An Evaluation of Habitat Rehabilitation on Coastal Dune Forests in Northern KwaZulu-Natal, South Africa

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Abstract

The rehabilitation program conducted by Richards Bay Minerals (RBM) of areas exposed to opencast surface mining of sand dunes north of Richards Bay (28°43′S, 32°12′E) on the coast of northern KwaZulu-Natal Province commenced 16 years before this study and has resulted in the development of a series of known-aged stands of vegetation. By assuming that these spatially separated stands develop along a similar pathway over time, instantaneous sampling should reveal successional or other changes usually associated with aging and should provide an opportunity to evaluate the success of rehabilitation. We compare relative densities of pioneer and secondary species, species richness, and a similarity index of the herbaceous layer, tree, beetle, millipede, bird, and small-mammal communities of rehabilitating areas of known age with those of 30-year-old unmined forests and unmined forests of unknown age adjacent to the rehabilitating area. Species richness for all but the mammalian taxa increased with increasing age of rehabilitating stands. For all taxa but the mammals and herbaceous layer, the unmined stands harbored more species than the mined rehabilitating stands. The relative densities of pioneer species of all the taxa decreased with an increase in the age of rehabilitating stands, whereas those of the secondary species increased with an increase in habitat age. Similarity between unmined stands and rehabilitating stands of different ages increased with increasing regeneration age of rehabilitating stands, suggesting that rehabilitating communities, in terms of species composition and relative densities, are developing towards the status of unmined communities. Rehabilitation based on RBM's management program of limited interference is occurring and may result in the reestablishment of a coastal dune forest ecosystem. But rehabilitation resulting from succession depends on the availability of species sources from which colonization can take place. In the Richards Bay mining operation the present mining path is laid out so that such refuges are present.

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Introduction

Large-scale, human-induced environmental disturbances are frequently followed by rehabilitation or restoration efforts aimed at inducing the transformation of the disturbed habitat in a predetermined direction (Saunders et al. 1993). Rehabilitation can be defined as a modulated change in an ecosystem after a discrete disturbance event, with the explicit aim of improving ecosystem structure and function. This implies emulating a defined undisturbed ecosystem but achieving only partial success (Bradshaw 1990). The scientific evaluation of the success of such environmental rehabilitation or restoration programs requires the development of criteria by which to assess whether their goals have been attained.

Increasing resemblance of the structure of a rehabilitating area to that of the same area prior to disturbance may indicate the success of rehabilitation efforts. But an adequate knowledge of the structure of certain areas prior to disturbance is often not available (Cairns 1988). In such cases structural variables of neighboring or matching undisturbed areas may have to serve as references to which the variables of the disturbed system can be compared. It is thus important to obtain some measure(s) and description of the extent to which rehabilitated or rehabilitating areas resemble the reference areas in terms of structure, function, and dynamics.

The development of biological communities following a discrete disturbance event—for instance, clear cutting (Kirkland 1990) or the removal of most apparent forms of life as part of surface mining (Fox 1980; van Aarde et al. 1996)—can be equated with the development of communities from the simple to the relatively complex. Such development is expected to result from local colonization and extinction. Temporal changes in species composition, densities, and richness following disturbance may thus serve as measures of the response of communities. When disturbances are followed by rehabilitation efforts, values of these variables in rehabilitating areas as well as in the predisturbed or undisturbed state may serve as indicators of the success of the rehabilitation effort. Should rehabilitation be associated with ecological succession, directional and definable trends may be expected as the rehabilitation proceeds.

The rehabilitation of areas exposed to opencast mining of sand dunes north of Richards Bay on the coast of northern KwaZulu-Natal Province, South Africa, commenced in 1978 and has resulted in a continuous series of known-aged stands. By assuming that these spatially separated stands may develop along similar pathways over time, their instantaneous sampling should begin to reveal successional or other forms of change usually associated with aging (Twigg et al. 1989) and should thus provide an opportunity to evaluate the success of this rehabilitation program.

In an effort to evaluate the rehabilitation process, we compare relative densities of pioneer and secondary species, species richness, and a similarity index of the herbaceous, tree, beetle, millipede, bird, and small-mammal communities of rehabilitating areas of known age with those of abutting unmined areas. Despite problems inherent in the use of these variables, we believe that these are easy to understand and, when measured over a broad range of taxa, give a good overview of ecosystem-wide community changes. Although we have set our own criteria, we also compare our results with criteria suggested by Ewel (1990).

The Study Area and the Rehabilitation Program

The study was conducted on unmined and rehabilitating dunes along a 40-km stretch of coast between Richards Bay (28°43′S, 32°12′E) and the Mapelane Nature Reserve (32°25′S, 28°27′E) (Fig. 1). The coastal dune forests of this area have a long history of human presence. Iron-age man has been present since at least 270 A.D. (Maggs 1976), and Bantu people practicing a slash-and-burn agriculture since the fifteenth century (Bruton et al. 1980). During the nineteenth century the area was inhabited by the Mbonambi tribe of blacksmiths who made the stabbing spears used by the Zulu king Shaka. Aerial photographs taken during 1937 show highly degraded vegetation owing to the activities of local inhabitants. But depopulation of it resulted in much of the area having recovered through natural succession by 1974 (Weisser & Marques 1982). The soils of the area are mainly sandy, and the climate is humid to hot with a high mean annual rainfall (1292 mm).

Richards Bay Minerals has been extracting heavy metals (zircon, rutile, and ilmenite) from some of the dunes northeast of Richards Bay since July 1977. Here dune mining is preceded by removal of all surface vegetation. Topsoil is collected for later use in rehabilitation. A dredger, floating on a pond maintained within the dune, sucks up the sand and separates the heavy minerals before they are pumped to a stockpile on land. The remaining sand (> 94% of the original volume) is pumped to the area behind the pond where, after "dewatering," a new dune is formed and subsequently reshaped to resemble the topography of dunes prior to mining (Camp 1990). In accordance with the policy of the landowners, the rehabilitation program at Richards Bay is directed at establishing an indigenous coastal dune forest on one-third of the area exposed to mining.

