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Factors influencing colonisation processes in two contrasting mine sites in the Namib Desert

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ABSTRACT

I investigated vegetation recovery in a uranium mine in the central Namib and a diamond mine in the southern Namib to better understand natural recovery processes in arid areas. Environmental variables influencing colonisation processes were investigated using multivariate analyses to examine the relative importance of environmental variables on vegetation recovery at the two mines. Disturbance level was the most important variable influencing colonisation processes in the central Namib whereas distance to seed source was the most important in the southern Namib. At both mines, the proximity of a species pool to the disturbed areas (reference species pool) was more important than the pool of available species in the broader ecological community in which the mines were located (ecological species pool). The study indicates that merely relying on spontaneous, natural recovery is insufficient in the Namib if (1) pre-mining conditions are the restoration goal and (2) presently undisturbed or well recovered areas in the mine cannot be preserved as a suitable seed sources in the southern Namib. Appropriate completion criteria need to be developed that consider local conditions in order to ensure that restoration of mines in arid areas is realistic.

A range of factors, such as time since disturbance, severity of alteration, distance to seed sources (Poulin et al., 1999) and species pool in the surrounding areas (Zobel, 1997), influence colonisation processes, but conflicting information is available for arid areas. Time spans of colonisation processes in arid areas are believed to be in the region of decades or longer. Some studies (Gibson et al., 2004) report recovery in arid areas of less than ten years, but others support the notion of long-term processes (Bolling and Walker, 2000; Knapp, 1991). Results are also not consistent with regard to distance to available seed sources, and while some indicate no effect of distance to seed source (Lopes et al., 2012), others show a correlation (Tischew and Kirmer, 2007). Nevertheless, climatic conditions were found to be critical factors influencing colonisation processes in most studies. These inconsistencies are due to the complexity of ecological processes and the fact that factors were often investigated in isolation. Severe disturbances such as mining create opportunities to study colonisation processes that are difficult to observe under natural conditions (Walker and del Moral, 2003). Understanding natural recovery processes in the Namib is critical as mining disturbs large parts of the Namib Desert and most mines rely on natural recovery, even if the processes and time spans are unknown (Burke, 2003).

I examined factors influencing colonisation processes at two open-cast mines in the Namib Desert in two different arid climatic regimes. The central Namib site is an uranium mine positioned 65 km from the Atlantic coast in a summer rainfall regime (mean annual rainfall about 30 mm). A large, open pit, and associated disturbed areas such as waste rock dumps, a tailings storage facility and areas disturbed by infrastructure are located in a varied landscape of gravel plains, water courses, hills, mountains and gorges. The second site is a diamond mine in the southern Namib, positioned in a wind-swept coastal area receiving winter rainfall (mean annual rainfall 54 mm). The diamond mine consists of a large strip of beach and sand plains that have been mined and re-mined during several phases, and today presents a man-made mosaic landscape of overburden and tailings dumps, mined out (bedrock) areas, accreted beaches, ponds and disturbed areas between these dumps.

Vegetation, a first step in natural recovery (Abella, 2010; Khater et al., 2003), was recorded on naturally colonised areas. The selection of the sample sites was guided by available site history, assuming that sample sites were undisturbed since the last impact and represents the types of disturbances created by the mines

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(Table 1). I used multivariate analyses to examine the effects of the most commonly cited factors influencing colonisation processes at a site level (Kirmer et al., 2008; Tischew and Kirmer, 2007) and which were unrelated to the climate of the sites. The relative importance of age (time since disturbance), disturbance level, distance to available seed sources, species pool of reference sites, and ecological species pool on plant species composition of colonised areas was tested using Canonical Correspondence Analyses (CCA) and non-metric Multi-Dimensional Scaling (nMDS) with the PAST Statistics package (Version 3.13; Hammer et al., 2001). More information on the study areas, survey methods and data analysis is provided in the online supplement.

The complete plant species pool was 189 species in the central Namib and 120 species in the southern Namib. Both colonised areas were free of invasive alien plants. Nearly half of the available species had colonised the disturbed areas in the southern Namib but only 17% in the central Namib.

Both multivariate analyses generated similar results for the most important variables influencing colonisation processes, but differed in the order of importance in the lower ranking variables (Table 2). To compare the two multivariate analyses and extract overall patterns, an index was calculated for each environmental variable using the sum of the correlation with each axis multiplied with the percent variation explained. This overall index incorporated the strength of the ordination axis with the contribution of each environmental variable, and ranks the environmental variables in order of overall contribution to the models (Table 3). However, the calculated values have no quantitative meaning. A comparison of the models using these indices indicated that the three most important variables in both analyses in the southern Namib were reference species pool, ecological species pool and distance to seed source (Table 3). In the CCA, these three variables contributed almost equally to the model, while reference species pool appeared as the third most important variable in the nMDS, and the contribution of disturbance level was negligible in the nMDS. In the central Namib, the two analyses produced similar results with regard to the two most important variables, but distance to seed source received a more important rank in the CCA than in the nMDS, where it appeared as the least important variable (Table 3).

