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Testing a Scandinavian Biodiversity Assessment Tool in an African Desert Environment

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Abstract Life cycle assessment-based environmental product declarations (EPDs) require the inclusion of biodiversity impacts across the entire supply chain. The objective of this study is to test the applicability of a Scandinavian biodiversity assessment tool, developed specifically for use with EPD applications, in an African desert environment, linking the industry types power generation and mining. For this purpose, a GIS-based spatial analysis tool—the biotope method—was adapted to a framework approach which allowed the selection of more suitable, site-specific biodiversity indicators. The biotope method provides a step-by-step process of defining system boundaries, mapping biotopes, categorizing biotopes based on site-specific indicators, and evaluating change in biotope status "before" and "after" the impact. The development of site-specific indicators was piloted in this study and determined by the affected ecosystem and the status of knowledge on biodiversity in this geographic area. Thus plants were used as indicators for biodiversity, and red-list status and endemism constituted the prime criteria for conservation value of plants. This in turn represented the key criterion for classifying biotopes. The tested biodiversity assessment tool has potential for application in different environments and operational settings but leaves room for improvement by including secondary impacts in the assessment and using a wider range of taxa for indicators of biodiversity.

Keywords Biotope method · Endemism · Environmental management · Impact assessment · Life cycle assessment · Environmental product declarations · Mining · Namib Desert

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Introduction

In the spirit of sustainable development (SAM 2007), identifying impacts on biodiversity is a crucial element of environmental impact assessments (IAIA 2005), life cycle assessments (LCAs) (Udo de Haes et al. 2002; Milá i Canals et al. 2006a), environmental product declarations (EPDs), and environmental performance reporting (GRI 2006). Although an array of biodiversity assessment tools has been developed (e.g., Parrish 2003; Hortal and Lobo 2005), applying these across a wide range of geographic and environmental conditions proves a challenge for globally operating companies. Experts have a wide variety of positions on the usefulness and applicability of major concepts involved in biodiversity assessments (Milà i Canals et al. 2006a, b), and the use of indicators (e.g., Balmford 1998; Reid 1998; Reyers and van Jaarsveld 2000; Lunt 2003; Coles-Ritchie 2007) and indirect methods such as tracking land use changes (Brentrup et al. 2002; Milà i Canals et al. 2006b; Butler et al. 2007) are often applied. Marrying the use of indicators and tracking land use changes, the Swedish power-generation company Vattenfall developed a GIS-based method that measures changes in biotopes (mapping units defined by ecological characteristics)—in essence, an ecologically based measure of land use change (Kyläkorpi et al. 2005). While the biotope method has been successfully used on a variety of electricity-generating technologies as part of the company's EPD work in Nordic countries (www.environdec.com), rolling out the methodology to the company's suppliers (in this instance a mining company in an African country) required some adjustments.

The identification of appropriate indicators to measure biodiversity-related aspects, environmental services, and ecosystem functioning has been debated extensively among biodiversity specialists and practitioners (e.g., Noss 1990; EPBRS 2003; Lombard et al. 2003; Millennium Assessment 2004; ICMM 2005). Universally applicable, quantifiable indicators are bound to be generic, thereby providing measures too coarse at the local level (Reid 1998; Reyers 2004). Moreover, many biodiversity indicators, mirroring the complexity of biodiversity itself, are intrinsically complicated (e.g., Ekstrom 2006) and make it difficult (1) to repeat the method elsewhere and (2) to be understood by nonspecialists.

The application of a quantitative biodiversity assessment in an African country can present numerous challenges. Biodiversity baselines are often not available in the impact areas and biogeographic knowledge on taxa is frequently poor (La Ferla et al. 2002; Küper et al. 2006). Apart from ecological considerations, the selection of appropriate indicators therefore needs to take the status of knowledge on biodiversity into account. This article presents the methodology development carried out in a cooperative effort between Vattenfall and the Rio Tinto-owned Rössing Uranium in Namibia, and outlines a standard framework and transparent process that enables aggregation of environmental performance measures in life cycle assessments, which adapts the determination of appropriate biodiversity indicators to the local conditions.