After stabilization of the dune (6–12 months after the removal of vegetation), topsoil collected prior to mining is spread in a 10–15-cm layer over the reshaped dune. A seed mixture comprising *Pennisetum americanum* (babala grass), *Sorghum* sp. (sorghum), and *Crotalaria juncea* (sun hemp), as well as seed from several indigenous species collected prior to mining, is sown on the dune

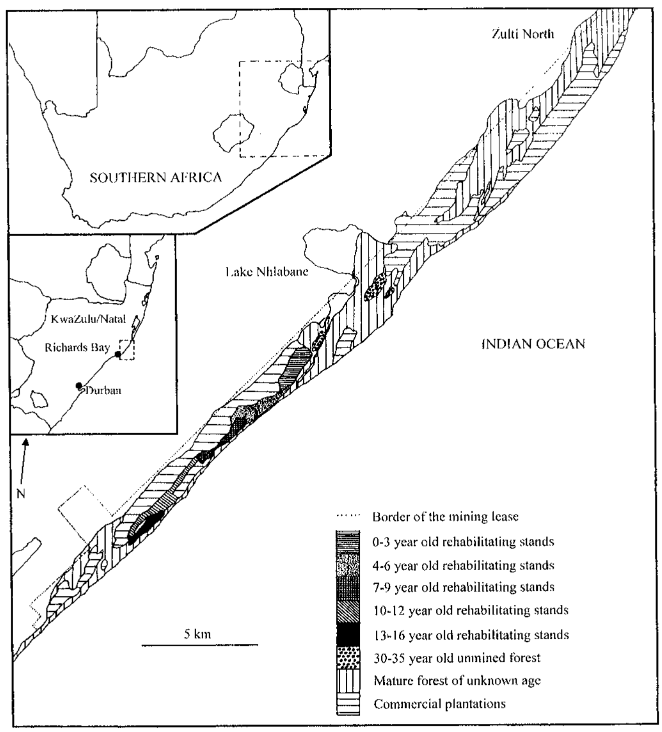
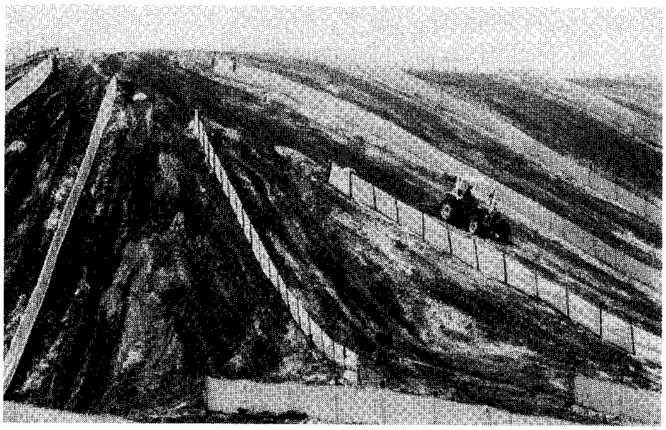


Figure 1. Map of the study area illustrating the location within southern Africa as well as the location of rehabilitating and unmined dunes. For the purpose of illustrating the distribution of known-aged rehabilitating stands, the rehabilitating areas are presented according to the distribution during December 1992. The location of unmined stands 30–35 years old and mature unmined stands of unknown age is also indicated.

(Camp 1990). Windbreaks (1.5 m high) are erected across the dune, facing the prevailing winds (Fig. 2a). These structures reduce erosion, wind-induced surface evaporation, and conceivably transpiration from newly germinated seeds. The windbreaks are usually removed after about 3 months. These actions result in the development of a dense cover crop within a month, which may ameliorate the surface microclimate for the germination and subsequent establishment of indigenous species (Lubke et al. 1992). After 6–8 months the cover crop dies off, leaving the dunes covered by dense stands of the indigenous grass *Eragrostis curvula* (weeping love grass). All vegetation establishment after the initial seeding described above is from the seedbank in the topsoil and from dispersal from surrounding rehabilitating and unmined areas.

At the time of this study, the landscape where dune mining took place included a series of regenerating areas varying in age from a few months to 16 years, a belt 100–250 m wide of unmined coastal dune forests fragmented by plantation patches, mainly *Eucalyptus saligna* (blue gum) and *Casuarina equisetifolia* (beefwood), along the coast, and a belt forested with *Casuarina equisetifolia*, which do not invade the rehabilitating areas, on the inland side of regenerating areas. These *Casuarina* belts range in age from a few months to more than 8 years. The areas inland of the mining operation are relatively densely populated and are characterized by patches of exotic and indigenous vegetation, in most cases continuously disturbed by grazing. The landscape also includes patches of sand dunes stripped of vegetation in preparation for mining, and dunes being reshaped and prepared for rehabilitation.

Most of the unmined patches of secondary coastal dune forests north of Richards Bay, some of which abut the rehabilitating areas, have a relatively short ecologi-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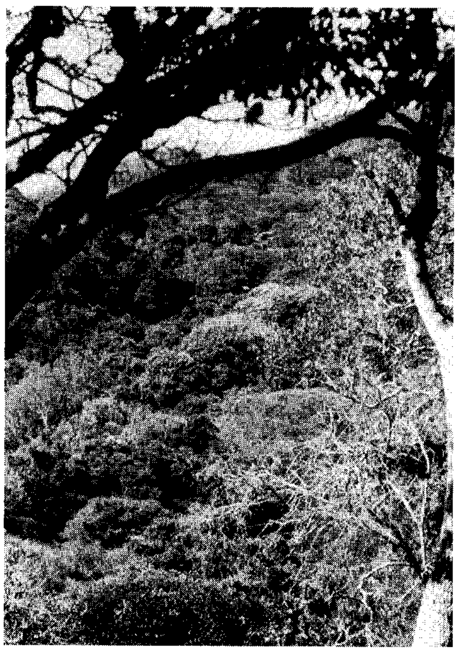
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Figure 2. The spreading of topsoil on reshaped dunes is followed by the sowing of a mixture of seeds of fast-growing annuals, indigenous grasses and selected trees (a). Note the Hessian windbreaks which are erected to limit wind erosion. A 4-year-old rehabilitating stand dominated by *Acacia karroo* (sweet thorn) and *Dodonea angustifolia* (sand olive) (b). A 14-year-old rehabilitating stand with well-developed canopy dominated by *Acacia karroo* (sweet thorn) and emerging secondary species (c). An unmined stand of coastal dune forest of unknown age on the coast of KwaZulu-Natal (d).