Overall, the relative importance of environmental variables influencing colonisation processes differed between the southern and central Namib (Table 3). This supports the notion that local site conditions drive natural recovery processes in these arid areas, which is supported by studies from other deserts (Bestelmeyer et al., 2006; Coffin et al., 1996). While the ecological species pool, reference species pool and distance to seed source greatly influenced the species composition of the colonised areas in the southern Namib the species pool of the reference sites, disturbance level, age and distance to seed source made the greatest contribution in the central Namib (Tables 2 and 3). This is likely due to the different climatic regimes of the two sites and the associated vegetation. Winter rains in the southern Namib are more predictable than summer rains in the central Namib, and also fall more often as gentle, soil-infiltrating events than the more intense bursts of rainfall associated with thunderstorms in the central Namib (Eckardt et al., 2013). Succulent dwarf shrubs of the Succulent Karoo Biome dominate in the southern Namib while dwarf shrubs of the Desert Biome are dominant in the central Namib (Burke, 2006; Burke et al., 2008). This, coupled with differences in the moisture-receiving substrates, likely results in different ecological processes and responses of plants and animals (Milton et al., 1999; Bestelmeyer et al., 2006).

Runoff is one of the most important colonisation “tools” in the central Namib (Antje Burke, pers. obs.), but is only effective where colonisation sources are available upstream. Runoff is more likely where rain falls on an impermeable surface such as the central Namib's calcrete crusts. This ecosystem process does not occur in the southern Namib to the same extent, as the substrate consists largely of sand, which favours infiltration of water rather than producing runoff (Lane et al., 1998). Hard surfaces (e.g. bedrock) in the southern Namib are only exposed in low-lying areas (Fig. S4), which results in ponding rather than water flow. In arid environments, ponding increases salinity levels, while water flow helps to remove excess salts, thereby making initially saline substrates suitable for plant growth (Antje Burke, pers. obs.). Also, although the disturbance types are similar at both mines, the human constructed landforms differed, based on the nature of mining (deep pit cf. extensive open-cast surface mining) and the landscapes that are being disturbed (rocky hills and plains in the central Namib cf. coastal dunes and sand plains in the southern Namib). This creates very different open landscapes and surfaces available for colonisation and partly explains why factors influencing colonisation processes differ.

Compared with other studies of mining rehabilitation such as rehabilitated mine sites in Australia (Gould and Mackey, 2015), naturally recovered sites in the Sonora and Mojave deserts of North America (Abella, 2010) and the coastal dune systems of South Africa (Weiermans and van Aarde, 2003), where time since disturbance was an important factor in the recovery of vegetation, time since disturbance played a subordinate role in both multivariate models (Tables 2 and 3) in this study. No clear difference between the two sites were indicated, despite the fact that the oldest site in the southern Namib was 20 years older than the oldest site in the

Table 1
Characteristics of the study sites and investigated disturbance types (a range of scores for “disturbance level” indicates that different types of sites were sampled and treated separately (e.g. compacted and non-compacted areas); n: indicates no. of samples not included in analysis because of 0 values).

Mine site	Bioregion and dominant vegetation	Disturbance types	Age (years)	Disturbance level	n
Rössing Uranium	Central Namib	Pipeline	31	2	3
	Desert:	Construction camp	31	3	4
	Grassland and dwarf shrubland	Tailings Storage Facility	26–31	6	13 (−6)
		Waste rock	12	4–5	9
		Quarry	13	3–4	13
		Sand pit	21	2–4	19 (−1)
Namdeb Mining Area 1	Southern Namib	Accreted beach	12–16	1	2
	Succulent Karoo Biome:	Bedrock	10–31	4	15
	Succulent dwarf shrubland	Tailings dump	51	4	3
		Bowl-scraper overburden dump	13–34	4	33
		Bucket-wheel overburden dump	13–24	4	12
		ADT overburden dump	10–19	5	8
		Disturbed valley between dumps	31–41	2	5

Table 2
Results of Canonical Correspondence Analysis (CCA) and non-metric Multi-Dimensional Scaling (nMDS) for recovering sites in the southern Namib and central Namib (MC = Monte Carlo test).

