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Ensuring the future of the Namib's biodiversity: Ecological restoration as a key management response to a mining boom

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ABSTRACT

The Namib Desert is an ancient desert on the west coast of southern Africa. The Namib has unique endemic biodiversity and scenic landscapes, with a major part contained in the Namib Naukluft Park and the adjacent Dorob National Park, together forming a major tourism attraction in Namibia. There are currently large exploration and mining developments in the central Namib, fuelled by rising global demand for uranium. Mining contributes significantly to the Namibian GDP, but through destruction of habitats and ecological processes, may cause environmental degradation and loss of ecosystem services. Additionally, Namibia stands to lose a significant part of the biological diversity that makes it unique. These direct impacts are occurring in the context of regional climatic changes that are predicted to have their own severe impacts on biodiversity. A number of tools exist to counter these impacts, among which ecological restoration is an important one. Yet the extent of the damage to ecological processes and functions of the Namib, the interactions with climate change and the mechanisms through which the impacts will occur are still not well known. There is thus a crucial need for a better understanding of these arid ecosystems and their response to disturbance, to devise better restoration techniques, and to inform decision makers about management options. This paper analyses the extent of the threats to the central Namib's ecosystems and biodiversity due to mining, identifies critical knowledge gaps for restoration, defines policy needs, and proposes a broad strategy which is intended to be a framework for research, planning and management for sustainable use of this unique desert.

1. Introduction

The Namib Desert on the western coast of Namibia is among the oldest deserts in the world. Although current hyper-arid conditions date back only about 5 Ma, geological evidence suggests that the onset of aridity may have occurred around the late Cretaceous to early Tertiary (65 Ma). Fully developed arid conditions have probably been present, with minor interruptions, since the late Eocene (43 Ma) (Seely and Pallett, 2008; Ward and Corbett, 1990). Most of the ~80 900 km^2 of the Namib is hyper-arid, characterized by low humidity and high evaporation rates, high temperatures, low rainfall (15–100 mm pa) and strong winds (Jacobson et al., 1995; Lancaster et al., 1984).

Recent development of mineral resources in the Namib Desert has brought the potential use of ecological restoration as a tool to mitigate impacts on biodiversity into sharper focus (Wassenaar and Yates, 2008). However, this has to be evaluated in light of the Namib's bio-physical characteristics. Despite the extreme and unfavourable climatic conditions, and partly because it is so ancient, the Namib Desert's biotic communities are extraordinarily interesting and rich in endemics. The whole Namib, but especially the central part, is well known for its diversity of endemic invertebrates. Most of these invertebrates are substrate specific (Griffin, 1998a; Irish, 1990; Koch, 1962; Seely, 2004) with highly restricted ranges. The winter-rainfall southern Namib is part of the Succulent Karoo, one the world's 25 biodiversity hotspots (Burke, 2004; Myers et al., 2000), containing a large number of endemic plant species with a remarkably high representation of the families Mesembryanthemaceae and Liliaceae (Burke, 2003a, 2003b, 2004,

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2005; Van Wyk and Smith, 2001). The northern zone of the Namib, stretching into Angola to the Carunjamba River (Ward and Corbett, 1990), forms part of the Kaokoveld Centre of Endemism (Maggs et al., 1998), and further contains many mammal, reptile and invertebrate endemics not found elsewhere in the Namib (Griffin, 1998b; Koch, 1962; Simmons et al., 1998).

A key ecological driver, especially in the central zone, is the frequently occurring coastal fog. Fog is influenced by the movements of the south Atlantic anticyclone and the cold Benguela current and offshore upwelling, in conjunction with southwest trade winds on the coast (Jacobson et al., 1995; Kimura, 2005). Vegetation patterns and plant growth, as well as many invertebrates and specialized reptiles depend on fog for survival (Hachfeld and Jürgens, 2000; Hamilton and Seely, 1976; Henschel and Seely, 2008; Lalley and Viles, 2008; Louw, 1972; Seely and Hamilton, 1976; Seely and Pallett, 2008). Fog is also a major driver of diversity and patterns of lichen communities (Lalley and Viles, 2005), which play important roles in landscape function, soil stabilization and primary production in the Namib ecosystem (Lalley and Viles, 2008). As with most deserts, episodic and often unusually large rainfall events have long-lasting effects on landscapes and plants, driving long-term growth in perennials (Henschel and Seely, 2000; Henschel et al., 2005; Seely and Louw, 1980), and determining many aspects of the ecology of annual plants. Apart from these moisture sources, the absorption of atmospheric vapour by organisms and soil plays an extremely important role in water turnover (Kaseke, 2009).