Materials and Methods

The Study Area

The study area is located in west-central Namibia, near the town of Swakopmund, in the southwestern part of the African continent (Fig. 1). The climate is arid—a fog-influenced desert (Köppen 1923) climatic classification Bn, with an annual average rainfall of 30–35 mm. It is located some 60 km from the coast and fog precipitation occurs occasionally (Hachfeld and Jürgens 2000). Average temperatures range from 23.8°C in late autumn (May) to 15.4°C in spring (October). Rains fall predominantly in late summer (January–March). Net potential evaporation amounts to 2170 mm (Ashton et al. 1991).

The study area covers Rössing's mining license and parts of the accessory works areas of $\sim$140 km^2, where mining and associated activities have taken place. The main impact areas are an extensive and deep pit, waste rock dumps around the perimeter of the pit, a large tailings dam, and areas occupied by a processing plant, offices, workshops, and other accessory works. Infrastructure related to the mine include roads, water pipeline, dams and reservoirs, power lines, and telephone lines. The study area encompasses elements of a typical Namib desert landscape, including plains, drainage lines, rocky outcrops, undulating hills, mountain areas, and gorges, as well as a large ephemeral river. The underlying geology is complex, with metamorphic gneisses, schists, quartzites, marbles, and amphibolites, intruded by a suite of granites and pegmatites. Based on rock types and geomorphological processes, soils are variable in chemical composition but lack, or have a very poorly developed, vertical structure. Biologically, the study area is situated in the central Namib Desert and the semidesert and savanna transition areas (Giess 1971). Dwarf-shrubs, shrubs, and small trees are the main components of the perennial vegetation and provide a sparse cover. After good rains, grasses and herbs can cover much of the area. The study site is positioned in an area of great importance for endemism among plants (Burke 2007) and invertebrates (Holm 1986; Irish 1989), indicating that aspects of biodiversity require attention. The greatest challenge on-site was that no biodiversity baseline study had been undertaken prior to the establishment of the mine (Ashton et al. 1991).

The Biotope Method

The main purpose of the biotope method is to quantify ecological changes (biotope or habitat changes) that take place when a land area is put to a new use. This method consists of a number of steps. (1) System boundaries have to be defined and then subdivided into discrete biotopes or habitats of site-specific ecological characteristics (Fig. 1). (2) This is done for both "before"- and "after"-the change situations. (3) Based on ecological setting, indicators (e.g., red-list species) are selected to assign the relative importance of the biotopes in the local context. (4) Biotopes are grouped into four standard categories: (a) critical, (b) rare, (c) general biotopes, and (d) areas which no longer support biodiversity, termed technotopes (Kyläkorpi et al. 2005). (5) Determining losses and gains in total area per biotope category by comparing the "before" and "after" situation (in hectares or as a percentage) allows the quantification of impact using a Geographic Information System (GIS). A comparison of the "before" and "after" situation in a simple graph illustrates the approach (Fig. 2). Here 38% of the study area was classified as "critical" biotope before