Southern Namib				
CCA results				
Axis	Eigenvalue	Percent variation explained	MC permutation p	Environmental variables (correlation > 0.25 shown)
1	0.28	34.5	0.067	Ecological species pool (0.55) Distance seed source (0.45) Age (−0.4)
2	0.25	30.6	0.002	Distance seed source (0.37) Age (0.32)
3	0.17	20.8	0.001	Reference species pool (0.35)
nMDS results				
Axis	R2		Stress	0.13
1	0.54			Distance seed source (−0.33) Ecological species pool (−0.31)
2	0.38			Reference species pool (0.24)
Central Namib				
CCA results				
Axis	Eigenvalue	Percent variation explained	MC permutation p	Environmental variables (correlation > 0.35 shown)
1	0.73	39.1	0.002	Reference species pool (−0.71) Disturbance level (0.7)
2	0.66	35.3	0.001	Age (−0.54) Reference species pool (0.4)
3	0.34	18.1	0.001	Distance seed source (−0.36) Disturbance level (−0.34)
nMDS results				
Axis	R2		Stress	0.073
1	0.55			Reference species pool (0.55) Disturbance level (−0.39)
2	0.37			Age (−0.41)
3				Disturbance level (0.29)

Table 3
Overall index of sum of contribution of each environmental variable to the multivariate models (CCA= Canonical Correspondence Analysis, nMDS = non-metric multi-dimensional scaling).

	Environmental variable	CCA index	nMDS index
Central Namib	Reference species pool	42.60	0.33
	Disturbance level	42.04	0.21
	Distance to seed source	23.90	0.09
	Age	20.64	0.20
	Ecological species pool	19.35	0.17
Southern Namib	Reference species pool	30.27	0.16
	Ecological species pool	30.13	0.25
	Distance to seed source	30.11	0.24
	Age	29.08	0.11
	Disturbance level	17.76	0.09

central Namib (31 years).

Disturbance level had been reported to influence species composition in colonised arid areas in the Mediterranean basin (Khater et al., 2003), North American deserts (Bolling and Walker, 2000; Knapp, 1991; Prose et al., 1987) and the Succulent Karoo (van Rooyen et al., 2010), all in comparatively stable environments. This was supported by the central Namib mine, where disturbance level showed a greater influence than in the southern Namib (Table 3). At the more dynamic coastal site in the southern Namib, where natural forces (wind and sand transport) are strong and thereby result in faster recovery, level of disturbance played a less important role.

Distance to seed source emerged as an important variable at the southern Namib colonised sites, but less so in the central Namib. The southern Namib samples were within a large matrix of disturbed area, with distances to seed sources greater than in the central Namib, where most colonised sites have seed sources within 20 m. Preserving sufficient seed sources in the vicinity of the disturbed areas is therefore critical at the southern Namib mine. Vegetation recovery in a fragmented Mediterranean semi-arid landscape (Pueyo and Alados, 2007) supported the findings for the southern Namib, and natural vegetation within 30 m of abandoned basalt quarries was important in establishing target species in central Europe (Prach et al., 2007). Short distances from seed sources on linear features like roads are believed to facilitate seed dispersal in the Mojave Desert (Hunter et al., 1987), and distance from seed sources is particularly important for colonisation of large-scale disturbances (Turner et al., 1998).

1. Practical implications

This study showed that environmental factors influencing colonisation processes differed at the two sites, indicating that restoration protocols, indicators of success and completion criteria must be tailored to a particular site. The difference in importance of ecological compared with reference species pools between the two sites underscores the difficulty of defining appropriate completion criteria to assess the success of restoration interventions in highly variable environments such as arid areas. Should these benchmarks be based on the reference species pool (nearby vegetation) or the ecological species pool (a landscape-level approach)? These aspects have not been adequately addressed in arid environments and deserve more in-depth discussion and testing. Also colonisation by plants is one step in the process of natural recovery, but soil development and colonisation by animals need to be observed to assess functional ecosystems and to ensure that these systems are self sustaining (Hobbs et al., 2014; Tongway et al., 2003). Long-term recovery remains untested in this study and requires further research.

Letting spontaneous recovery take its course is acceptable in the Namib, because no alien or ruderal species dominate the sites (Burke, 2007; del Moral et al., 2007), but is this sufficient? It is evident that reliance on natural recovery processes in the Namib will not result in the reinstatement of pre-mining conditions within one human generation (±30 years, Burke, 2007; Prach et al., 2007). Either restoration interventions are therefore required, or secondary ("novel") ecosystems, as suggested by some restoration scientists (Hobbs et al., 2014; Richardson et al., 2010), have to be accepted as the final restoration goal. In this context Namibia still has a long way to go to define what is required, feasible and acceptable in terms of restoration and how to achieve this (Burke, 2003).

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jaridenv.2017.09.012.

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