cal history. From aerial photographs it is known that, until 1937, many present-day areas of broad-leaved dune forests were maintained as degraded grasslands, probably through shifting cultivation, fire, and grazing by cattle. In spite of this, these patches of dune forests presently appear spatially heterogeneous, with species-rich mixed stands of trees giving the impression of relatively mature dune forests. Other unmined dune stands presently dominated by *Acacia karroo* (sweet thorn) are known from aerial photographs to have been degraded up to 30–35 years ago.

Our study concentrated on rehabilitating areas of known age, unmined areas of known age, and an area of unmined mature coastal dune forests of unknown age about 30 km north of the ecology center situated near the southern end of the rehabilitating area (Fig. 1). In the rehabilitating areas, early stages of regeneration are dominated by low-growing *Acacia karroo* shrubs (Fig. 2b), which develop into woodlands (Fig. 2c) with broad-leaved tree species characteristic of the surrounding indigenous forests establishing themselves after 12 years. In such areas *A. karroo* is starting to senesce, and species typical of surrounding unmined areas, such as *Sideroxylon inerme* (white milkwood), *Celtis africana* (white stinkwood), *Mimusops caffra* (coastal red milkwood), *Vepris lanceolata* (white ironwood), and *Trichilia emetica* (Natal mahogony) are beginning to occupy the canopy gaps and are common in the undergrowth.

Materials and Methods

The study was conducted on known-aged stands of rehabilitating areas ranging from one week to 16 years in age, as well as on surrounding unmined forests (Table 1). Surveys were also conducted on unmined stands 30–35 years old and in a mature forest of unknown age (Fig. 1). For the purpose of this paper, analyses were restricted to data collected during the austral summers from 1992 to 1994.

Species richness for various groups of plants and animals was taken as the total number of species recorded during the summer(s) when the surveys were conducted. For the purpose of this study, pioneer species were defined as those having their highest relative density in stands less than 5 years old, except for the herb layer, where stands less than 8 years were included in this category. All other species (excluding the pioneer species) recorded on the unmined stands were designated as secondary species. Relative densities for various groups of plants and animals for each of these two categories were calculated as the sum of the relative densities of all species within the group. Estimation of species-specific relative densities differed between taxa and is described below.

Similarities between the different stands and the unmined stands were calculated with the Bray-Curtis similarity coefficient (Bray & Curtis 1957), also called Steinhaus' similarity coefficient (Legendre & Legendre 1983). The index was calculated as $S = 2W/(A + B)$, where S is the similarity coefficient, W is the sum of the minimum densities of species occurring on the stands being compared, and A and B are the total densities of the relevant species on each individual stand, respectively.

Herbaceous Communities. The herbaceous layer was defined as all nonwoody vegetation less than 1 m in height. Thirty plots (1,250 m^2) were located randomly in each of three different-aged stands within the rehabilitating area. Five to six 1 m^2 quadrats were located at each plot and the cover frequency—the percentage of quadrats per plot in which a given species contributed to the cover (Barbour et al. 1987)—was recorded. Relative density for each species was calculated as the fraction of total frequencies for all species within a stand.

Tree Communities. Tree community surveys were based on point-centered quarter transects (Cottam & Curtis 1956). Four to six transects were located on each of the stands and marked at 10-m intervals. The number of intervals varied according to the length of the transect and ranged between 8 and 14 intervals. Two-thirds of the marks on the transect were randomly selected to be sampled, which ensured that the same individuals were seldom represented in more than one sample. At each mark the nearest distance to a woody canopy species (trees > 2 m), and a woody undercover species (shrubs $> 1 < 2$ m) was recorded and the species identified. Density was calculated for each canopy and each undercover species by the method of Cottam & Curtis (1956). Total stand density was calculated by summing all species-specific densities. Species-specific relative density is species-specific density presented as a fraction of total density within a stand.

Millipede Communities. The survey design and methods employed have been described by van Aarde et al. (1996). Information required to estimate stand- and species-specific relative densities was collected on fixed-width transects (35×6 m) randomly located in each of six different stands as unique sampling areas. To account for potential diurnal changes in activity, only data collected between 06:00 and 11:59 were included in our analysis. During the study period of three weeks in December 1992, $\approx$3,200 millipedes were collected and classified into morphospecies. Specimens of each morphospecies were identified from reference material kept at the Natural Science Museum in Durban, South Af-

Table 1. Characteristic of rehabilitating and unmined coastal dune areas of different ecological age in the KwaZulu-Natal province, South Africa.*