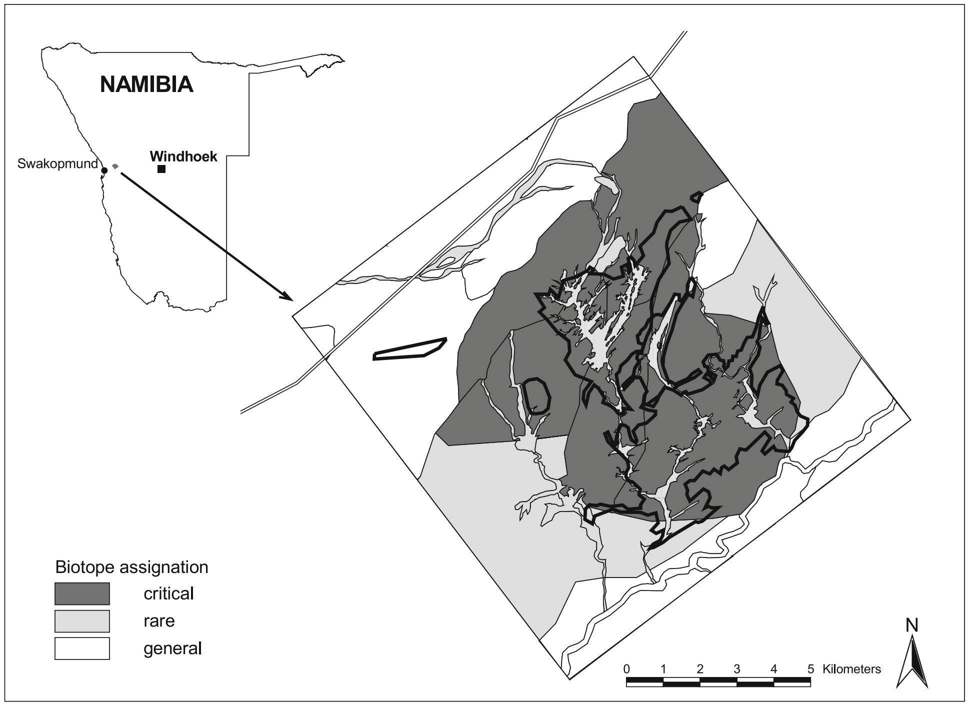

Fig. 1 Biotopes, biotope classes of the "before" situation, and impacted areas (thick, black outline) in the Rössing Uranium Mine license area in Namibia. In the "after" situation all biotope areas within the outline of impacted areas become technotopes

the mine was established. The establishment of the mine affected roughly one-third of this, leaving 25% of the entire study area as "critical" biotope.

Acknowledging that this is a simplification of reality, the biotope method is based on the assumption that the losses and gains of the various biotope categories caused by a land use change reflect the associated changes in biodiversity. An important aspect of the method is that results can be compared to units of production of some sort (e.g., tons of uranium, or kilowatt hours of generated electricity, per unit area of a certain biodiversity quality). This makes the method useful in life cycle assessments, which demand a functional unit (Udo de Haes et al. 2002). A detailed description of each step of the method, including outlining the rationale for selecting certain indicators, accompanies the assessment (for more detail see Kyläkorpi et al. 2005). In this paper we adopt the definition of biodiversity as the number of organisms in the ecological complexes in which they naturally occur (National Safety Council 2007), and for practical reasons, we use plants as indicators for biodiversity.

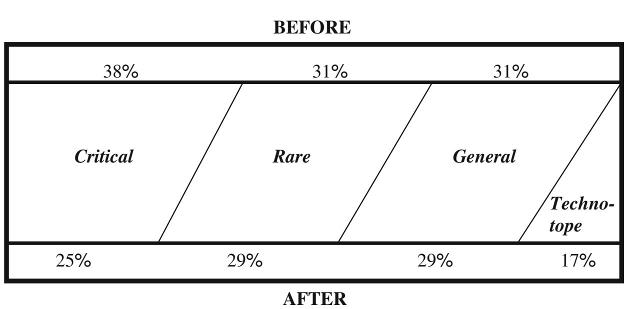

Fig. 2 Change in biotope assignation in the Rössing study area

Application of the Biotope Method at the Rössing Uranium Mine

A method for measuring the impact on biodiversity developed in a boreal forest area requires adaptation when applied in a completely different environment. One major challenge in applying the biotope method to the Namib Desert was the prescribed use of red-listed species (vulnerable and higher categories) as the main indicators for the assignation of biotope category. Given the preliminary status of the national red list for plants—most assessments are based on desktop study rather than field data in Namibia (Loots 2005), and therefore few species are listed at the required red-list level in the mining area (only one was identified in the study area)—other indicators were needed to determine the relative importance of the different biotopes.

As endemism had been identified as an important feature in the study area, the presence of endemic plants in a mapping unit was added as an indicator for species of conservation importance, which resulted in a total of 24 species used for the biotope classification. Endemics were classified according to range in three range categories (Table 1 [based on Burke 2007]). Those with the most restricted range received the highest rating on a 3-point scale (Table 1). Presence/absence of those indicator

Table 1 Rating of endemism: 3 = highest, 1 = lowest

Range	Rating
Central Namib	3
Central Namib and one more biogeographic region	2
Central Namib and several other regions in Namibia	1

Note. Adapted from Burke (2007)

Table 2 Ranges of biodiversity scores and associated biotope categories

Score	Biodiversity score	Biotope class
0	None	Technotope
1–9	Low	General
10–14	Medium	Rare
15–20	High	Critical

species was recorded and the species' scores summed up per biotope. The rating was divided into four classes, representing the biotope categories of technotope and critical, rare, and general biotope (Table 2). Technotopes were defined as areas so affected by land use change that they support no indigenous vegetation or other biodiversity, while the other classes were assigned based on the spread of calculated scores. Data quality of the field assessment was rated as poor, medium, or good for each biotope, based on sampling intensity and whether or not data from different seasons were available.