The Namib also contains spectacular land formations. Major geomorphic features include large sand dune systems (the Kunene Sand Sea, the Skeleton Coast dune field, and the central Namib Sand Sea) and gravel plains interspersed with inselbergs and mountain outcrops (Goudie, 2002; Seely and Pallett, 2008). Apart from being scenic attractions, geomorphic features play a fundamental role in the ecology of the Namib. Inselbergs feature prominently as islands of diversity, as refuges for biota that are adapted to higher rainfall environments, and as drivers of ecological processes (Burke, 2002a,b,c; Burke et al., 1998). A number of ephemeral rivers cut across the desert as extensive linear oases, enabling the range extension of species from more mesic areas inland into the hyper-arid Namib itself (Jacobson et al., 1995; Loutit, 1991; Seely and Pallett, 2008). Dune seas, inselbergs and numerous mountain ranges create the template for metapopulation dynamics in a number of species and groups (Burke, 2002a; Endrödy-Younga, 1982; Irish, 1990; Jürgens and Burke, 2000; Marsh, 1990).

One of the remarkable properties of all these landscapes is the near absence of human-made structures (Seely and Pallett, 2008), partly because most of the Namib is contained in several different protected areas, including the recently proclaimed Sperrgebiet National Park, the Namib Naukluft Park, the newly proclaimed Dorob National Park and the Skeleton Coast Park (Fig. 1). These parks extend along the entire coast of Namibia as one continuous protected area, making it the largest park in Africa.

The Namib's protected status reflects its economic importance: the Namib Desert is the second largest tourism attraction in Namibia after Etosha National Park, enjoying world-wide recognition for its unique blend of scenic attractions, wilderness experience and comfort (Alberts and Barnes, 2008; Gimlette, 2009). Namibian tourism, and specifically Namib-based tourism, has grown rapidly over the last few decades. In 2006 the tourism sector's contribution to Namibia's GDP was 14.2%, being second after the mining sector, which contributed 15.4% (Namibian Tourism Satellite Account, 2008). In 2006 about 75 000 Namibians were employed in the tourism sector (Namibian Tourism Satellite Account, 2008), representing about 18.7% of the Namibian workforce.

The Namib's protected status has, however, not prevented extractive land-uses such as mining from becoming an integral part of its economy. Minerals such as diamonds, uranium, copper and zinc have been mined extensively for almost a century and high quality deposits of a range of minerals wait to be fully explored (Miller, 2008). Currently the central Namib is experiencing an unprecedented increase in uranium mining driven by high oil prices and a global move towards non-fossil fuels (SAIEA, 2010). The exploitation of the Namib's uranium resources is a key factor in Namibia's economic growth planning and is strongly motivated by staggering unemployment levels (formal estimates are ~50% unemployment, while some authorities estimated this at ~75% in 2010). Five uranium mining licences have been awarded in the Namib. Apart from the two established mines (Rössing Uranium and Langer Heinrich Uranium), Trekkopje and Husab mines are under construction, while the development of the Valencia mine is pending. In addition, more than 39 Exclusive Prospecting Licences (EPLs), covering an area of about 18 000 km^2, have been granted (SAIEA, 2010). Up to eight mines may be operational by 2020, depending on uranium prices, many in protected areas or conservancies (Fig. 2).