Age of the Habitats in Years	*Description*
0 to <1	Rehabilitating area comprising a pioneer community composed of covercrop. Vegetation is low (≈50 cm) and is characterized by *Sorghum* spp. (sorghum), *Pennisetum americanum* (babala grass), *Dactyloctenium geminatum* (sign grass), *Zornia capensis* (legume), and *Bulbostylis contexa* (herb).
1 to <2	Rehabilitating area comprising a simple grassland community with scattered *Acacia karroo* (sweet thorn) colonizing. Vegetation (≈70 cm) is characterized by *Dactyloctenium geminatum*, a ground creeper *Canavalia martima*, *Pennisetum americanum*, and juvenile *Acacia karroo*.
2 to <5	Rehabilitating area comprising an *Acacia karroo* shrubland with thick undergrowth dominated by grass species. The vegetation is characteristically 1–1.5 m high, with *Acacia karroo* and *Dodonea angustifolia* (sand olive) the most prominent woody species, and *Chrysanthemoides monolifera* (bush tick berry) and *Passerina rigida* (dune gonna) occurring frequently. The ground cover consists of *Dactyloctenium geminatum*, a ground creeper *Canavalia maritima*, and two herbs, *Bulbostylis contexa* and *Mariscus dubius*.
5 to <8	Rehabilitating area comprising an *Acacia karroo* scrubland 1.5–3 m high, with sparse undergrowth. *Acacia karroo* dominates the canopy, while some *Dodonea angustifolia* is still present. The middle stratum, although sparse, is characterized by *Vepris lanceolata* (white ironwood) and *Brachylaena discolor* (coast silver oak). The ground cover consists mainly of *Panicum maximum* (guinea grass), *Digitaria diversinervis* (finger grass), *Acacia karroo*, and *Dactyloctenium australe* (L. M. grass).
8 to <11	Rehabilitating area comprising an *Acacia karroo* woodland 3–8 m high, with few secondary dune forest species present. The canopy is dominated by *Acacia karroo*, while a number of other woody species, including *Brachylaena discolor* and *Rhus nebulosa* (sand currant), are also present. Ground cover consists of a number of species, with *Digitaria diversinervis* the most important.
11 to <16	Rehabilitating area comprising an *Acacia karroo* woodland 9–12 m high and characterized by secondary dune forest tree species colonizing. These include *Trichilia emetica* (Natal mahogany), *Trema orientalis* (pigeon wood), *Mimusops caffra* (coastal milk redwood), *Celtis africana* (white stinkwood), *Vepris lanceolata*, *Albizia adiantifolia* (flat-crown), *Kraussia floribunda* (rhino-coffee), and *Apodytes dimidiata* (white pear). Climbers include *Sarcostemma viminale* (caustic creeper) and *Adenia gummifera* (umPhindamshaya), with *Digitaria diversinervis* making up the most important part of the ground cover.
30 to <35	Unmined area comprising a secondary coastal dune forest, with the canopy—12–15 m or higher—dominated by *Acacia karroo*. Other important canopy trees include *Celtis africana*, *Mimusops caffra*, *Allophylus natalensis* (dune false currant), *Teclea gerrardii* (Zulu cherry-orange), and *Ochna natalitia* (Mickey Mouse bush). The middle stratum consists of species such as *Teclea gerrardii* and *Celtis africana*. The herb and shrub layer is dominated by *Isoglossa woodii* (herb), and *Dracaena aletriformis* (large-leaved dragon tree) occurs commonly.
Mature stand	Unmined area comprising a secondary coastal dune forest, with the canopy 12–15 metres or higher. A number of species are abundant, *Celtis africana*, *Mimusops caffra*, *Allophylus natalensis*, *Teclea gerrardii*, and *Ochna natalensis*. The middle stratum consists of species such as *Ochna natalensis*, *Clausena anisata* (horse wood), *Diospyros natalensis* (small-leaved jackal-berry), *Tricalysia sonderiana* (coast coffee), *Carissa bispinosa* (forest num-num), and *Maytenus undata* (koko tree). The herb and shrub layer is dominated by *Issoglossa woodii*, the fern *Microsorium scolopendrium* occurs commonly.

*All species listed for areas more than 1 year old are indigenous to the coastal dune forests of KwaZulu-Natal.

rica. Stand-specific relative densities were calculated as the percentage contribution of each species to the total number of millipedes recorded on a given stand.

Beetle Communities. Beetles (Order Coleoptera) were collected by means of pitfall, flight-intercept, and sweeping methods in stands of known age, sorted to morphospecies, and counted. Four plots were placed randomly in each stand, with three pitfall traps per plot. The traps were placed on a transect in each of the plots, ≈5 m apart. Pitfall traps were constructed from 1-L plastic buckets with a diameter of ≈15 cm. The buckets were buried flush with the soil surface and left for two days (considered as one trapping session).

Two flight-intercept traps were placed on the plots used for the pitfall sampling. The flight intercept traps were constructed from 1-m^2 sheets of clear polycarbonate, with a gutter underneath the polycarbonate sheet. The gutters were filled with a mixture of water, salt, and detergent. Specimens were collected every two days (trapping session). Pitfall and flight intercept trapping was conducted for four periods during which five trapping sessions were completed. The analysis is based on 240 pitfall trap-days and 160 flight-intercept trap-days per stand.

Beetles were also collected by sweep-net sampling along two transects in each stand; the sampling was repeated four times. Sampling comprised 200 vigorous sweeps at 2 m intervals with a 1.5 m-long sweep-net with a diameter of 80 cm. All vegetation strata between ground level and head height ($\approx$1.7 m) were covered during sweeping. The insects and leaves that accumulated in the sweep net were put into a plastic bag with 70% alcohol, sorted into morphospecies, and counted by individuals. The analysis is based on 1800 sweeps per stand.

Relative densities and species richness of all beetles were determined separately for each of the sampling methods because these methods could sample beetle communities differentially. Stand-specific relative densities were calculated as the percentage contribution of each species to the total number of beetles recorded on a given stand for each sampling technique.

Bird Communities. The survey design has been described in detail by Kritizinger (1996). The information required to estimate stand- and species-specific relative densities, community composition, and species richness was collected along three 425–500–m fixed-line transects placed on each of the stands included in the study, except the stand 1–< 2 years old, where one transect was used. The distance between all transects was at least 200 m, ensuring independence of data collected along each transect. Due to the relatively small area of each stand, the starting point of each transect could not be randomized. But transects were placed without any prior knowledge of the distribution of birds or intrastand habitat heterogeneity. To ensure unrestricted movement of the observer along the transect, all vegetation on a narrow strip (< 1 m) on the transect was cut off at ground level at the onset of the study.

Each transect was surveyed seven times per day. On days when weather conditions did not enable seven surveys, the surveys were completed on the next day. The data for each day were treated as a single replicate for that transect and were collected as described by Burnham et al. (1980). The information included species identity, group size, and perpendicular distance from the line. Stand-specific relative densities (rD) were estimated with the formula $rD = rN/rV$, where rN = relative number seen and rV = estimated relative visibility of the species. rV was estimated by using mean sighting distance, through a regression formula obtained from 68 species-stand combinations for which enough data were available to estimate density with the computer software DISTANCE (Laake et al. 1993). We present only data collected during summer (October 1993 to middle March 1994). A detailed description and evaluation of the method are provided in Kritzinger (1996).