Reconstruction of Premining Biotopes

The delineation of biotopes in the "before" case was based on landform mapping derived from available aerial photographs, premining geological maps at different scales, and topographic maps with 1-m contours covering most of the premining license area. These were then used to reconstruct landforms that are now disturbed by mining, waste disposal operations, and infrastructure. As an added source of information on the premining vegetation, old photographs and anecdotal information were reviewed and analyzed. The reconstruction of premining biotopes followed a number of steps. (1) Based on field surveys plants present in currently undisturbed areas were correlated with underlying geology and topography. This way the distribution of characteristic plant species over specific landforms could be established. (2) Based on this correlation, biotopes were delineated for the reconstructed (now disturbed) landform. (3) Biotopes were then classified according to the predetermined criteria.

Assessing the Current Situation

Although biodiversity impacts often reach beyond the immediate footprint of a mine, for practical reasons, the system boundary was defined as the mining license and impacted accessory works areas. Only one extensive field survey was feasible during the study period, but this was supported by a previous survey in 2003 which covered the northeast section of the study area. Landforms and associated plants were used as the best surrogates for delineating biotopes. The field surveys took place in June 2003 and May 2005, at the end of the growing season in the central Namib Desert. Unfortunately, rains were poor during the 2005 season and the survey had to focus mainly on perennial plants. Some short-lived components of the vegetation thus may not have been recorded.

A preliminary classification based on landforms derived from a composite aerial photo (orthophoto) was used to direct the field survey. Data collection in the field focused on the main landforms: plains, ephemeral river, drainage lines, mountains, and hill areas. Data collection consisted of recording locality, habitat type/landform, and compilation of a plant species list at each sampling point. A sampling point was defined as a transect that traversed the biotope under study along a minimum of 500 m. All species within sight were recorded along this transect. Further, localities of key indicator plants such as *Aloe dichotoma, Euphorbia virosa*, and *Lithops ruschiorum* were taken throughout the study area. This resulted in a total of 125 sampling points, including those from the previous (June 2003) survey (Burke 2003a). Most plant identifications were either done by the lead author (e.g., Burke 2003c) directly in the field or subsequently verified at the National Botanical Research Institute of Namibia in Windhoek. Nevertheless, specimens of uncertain plants were collected and lodged at the Herbarium of the National Botanical Research Institute of Namibia. Mapping was carried out at a scale of 1:10,000 and delineated vegetation types, locally referred to as veld types (Acocks 1988), which could encompass several plant communities. Drainage lines, which are present throughout the study area, were only mapped where they were clear on the aerial photo. There were 24 endemic plant species recorded in the study area. Two species were restricted to the central Namib, *Lithops ruschiorum* and *Aizoanthemum galenioides*, while an additional eight species with limited distribution in Namibia (central Namib and one more region) (Table 3) were recorded. This includes the characteristic fog-zone plants, *Arthraerua leubnitziae* and *Zygophyllum stapffii*, but also two succulent *Euphorbia* shrubs, *E. damarana* and *E. giessii*, and the attractive succulent *Aloe asperifolia*.

Once the biotopes were delineated and categorized, the information was used in a GIS to overlay the outline of

Table 3 Species rating based on red-listing and level of endemism

Plant species	Endemism	Red-listing	Total rating
Aizoanthemum galenioides	3	0	3
Lithops ruschiorum	3	0	3
Adenia pechuelii	1	1	2
Aizoanthemum membrumconnectens	2	0	2
Arthraerua leubnitziae	2	0	2
Calostephane marlothiana	2	0	2
Euphorbia giessii	2	0	2
Hermbstaedtia spathulifolia	2	0	2
Sarcocaulon marlothii	2	0	2
Zygophyllum stapffii	2	0	2
Aloe asperifolia	1	0	1
Anticharis imbricata	1	0	1
Commiphora saxicola	1	0	1
Commiphora virgata	1	0	1
Euphorbia damarana	1	0	1
Monechma desertorum	1	0	1
Petalidium canescens	1	0	1
Polygala guerichiana	1	0	1
Psilocaulon salicornioides	1	0	1
Senecio alliariifolius	1	0	1
Sesbania pachycarpa subsp. *dinterana*	1	0	1
Stipagrostis damarensis	1	0	1
Stipagrostis hochstetteriana var. *hochstetteriana*	1	0	1
Zygophyllum cylindrifolium	1	0	1

mining, disturbance by mine waste, and infrastructure. This allowed measuring the areas that had been changed from critical, rare, or general biotopes to technotopes.