Unfortunately, mining is seldom compatible with nature-based tourism. Although the central Namib is recognized as an area of enormous tourism and environmental value, its biodiversity and landscapes are under serious threat from mining. Combined with natural forces, these activities have already resulted in extensive degradation of the ecosystem in places and may in the future threaten the resource base of economic activities such as tourism and agriculture. Clearly there is a need to manage these impacts to ensure that not only the benefits of mining continue to flow, but that the negative environmental impacts are mitigated. In response to this need, in 2009 the Ministry of Mines and Energy commissioned a strategic environmental assessment of uranium mining in the Namib (U-SEA) (SAIEA, 2010). The report is accompanied by a strategic environmental management plan (SEMP) that outlines mitigation measures to be implemented by both the uranium sector and government (SAIEA, 2010).

Mitigation of mining impacts should take place in accordance with the mitigation hierarchy – i) to avoid impacts, ii) to minimise and manage impacts, iii) to mitigate the effects (including rehabilitation and restoration), and iv) to compensate for those impacts that cannot be avoided, minimised or mitigated (ICMM, 2006). In reality however, many of these options are limited. For instance, mines are often unable to avoid impacts due to the sheer scale of mining activities (there is a need for waste rock dumps, tailings facilities and infrastructure in addition to the open pit/s) and the fact that ore bodies cannot be shifted. In addition, biodiversity offsetting is a new concept and its effectiveness over the long-term is yet to be tested (Gibbons and Lindenmayer, 2007; Norton, 2008). Especially in Namibia, the idea of locking out future access to certain areas - a key principle of offsetting – is not widely accepted, even within national parks (Anonymous, 2009). Here we focus on ecological restoration as one of the best options for mitigating mining impacts in the Namib Desert.

Restoration of arid ecosystems is challenging at the best of times, but in Namibia, two main factors constrain the successful implementation of restoration: a lack of capacity and awareness in the mining industry, among natural resource managers and in government, and a lack of knowledge on key aspects of ecosystem recovery in areas as hyper-arid as the Namib (Wassenaar and Yates, 2008). A third factor, shortcomings in the legal and policy framework, interacts with and exacerbates the first two (Burke, 2003b; Wassenaar and Yates, 2008). These are matters of great urgency, because the speed at which mining developments are taking place is threatening to swamp the good intentions and efforts of