Small-Mammal Communities. The survey design has been described by Ferreira (1993) and Ferreira and van Aarde (1996). Small mammals (rodents and shrews) were captured with Sherman livetraps set on permanent trapping grids for five consecutive days and nights (a trapping session) per stand. The traps were checked at dawn, and all individuals captured were marked by toe clipping before release. Only data collected during the summer months (December, January, and February) of 1992 to 1994 are presented.

Population estimates for each trapping session were obtained by the mark-recapture models of Otis et al. (1978) and converted to density by means of the area covered by the trapping grid. We assumed no edge effects, immigration, or emigration during the 5 days of each trapping session (Ferreira & van Aarde 1996). The species-specific estimated densities for each stand were used to calculate total stand-specific density by summing all the species-specific densities within a stand. Stand-specific relative densities for each species were then calculated as species-specific densities within a stand expressed as a fraction of stand-specific total density.

Results

The rehabilitating and unmined stands are characterized by a progressive age-related increase in heterogeneity, with the earliest stages of recovery appearing as grasslands, which are soon transformed into an almost impenetrable shrub layer dominated by *Acacia karroo* (Table 1). Stands 5–8 years old were still dominated by *A. karroo*, which had attained a height of 1.5–3 meters. Older stands (8–11 years) were still dominated by *A. karroo* up to 8 m high and a ground cover dominated by the indigenous grass *Digitaria diversinervis* (finger grass). The 11–16–year–old stands comprise a well-developed woodland canopy, and, although dominated by *A. karroo*, patches of treefalls resulting from senescence were dominated by a variety of secondary dune-forest tree species at heights up to 5 m (Table 1). The 35-year-old stands appeared as stands with a relatively

Table 2. The number of species of different biological groups on rehabilitating stands of known age and on unmined stands on the coast of northern KwaZulu-Natal.[1]

Age of Stand (years)	Herbaceous Layer	Trees > 2 m	Millipedes	Beetles: Sweeping	Beetles: Flight Intercept	Beetles: Pitfall	Birds	Rodents	Shrews
0 to <1	—	—	—	24 (2)	67 (4)	23 (4)	—	4 (4)	0 (4)
1 to <2	—	—	—	26 (2)	55 (4)	23 (4)	17 (1)	4 (4)	2 (4)
2 to <5	—	5 (129)	2 (7)	42 (2)	84 (4)	35 (4)	20 (3)	3 (9)	2 (9)
5 to <8	41 (7)	12 (104)	3 (9)	54 (2)	74 (4)	25 (4)	40 (3)	1 (1)	0 (1)
8 to <11	53 (11)	18 (122)	4 (10)	—	—	—	39 (3)	3 (7)	2 (7)
11 to <16	94 (48)	22 (108)	6 (12)	80 (2)	107 (4)	16 (4)	39 (3)	3 (11)	1 (11)
30 to <35	—	21[2] 26[3] (40)	9 (10)	—	—	—	51 (3)	—	—
Mature stand	52 (4)	—	11 (3)	116 (2)	188 (4)	40 (4)	—	4 (2)	1 (2)

[1] The values in brackets represent sample sizes (number of trapping grids, quadrats, transects or sample points).
[2] A stand 30–35 years old dominated by *Acacia karroo*.
[3] A stand 30–35 years old dominated by *Apodytes dimidiata*.

greater diversity than the oldest rehabilitating stands, with *A. karroo* less dominant in the canopy layer. The unmined forest of unknown age included in the present study was characterized by a canopy 12–15 m high comprising a variety of tree species. The canopy had several gaps resulting from tree falls.

Species Richness. In general, for all but the mammals, the number of species increased with increasing age of rehabilitating stands (Table 2). Furthermore, with the exception of the mammals and herbaceous layer, the unmined stands harbored more species per group than the mined rehabilitating stands. In the case of the trees and the millipedes, increased species richness with stand age was characterized by the addition of species. In the case of the beetles and the birds, however, the increase in species richness was characterized by both species addition and replacement.

Relative Densities. For all the groups the general trend was a decrease in the relative densities of pioneer species as stand age increased (Table 3). Relative densities for pioneer species for all the groups were also considerably lower on unmined stands than on the mined rehabilitating stands. This suggests that, although increasing age of stands is not always associated with species replacement, it is associated with a decrease in the relative densities of those species first to colonize areas disturbed by mining.

The relative densities of secondary species for all groups progressively increased with an increase in stand age (Table 4). The relative densities of species contributing to 50% of the total taxon-specific density of each stand are presented in Appendix 1.

Similarity Indices. Similarity between unmined stands and rehabilitating stands of different ages increased with increasing age of rehabilitating stands (Table 5). This suggests that all these rehabilitating communities, in terms of species composition and relative densities, are developing towards the unmined communities.

Table 3. Relative densities for pioneer species of different groups (as % of all species) recorded during the summer months in rehabilitating and unmined forests on the coast of northern KwaZulu-Natal.*

Age of Stand (years)	Relative Densities: Herbaceous Layer	Trees < 2 m	Millipedes	Beetles: Sweeping	Beetles: Flight Intercept	Beetles: Pitfall	Birds	Rodents
0 to <1	—	—	—	99 (22)	98 (58)	98 (16)	—	91 (1)
1 to <2	—	—	—	98 (23)	96 (42)	87 (16)	87 (10)	96 (1)
2 to <5	—	98 (3)	94 (1)	93 (35)	81 (60)	79 (20)	69 (7)	93 (1)
5 to <8	79 (30)	95 (3)	16 (1)	29 (8)	18 (19)	12 (45)	18 (4)	0 (0)
8 to <11	30 (17)	50 (1)	2 (1)	—	—	—	13 (4)	56 (1)
11 to <16	22 (19)	25 (2)	9 (1)	9 (8)	18 (5)	0 (0)	5 (3)	13 (1)
30 to <35	—	5 (2)	1 (1)	—	—	—	1 (2)	—
Mature stand	3 (3)	—	3 (1)	11 (18)	16 (14)	1 (5)	—	7 (1)

*Pioneer species were defined as those species with their highest relative densities recorded on the stands younger than 5 years of age, or the youngest stand for which data were available for each taxon. We excluded a 30–35-year-old stand of trees dominated by *Apodytes dimidiata*. The values in brackets represent the number of species.