Results

Of the 140 plant species recorded during the field surveys, only 1, *Adenia pechuelii*, was assigned a red-list threat category ("near threatened" [Loots 2005]). However, some 24 endemic species were identified, which were used for the biotope assignation (Table 3). Based on the mapping exercise, 16 biotopes were delineated in the Rössing study area. Their delineation was based mainly on the prevailing landform and position in the study area (e.g., Gorges and Western granite hills), but also on characteristic plants (e.g., *Aloe asperifolia* plains and *Euphorbia virosa* belt).

The combined rating per biotope (excluding technotopes) ranged in score from 4 to 19. Based on the biotope assignation (Table 2), this resulted in four areas of critical biotope, five rare biotopes, and seven general biotopes (Fig. 1). The critical biotopes were located in the center of the study area and included those named central hills, *Euphorbia virosa* belt, undulating granite hills, and western granite hills. Data coverage was 'good' only in three biotopes—namely Gorges, Khan River, and undulating granite hills.

Premining, the largest portion of the Rössing study area (38% or 53 km^2), fell into the category of critical biotope; 31% (43.3 km^2) was assigned as rare, and another 31% (43.7 km^2) as general biotope (Fig. 2). In 2005, 29 years after the establishment of the mine in 1976, the impacts from the operations have resulted in net losses of approximately one-third of the critical biotopes, which now amount to 34.6 km^2, and some very small losses of rare (3 km^2) and general (2.6 km^2) biotopes. Seventeen percent of the area (24.2 km^2) in the "after" situation was classified as technotope (Fig. 2).

Discussion

There is a need to integrate measures of impacts on biodiversity in environmental performance (SAM 2007), but at the same time there is a lack of consensus on standard measures for biodiversity to be adapted by industries worldwide (Rio Tinto 2004; ICMM 2005). Making science applicable to the requirements of industry, biodiversity indicators will require geographic adaptation (Schenck 2001), which poses practical challenges that have to be overcome.

Our study showed that adapting a biodiversity assessment tool developed in Scandinavia, the biotope method, to an African country was feasible. A systematic and thereby transparent process was developed that facilitated the reconstruction of preimpact biotopes as well as the identification of biodiversity indicators suitable to the site-specific environment. Based on local knowledge, adjustments could be made in the approach to the biotope assignation, which now included the use of endemism as an indicator (Burke 2007). This thereby introduced a wider scope for the selection of indicators. The result was easily translated to the standard biotope categories. The findings and lessons from the Namibian study showed that a framework approach (Fig. 3) is more suitable to allow a wider geographic applicability. This is in line with "best practice" principles, which strive to provide standard, transparent processes, rather than prescribing detailed measures. However, any attempt at standardization has limitations which are discussed below.

The Case Study

The most important challenge in the application of the biotope method at the Rössing Mine was the lack of a premining survey. In the biotope method, lack of information is dealt with through a variety of simplifications, all of which result in reduced assessment quality and intentionally (based on a precautionary approach) higher-than-realistic resulting negative impacts. Thus backward projection of preimpact biotopes is considered an improvement of the method.

In terms of the outcome of this case study (Figs. 1 and 2), the area assigned to technotope is equivalent to the footprint of the mine, where mined-out areas, clearing, and sealing of ground for infrastructure and mine waste disposal have eliminated natural communities. However, this does not mean that there is no biodiversity in these biotopes, as regrowth can be observed in some disturbed areas. The technotopes also include the mainly exotic gardens established around office complexes. For the purpose of this study, these gardens are not considered functional ecological units, given that they harbor (mostly) nonnative species and require intervention (e.g., watering) to be maintained. Due to the nature of impacts related to open-cast mining, only complete transformations from a certain biotope category of importance to technotope were recorded in this study. In other cases land can also change from, for example, critical to general biotope due to less severe land use impacts (Kyläkorpi et al. 2005).