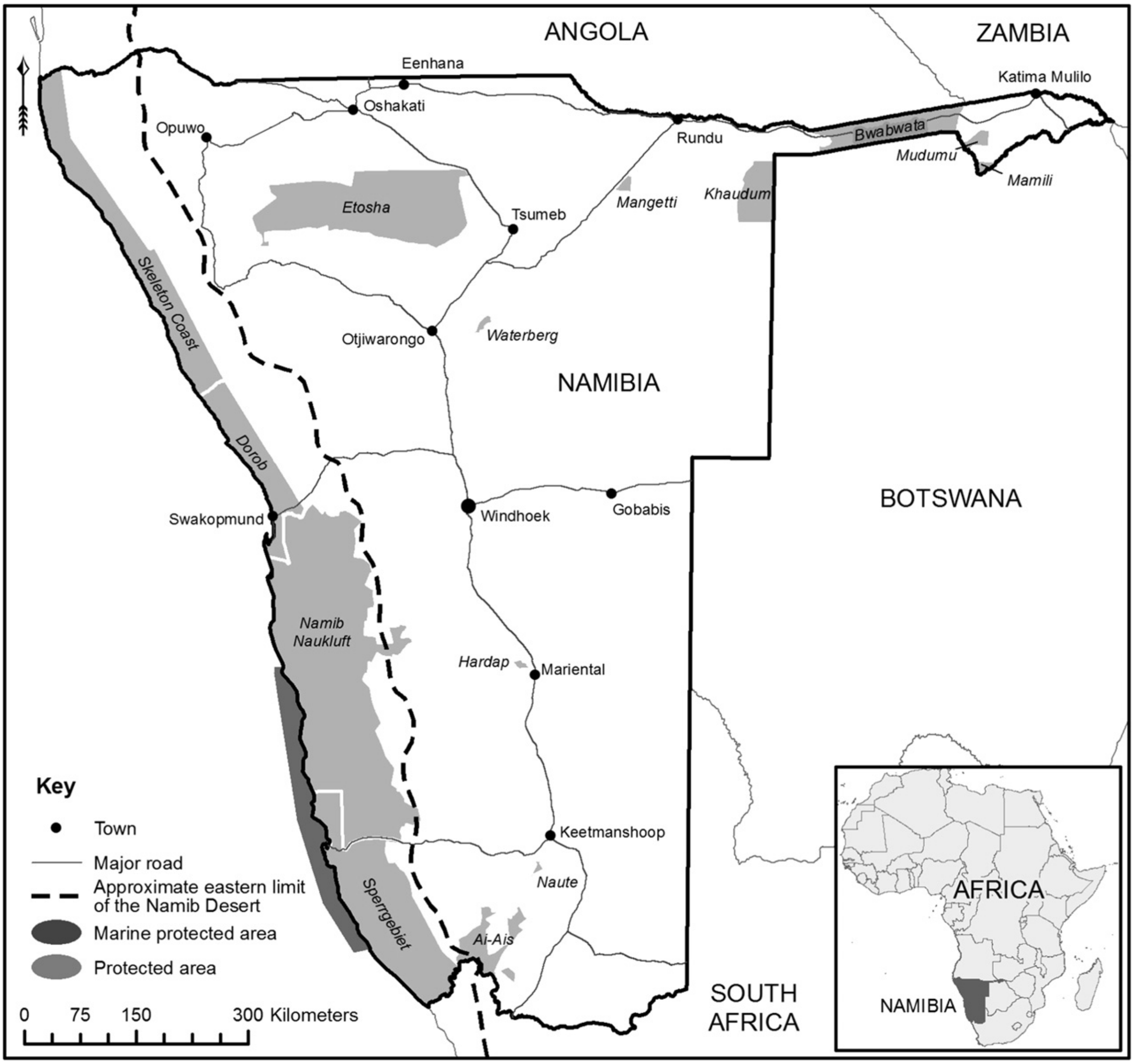

Fig. 1. Namibia's protected areas, with the approximate eastern extent of the Namib Desert shown as a dotted line.

environmental managers. In this paper, which was written in support of the U-SEA and the SEMP (SAIEA, 2010), we look at:

- The current and likely future impacts of mining in the Namib;
- Key concepts in ecological restoration;
- The requirements and shortcomings of restoration in the Namib;
- A framework for the development of a restoration research, training and policy development initiative.

2. Some current and likely future impacts of mining in the central Namib

The mining sector is the largest contributor to export earnings (at 11.7% in 2006 (CoM, 2008)) and is the largest contributor to the Namibian Gross Domestic Product after government services. Mining is consequently also one of the major employers in the country. For instance, in 2008 Rössing Uranium Mine employed a total of 1307 permanent employees of which 97.6% were Namibians (Rössing Uranium Mine, 2008). Namdeb Mine employed a total of 2940 in 2007 and 2520 in 2008. Recent contraction of the diamond industry as a result of the global recession notwithstanding, these figures illustrate Namibia's profound dependence on mining, and explain the continuous pressure to develop the industry even further. Environmental baseline studies related to mining have substantially contributed to increasing the biodiversity knowledge base in areas where mines are planned (SAIEA, 2010). There can be no doubt about the sector's importance and its benefits for the country, but its negative impacts are likely to be many, diverse and long-lasting. Amongst other impacts, mining results in clearing of large areas for roads, water pipelines and buildings during both the prospecting and mining stages (Dean and Milton, 2010). The visual impacts of these activities and infrastructure may significantly detract from the scenic value of a place (Henrik et al., 2007; SAIEA, 2010), and thus decrease its value as a tourism resource. More germane from our perspective however, without mitigation the physical perturbation caused by mining may also negatively affect the integrity of the arid ecosystem including environmental goods and services.