Table 4. Relative densities for secondary species of different groups (as % of all species) recorded during the summer months in rehabilitating and unmined forests on the coast of northern KwaZulu-Natal.*

	Relative Densities							
				Beetles				
Age of Stand (years)	*Herbaceous Layer*	*Trees > 2 m*	*Millipedes*	*Sweeping*	*Flight Intercept*	*Pitfall*	*Birds*	*Rodents*
0 to <1	—	—	—	1 (1)	2 (7)	2 (4)	—	7 (2)
1 to <2	—	—	—	2 (1)	3 (7)	8 (3)	13 (3)	1 (2)
2 to <5	—	0 (0)	6 (1)	3 (3)	14 (16)	17 (6)	29 (9)	3 (2)
5 to <8	15 (6)	1 (4)	84 (3)	9 (6)	69 (17)	26 (5)	69 (22)	100 (1)
8 to <11	37 (15)	12 (5)	98 (3)	—	—	—	85 (19)	30 (2)
11 to <16	57 (24)	26 (7)	91 (6)	49 (18)	51 (29)	83 (8)	93 (20)	78 (2)
30 to <35	—	96 (20)	99 (8)	—	—	—	99 (45)	—
Mature stand	97 (49)	—	97 (10)	89 (90)	94 (155)	98 (32)	—	91 (2)

*Secondary species were defined as those occurring in unmined mature forests excluding pioneer species. We excluded a 30-year-old stand dominated by *Apodytes dimidiata*. The numbers in brackets represent the number of species.

Discussion

The success of this rehabilitation program may be assessed in terms of structural (e.g., species richness and species diversity) and functional (e.g., cycling and fixation of energy and minerals) similarities of rehabilitating areas with those of unmined areas. Because the rehabilitation program was initiated only 16 years ago, differences are likely to exist between the oldest rehabilitating stand and unmined areas. The evaluation of the rehabilitation program thus has to rely on (1) the trends of community development there being either similar to those recorded on disturbed but unmined areas; or (2) the temporal trends of community variables on rehabilitating stands either forming or having a high likelihood of forming a continuum with values recorded on unmined areas—increasing similarity with unmined areas.

Instantaneous sampling of community characteristics, furthermore, can depict temporal trends or patterns only when there exist spatially separated successive stages representative of temporal changes in community characteristics. The presence of a known-aged series of habitats in our study area provides an opportunity to describe such temporal trends in the development of selected community characteristics.

It is important to note that the stands sampled during this study do not represent a complete successional sere, but that the rehabilitating stands are representative of relatively early stages (0–16 years) of community development. The unmined areas 30–35 years old have

Table 5. Stand-specific Bray-Curtis similarity indices with mature unmined stands for different groups recorded during the summer months in rehabilitating and unmined 30-year-old forests on the coast of northern KwaZulu-Natal.[1]

	Bray-Curtis Similarity Indices with Mature Unmined Stands							
				Beetles				
Age of Stand (years)	*Herbaceous Layer*	*Trees[2] < 2 m*	*Millipedes*	*Sweeping*	*Flight Intercept*	*Pitfall*	*Birds*	*Rodents*
0 to <1	—	—	—	12.50	12.63	18.93	—	56.09
1 to <2	—	—	—	11.94	14.74	19.14	58.27	58.94
2 to <5	—	12.3	27.99[3] 31.03[4]	17.62	22.59	28.15	57.16	63.13
5 to <8	16.73	26.3	36.32[3] 51.87[4]	15.78	21.61	27.84	60.77	34.10
8 to <11	30.39	28.0	39.72[3] 59.69[4]	—	—	—	82.22	63.21
11 to <16	36.12	39.0	58.84[3] 75.28[4]	23.38	24.76	31.53	90.04	87.09
30 to <35	—	—	76.03[3]	—	—	—	—	—

[1]All similarities are with unmined mature stands of coastal dune forest at Zulti North except when indicated otherwise.
[2]We excluded a 30-year-old stand dominated by *Apodytes dimidata*.
[3]Denotes similarity with unmined mature forest at Zulti North.
[4]Denotes similarity with 30–35-year-old forest.

been selected to represent a later seral stage, and the other unmined area (Zulti North) a relatively older coastal dune forest to represent a mature coastal dune forest (Weisser 1987). The analyses presented here show definite increasing trends in species richness for the trees, beetles, millipedes, and birds. The lack of a similar trend for rodents and shrews may be ascribed to the low species richness of these communities, and a low sampling effort of unmined areas may account for the relatively few herbaceous species found here. Other studies, using different indices of diversity and species richness, on woody plants (Lubke et al. 1992; Mentis & Ellery 1994), millipedes (van Aarde et al. 1996), beetles (Vogt 1993), ants (Majer & de Kock 1992), birds (Kritzinger 1996), and rodents (Ferreira 1993; Ferreira & van Aarde 1996) of the area showed increasing species diversity.

Our definitions of pioneer and secondary species make it inevitable that a decrease in pioneers and an increase in secondary species will be observed with an increase in habitat regeneration age. These trends, however, serve as an illustration of unidirectional changes in species composition, as can occur during ecological succession. Species composition for the different stands differed considerably (Appendix 1) and resulted from the addition and/or replacement of species. It thus seems that ecological succession is driving the development of the communities from relatively simple (e.g., communities dominated by relatively few pioneer species) to relatively complex (e.g., communities dominated by several secondary species). A study on the vegetation of the area resulted in Mentis and Ellery (1994) also concluding that succession is taking place on the mined areas and that this succession is not different to that taking place on unmined areas.