Seasonal effects have to be accounted for, as the poor rainfall conditions during the survey periods may have resulted in the omission of some critical indicators. For example, three central Namib endemic herbs that have been found in the broader area previously, but are known to be rare (Craven 2002), were not recorded during the field surveys. Their presence in a particular biotope could influence the biotope assignation, as could plants whose identifications are still outstanding. Although arithmetic rules were applied when defining the class ranges for the biotope assignations, the thresholds are artificial and therefore need to be considered as such.

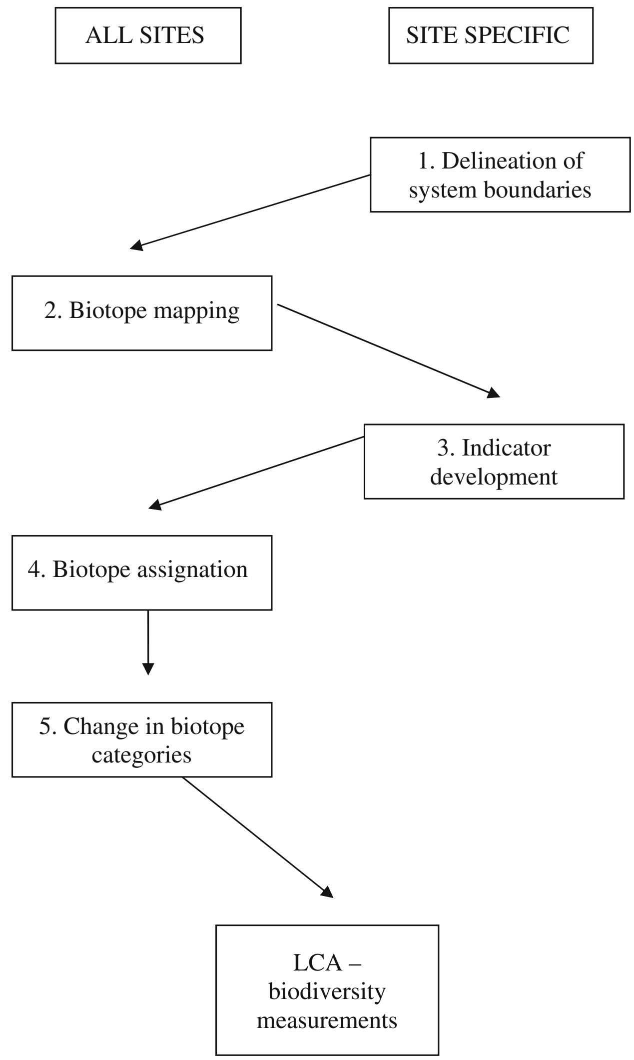

Fig. 3 The framework of the biotope method showing steps that apply to all sites (left) and steps that require site-specific input (right). In the final step the outcomes of the biotope method can then be incorporated as the biodiversity component in life cycle assessment (LCA)

Biotope Assignation

Although initially red-listed species were proposed as indicators for biotope assignations because of their internationally accepted status (IUCN 1994; Kyläkorpi et al. 2005), the case study in the central Namib describes a process that uses indicators applicable to the site-specific context to assign biotope categories. The selection of indicators and the way these are assessed in order to derive the biotope assignations are thus site-specific. Site-specific refers to the geographic and environmental setting, as well as to the availability of biodiversity information, which in this study resulted in the use of plants as biodiversity indicators. Availability of biodiversity information equally affects conservation planning (e.g., Poiani et al. 2001; Kier et al. 2005) and impact-related assessments (Thompson et al. 2007), and adjustments to local conditions are therefore necessary. For example, in a geographic context where aquatic and riparian ecosystems are affected, and indicators for ecosystem functioning of those aquatic systems are known, these would be more useful than the presence of red-list or endemic plant or animal species (Coles-Ritchie 2007). Biodiversity specialists undertaking such assessments would therefore assign biodiversity indicators adapted to each specific case. The choice of biodiversity indicators will also be affected by the diversity of the study area. The landscape-level approach taken in the central Namib provided a good reflection of the uniqueness of the area (Seely 1984), and selecting endemics as indicators was therefore appropriate. However, a study at the landscape level may not be appropriate for other types of impacts. Likewise indicators reflecting local conditions would be more useful where impacts are more localized.

