond closely to the natural distribution of species, with those species used more frequently for stabilization (e.g. *Ehrharta villosa*) falling outside their natural range. Most species in the study sites occur within their natural range.

Many of the pioneer species at the stabilization sites are not typical foredune colonisers. This is probably because the planted species, such as *Carpobrotus edulis* and *Silene primuliflora*, are easier to propagate by means of cuttings or seeding. Others, such as *Rhyncosia carribea* and *Cynanchum natalitium,* are creepers which rapidly spread over the brushwood. The latter is a fairly widespread species common along forest margins. *Zaluzianskya maritima* and *Anthospernum littoreum* probably invade the temporarily stabilized area also as seed, which could be sown in the early stages of the stabilization programme to help bind the sand further.

Of the grasses, *Ehrharta villosa* is a very suitable species for dune stabilization. *Stipagrostis zeyheri* was common in sites towards the west, and occurs naturally in bushclumps and coastal grasslands. *Pentachistis heptamera* was fairly common in sites around the Fish River (Fig. 1). Both species should therefore be used more frequently.

Widely distributed species were common in most stabilization sites. In particular the herbs *Helichrysum praecinctum* and *Senecio litorosus*, and the sedge *Ficinia lateralis* were frequently dominant, particularly towards the west. (Table 1 and Fig. 5). Most of these species were not planted or seeded and were able to invade the areas spontaneously because of the presence of an adequate seed source in the adjacent natural vegetation. Clearly, the use of these three species, as well as some other *Helichrysum* spp., will increase the initial vegetation cover and facilitate invasion by more species.

Myrica cordifolia, Rhus crenata, Stoebe plumosa, Metalasia muricata and *Chrysanthemoides monilifera* are all woody species used extensively with great success. They therefore fall within the bold line of Fig. 5. *M. cordifolia* and *S. plumosa* are naturally more common west of East London, and are well established in stabilization sites here. The other three species, together with *Brachylaena discolor* and *Eugenia capensis* are also suitable woody species. They are fairly common in stabilization sites and fall within the bold line of Fig. 5. It would therefore be wise to plant these later succesional species early in the stabilization programme, thus accelerating the natural succession towards dune thicket, which follows a similar pathway of vegetation change (Avis 1992). The planting of these woody species at an early stage is in line with suggestions that during stabilization natural succession should be stimulated (Davis 1975; Stehle 1981; Sellery et al. 1983; Avis 1986). This is feasible as the main mechanism of succession along this coastline follows the facilitation pathway (see Connell & Slatyer 1977; Avis 1992). Much of this 'facilitation' takes place when the sand is temporarily stabilized by brushwood packing and fences. The reduction in sand movement, and protection from sand abrasion and salt spray is adequate to allow secondary species [many of which are key species in succession along this coast (Avis 1992)] to survive. However, the later successional thicket and forest species, which fall outside the bold line of Fig. 5, can only survive in older sites. The exceptions are alien species which are able to colonize available niches at the expense of the indigenous flora (Avis 1985). This was the case for the alien tree, *Casuarina equisetifolia*, which together with *Senecio litorosus* was an outlier in Fig. 5. These two species are usually closely associated as the latter is one of the only indigenous plants capable of growing in the copious leaf litter of *Casuarina* trees, as noted at Gulu East and West (Fig. 2). Consequently, this close association has resulted in these species being isolated from other species groups.

The use of a variety of indigenous species for dune stabilization has resulted in the successful establishment of vegetation, which in turn has successfully limited sand movement at most of the sites sampled. This is also shown by long-term studies of a stabilization site at Kleinemonde (Lubke 1983 unpubl.). However, maintenance often remains necessary to prevent the areas being inundated with new sand. It is also important to limit pedestrian and vehicle use within stabilized areas, as the young vegetative shoots are very vulnerable to trampling (Avis 1992). Dune stabilization using indigenous species is a slow process, particularly when compared to higher rainfall areas such as Natal (Lubke et al. 1992). Erosion and accretion of sand remains a limiting factor even when a good vegetation cover has developed. Masson (1990) found a strong negative correlation between sand mobility/transport and vegetation cover ($r = 0.82$) in a stabilized foredune in South Africa. Aeolian transport of sand is therefore an important determining factor for plant communities in stabilized areas.

Although the use of indigenous species is desirable, dune stabilization is not always a necessary and suitable management tool since many problems may arise from its use (Avis 1989). Jungerius & van der Meulen (1985) propose that it is not always desirable to stabilize mobile sands. Firstly, they are part of a natural landscape, secondly the activity alters aeolian processes and thirdly it is costly. It is likely that some of the areas surveyed in this study may not have been stabilized at all if case studies, involving cost-benefit analyses, feasibility studies and risk assessments had been undertaken. A stabilization programme should only be initiated once the need therefore has been determined through careful study. The objective should then be the creation of a functional, aesthetic ecosystem This study has shown that indigenous vegetation can be used successfully in such programmes along the South African coastline, and has provided information on the most suitable indigenous species to be used.

Acknowledgements. The financial support of the Foundation for Research Development and the Department of Botany, Rhodes University are thanked for awarding me bursaries. The Flora Conservation Committee of the Botanical Society of South Africa is acknowledged for awarding me their Flora Conservation Scholarship for this study. The co-operative attitude of the Directorate of Forestry is appreciated, as is the support received from my colleague Roy Lubke.

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Received 5 December 1994;
Revision received 5 July 1995;
Accepted 27 July 1995.