The unmined forest 30–35 years old represents a later seral stage of coastal dune forest succession, while the unmined area at Zulti North depicts a "mature" coastal dune forest of unknown age (Weisser 1987). In terms of the present investigation, these two areas may be considered as controls to which the rehabilitating stands have been compared. The analyses of patterns of similarity for all the studied taxa indicate that an increase in rehabilitating stand age is associated with an increase in the similarity of that stand with the unmined stand (Table 5). Thus, although the characteristics of the rehabilitating communities differ from those of the unmined stands, it appears that all the communities in rehabilitating stands are in the process of developing characteristics increasingly similar to those of communities in unmined stands. The absolute values of the similarity index have no meaning for our purposes, because the expected similarity between random samples of the same community is influenced by sample size and the diversity of the community (Wolda 1981).

The differences between rehabilitating stands and unmined areas are quite apparent in terms of stand-specific species richness, relative densities of pioneer species, and relative densities of secondary species. In this regard it is also of interest that a study by Majer and de Kock (1992) showed that the ant community on 13-year-old rehabilitating stands is starting to resemble ant communities of the unmined forest. The difference in species richness of the rehabilitating stands and the unmined stands most likely results from the absence and/or rarity of some forest specialists in rehabilitating stands. With many species typical of unmined areas already present in the oldest rehabilitating stands, however, it seems as if conditions within these areas are changing to facilitate the establishment of communities with characteristics similar to those of unmined areas, with a possible subsequent colonization by forest specialists. In the case of the vegetation this probably results from changes in light intensity and soil characteristics. Colonization of older rehabilitating areas by plant species typical of adjacent unmined areas is facilitated by fruit-eating birds and vervet monkeys foraging in unmined as well as rehabilitating areas (Foord et al. 1994). Colonization of rehabilitating stands by animal taxa through species addition and replacement probably results from habitat requirements being fulfilled through structural development of the vegetation. In this regard Kritzinger (1996) illustrated that the characteristics of the bird community are best explained by two multivariable sets of highly correlated habitat parameters related to stand age (e.g., canopy gaps, dense lower and middle vegetation layer) and a decrease in the relative density of *Acacia karroo*. Furthermore, a study of the rodents revealed that species composition on rehabilitating stands can be explained by species-specific habitat preferences (Ferreira & van Aarde 1996).

The criteria described above reflect on temporal trends in structural variables from which patterns can be deduced. The evaluation of the rehabilitation program, however, also requires a consideration of functional variables. These are being investigated at present, and for the purposes of this paper we regard it appropriate to reflect on community function by using the criteria set by Ewel (1990) to evaluate the success of the rehabilitation program. These criteria include sustainability, productivity, nutrient retention, invasiability, and biotic interaction. The unaided increase in species richness in most taxa, the large number of species occurring in the oldest rehabilitating stand, together with the enrichment of soil (Lubke et al. 1992) support the notion that these criteria are met.

The structure and function of ecological systems are interdependent. Our results show that there are still differences between the oldest rehabilitating stand and the unmined coastal forest, but that the similarity between rehabilitating stands and the unmined forest increases with regeneration age of the unmined stand. Our criteria therefore lead to the conclusion that rehabilitation of community structure is initially successful but not yet completed. It is our contention that the same will apply to the function of the rehabilitating ecosystem.

Conclusion

From our analyses it follows that rehabilitation is occurring and that this may result in the reestablishment of a coastal dune forest ecosystem. But rehabilitation affected by succession depends on the availability of species sources from which colonization can take place. In the case of the Richards Bay mining operation, the layout of the mining path results in such refuges being present in the form of a relatively narrow unmined seaward strip along the mining path, as well as fragments of relatively undisturbed forests ahead of and behind the mining path. To the landward side rehabilitating areas are bordered by intensely disturbed areas of plantations and densely inhabited areas. This could still serve as a source for some species. Topsoil collected prior to mining and spread over bare reshaped dunes as part of the rehabilitation program could serve as an additional route by which some species might become established.

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Appendix 1.
Relative densities (% of all species) of species contributing to at least 50% of the total density of each group in each of the stand.*

Age of Stand (years)	*Herbaceous Layer*	*Trees (subcanopy)*	*Millipedes*	*Beetles*			*Birds*	*Rodents*
				Sweeping	*Flight Intercept*	*Pitfall*		
0 to <1	Not sampled	No subcanopy		*Mesoplatys ochroptera* (48.8) Anthicidae species 2 (8.1) *Mylabris oculata* (8.1)	*Leioclirus* spp. (65.5)	*Leioclirus* spp. (60.3)		*Mastomys natalensis* (90.0) Multi-mammate mouse
1 to <2	Not sampled	No subcanopy		*Rhamphus* spp. (1) (28.1) *Cryptocephalus sheppardi* (7.0) Malachiinae species 1 (5.3) *Lophyra intermedica* (5.3) Lagriidae species 1 (5.3) Coccinelidae species 1 (5.3)	*Leioclirus* spp. (47.4) Elateridae species 1 (19.5)	*Trochalus* species 1 (12.0) *Blosyrus tubercullipennis* (12.0) *Leioclirus* spp. (10.8) *Bradybaenus opululentus* (10.8) *Lophyra intermedica* (9.0)	*Cisticola juncidis* (59.5) Fantailed cisticola	*Mastomys natalensis* (89.0) Multi-mammate mouse
2 to <5	Not sampled	*Acacia karroo* (90)	*Spinotarsus anguliferus* (95.0)	*Ramphus* species 1 (47.5) Staphylinidae species 3 (7.0)	Elateridae species 1 (15.9) Curculionidae species 13 (13.9) Tenebrionidae species 2 (9.9) *Lophyra intermedica* (7.6) *Trochalus* species 1 (6.4)	Elateridae species 5 (24.3) *Trochalus* species 1 (17.5) Caribidae species 6 (6.1) *Lophyra intermedica* (5.9)	*Cisticola chiniana* (40.7) Rattling cisticola *Camaroptera brachyura* (22.4) Greenbacked bleating warbler	*Mastomys natalensis* (90.0) Multi-mammate mouse
5 to <8	*Panicum maximum* (12.1) *Digitaria diversinervis* (8.5) *Dactyloctenium australe* (6.6) *Aneilema aequinoctiale* (5.9) Species K12 (5.6) *Aristida* spp. (5.3)	*Brachylaena discolor* (43) *Vepris lanceolata* (19)	*Centrobolus* spp. (83.9)	*Ellimenistes leasicollis* (10.6) Bostrychidae species 2 (7.0) Elateridae species 1 (6.3) *Apion* spp. (2) (6.3) *Paraiuongius* species 1 (4.2) *Dactylispa* species 4 (4.2) *Miarus* species 1 (3.5) *Ramphus* species 1 (3.5) *Scymnus* species 2 (3.5) Elateridae species 4 (2.8) Tenebrionidae species 1 (2.8) Tenebrionidae species 2 (2.8) *Melitonoma emarginata* (2.8)	*Trochalus* species 1 (59.7)	Elateridae species 3 (43.2) *Copris melanochilus* (15.9)	*Apalis flavida* (18.9) Yellowbreasted apalis *Camaroptera brachyura* (17.5) Greenbacked bleating warbler *Prinia subflava* (12.2) Tawnyflanked prinia *Phylloscopus trochilus* (11.3) Willow warbler	*Mastomys natalensis* (57.0) Multi-mammate mouse