Factors Influencing the Assessment

Scale has a major influence on biodiversity assessments (e.g., Holt 1993; Poaini et al. 2000; Rahbek 2005). For example, biotope assessments for wind power generation in Sweden, which used the immediate impact area as the system boundary, resulted in a nearly 100% loss of all natural biotopes (critical, rare, and general) (Kyläkorpi et al. 2005), while in this study the presence of a large number of endemic plants in the main impact area (pit and surrounding tailings) resulted in a relatively large loss of critical biotope (Fig. 1). Defining appropriate system boundaries is thus an important step in the biotope method. In an ideal world, when assessing impacts on biodiversity, the definition of impact area and resulting system boundaries should be inclusive of secondary impacts, for example, the effects on the groundwater water table and/or river systems due to water abstraction or similar impacts (International Finance Corporation 1999; IAIA 2005). Practically, lack of understanding of the extent of such impacts, as well as available time and budget, often prohibits such inclusive assessments. These shortcomings are noted and should be addressed where feasible.

This study also highlighted an interesting phenomenon possibly linked to environmental change, but likely not related to the mining operations. A large population of the charismatic, tall stem-succulent *Aloe dichotoma* appeared to have existed in this area before the mine was established. Today only remnants of this population were found in the vicinity, and these were in poor condition. Although at first glance this may be attributed to impacts caused by the mine, a recent study showed that, as a result of a general drying-up of the Namib Desert, *Aloe dichotoma* is retreating from the margins of its historical distribution along the Namib Desert (Foden 2002; Midgley et al. 2005), and the Rössing population was likely another outpost of this species at its westernmost boundary of distribution.

The relatively simple arithmetic and the use of spatial tools make the biotope method illustrative and easy to understand, compared to more sophisticated assessments (e.g., Stewart-Oaten and Bence 2001; Reyers 2004; Ekstrom 2006). On the other hand, although ecologically justifiable, using plants only as biodiversity indicators has its limitations and these need to be recognized.

Future Research

Incorporating the information on biodiversity impacts in life cycle assessments requires that the measures are expressed as functional units (e.g., area disturbed per kilowatt hour of produced energy). Hence comparisons are made with the actual measurement of the impact, and the percentages used to illustrate the before-after situation (e.g., Fig. 2) are of little relevance. Nevertheless, when comparing different operations, it must be clear whether or not secondary impacts were included.

We have not dealt with assessment of recovered/regenerated biotopes in this study. The biotope method fully incorporates such assessments, encouraging active management with mitigation programs and closure plans. The establishment of the Rössing Mine has affected about 17% of the license and accessory works areas, leaving a large portion of the area undisturbed, which could serve as a source for recruitment of plants and animals. The current mine closure plan makes no provision for active intervention to reestablish biodiversity. Thus these relatively undisturbed remaining areas are of crucial importance for rehabilitation, as these serve as seed sources to recolonize disturbed areas after mine closure (Milton 2001; Burke 2001, 2003b).

The biotope method also provides a tool to direct future research, using data quality assessment. This can assist in setting spatial priorities as well as in selecting taxa that require further study. A future development of the method is to enable predictive uses, i.e., assessments to predict post-intervention conditions, as well as management planning.

This is work in progress. Using a wider range of biodiversity indicators would result in a more representative biodiversity assessment. Integrating additional biodiversity indicators such as birds (Stacey 2005) and selected groups of invertebrates, which are of importance in this area (Holm 1986; Irish 1989), is under investigation at present.

Conclusion

The proposed framework to assess impacts on biodiversity—the biotope method—provides a practical tool for measuring biodiversity impacts in different environmental and operational environments. The step-by-step process of definition of system boundaries, mapping of biotopes, categorization of biotopes based on site-specific indicators, and evaluation of change in biotope status and extent of area per biotope provides a transparent process which is easy to follow. Even so, it leaves room for the incorporation of site-specific requirements, such as determined by the affected ecosystems and existing knowledge on biodiversity in the particular geographical setting. In this case study in the central Namib Desert the range of biotope indicators was extended from red-listed plant species to endemic plants, prompted by the importance of endemism in the study area. However, further opportunities for improvement exist in terms of dealing with secondary impacts, as well as the possibility of using other types of indicators for biodiversity such as different groups of taxa.

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