Appendix 1 continued

Age of Stand (years)	Herbaceous Layer	Trees (subcanopy)	Millipedes	Beetles: Sweeping	Beetles: Flight Intercept	Beetles: Pitfall	Birds	Rodents
8 to <11	*Digitaria diversinervis* (12.1) Species K12 (8.6) *Cheilanthes viridis* (6.8) *Panicum maximum* (5.5) *Aneilema aequinoctiale* (5.1) *Ipomoea* spp. (4.7) *Dactyloctenium australe* (3.8) *Coleotrype natalensis* (3.6)	*Brachylaena discolor* (46) *Rhus nebulosa* (12)	*Centrobolus* spp. (98.2)	Not sampled	Not sampled	Not sampled	*Apalis flavida* (22.1) Yellowbreasted apalis *Ploceus* sp. (18.5) Weavers *Camaroptera brachyura* (16.0) Greenbacked bleating warbler	*Saccostomus campestris* (49.0) Pouched mouse *Mastomys natalensis* (20.0) Multi-mammate mouse
11 to<16	*Digitaria diversinervis* (12.1) *Secamone* spp. (8.5) *Laportea peduncularis* (6.5) *Achyranthes aspera* (6.5) *Cynanchum ellipticum* (6.4) *Asytasia gangetica* (5.1) Species R60 (4.4)	*Brachylaena discolor* (34) *Rhus nebulosa* (16)	*Centrobolus* spp. (86.7)	*Longitarsus* species 1 (23.3) *Ramphus* species 1 (6.0) *Sciobuis spatulatus* (5.7) *Micrelus* species 1 (4.9) *Dactylispa* species 5 (4.6) Criocerinae species 1 (2.8) Chrysomelidae species 1 (2.8)	*Onthophagus* species 17 (15.4) *Copris melanochilus* (11.4) Melononthinae species 2 (7.0) Chrysomelidae species 4 (4.9) Elateridae species 6 (4.6) Bostrychidae species 1 (4.6) Melononthinae species 10 (3.5)	*Onthophagus* species 1 (38.3) *Copris melanochilus* (27.1)	*Apalis flavida* (29.9) Yellowbreasted apalis *Camaroptera brachyura* (19.2) Greenbacked bleating warbler *Pycnonotus barbatus* (7.1) Blackeyed bulbul	*Saccostomus campestris* (38.0) Pouched mouse *Aethomys chrysophilus* (38.0) Red veld rat
30 to<35		*Acacia karroo* community *Teclea gerrardii* (20) *Canthium inerme* (13) *Acacia karroo* (13) *Celtis africana* (5.0) *Apodytes dimidiata* community *Apodytes dimidiata* (29) *Tricalysia sonderiana* (11) *Strychnos* spp. (9.0) *Brachylaena discolor* (8.0)	*Centrobolus* spp. (87.5)	Not sampled	Not sampled	Not sampled	*Camaroptera brachyura* (28.0) Greenbacked bleating warbler *Apalis flavida* (9.0) Yellowbreasted apalis *Chlorocichla flaviventris* (8.7) Yellowbellied bulbul *Anthreptes collaris* (7.3) Collared sunbird	
Mature stand	*Isoglossa woodii* (12.1) *Microsorium scolopendrium* (6.9) *Draceana hookeriana* (4.4) *Laportea peduncularis* (4.4) *Asystasia gangetica* (3.8) *Psychotria capensis* (3.8) *Pupalia atropurpurea* (3.8) Species R1 (3.2) *Teclea gerrardii* (3.2) *Achyranthes aspera* (3.1) *Protosparagus* spp. (3.1)	Not sampled	*Centrobolus* spp. (36.9) *Sphaerotherium dorsale* (25.0)	*Sciobuis spatulatus* (24.8) Rutelinae species 1 (12.9) *Afidenta capicola* (7.8) *Piezotrachelus* species 1 (5.0)	*Copris melanochilus* (23.2) Curculionidae species 14 (5.7) *Onitis* species 1 (4.9) *Sisyphus* species 1 (4.7) Caraboidea species 22 (2.6) Rutelinae species 11 (2.5) Melononthinae species 6 (2.1) *Onthophagus* species 17 (2.1) *Sisyphus* species 2 (1.8) Chrysomelidae species 28 (1.6)	Carabidae species 6 (24.7) *Phanaerotomea* spp. 1 (21.4) *Phanaerotomea* spp. 2 (21.4)		*Aethomys chrysophilus* (48.0) Red veld rat *Mastomys natalensis* (36.0) Multi-mammate mouse

*The common names for birds and mammals are also presented in the table. The common names of herbs and trees are available in the text and in Table 1. Few common names exist for the other taxa.