An important way in which this impact may occur is through disruption of ecological processes such as the flow of nutrients

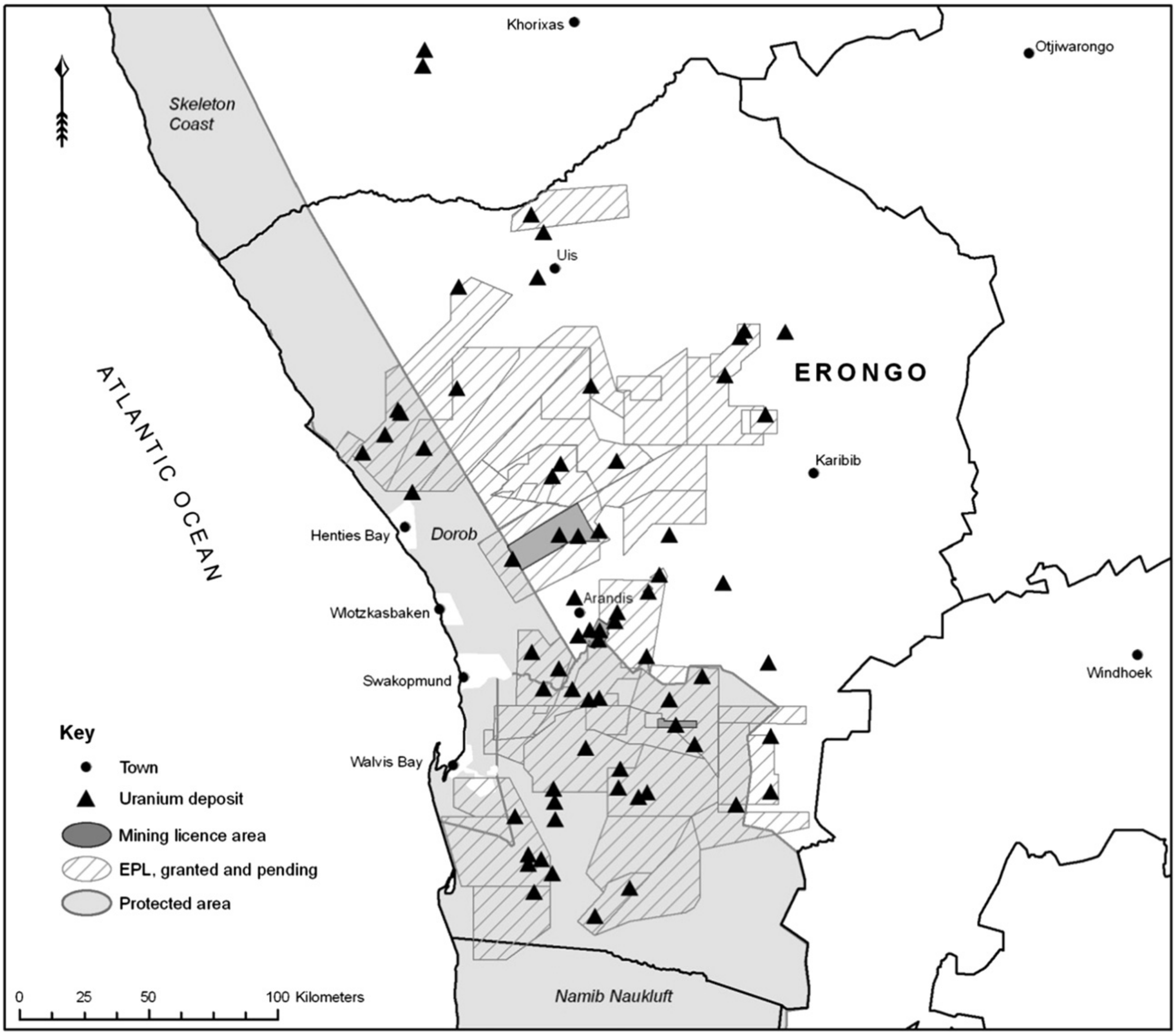

Fig. 2. Mining in the central Namib. Current Exclusive Prospecting Licences (EPLs), mining licences and known uranium deposits in relation to the main protected areas (Skeleton Coast, Dorob, and Namib Naukluft National Parks) are shown.

among different compartments of an ecosystem (Polis et al., 2004), or the movement of animals to and from water sources. These disruptions may occur on many temporal and spatial scales, especially in deserts where resources such as surface water, food and shelter tend to be sparsely and patchily distributed (Bainbridge, 2007; Whitford, 2002; Wilcox et al., 2003). Impacts also occur well beyond the mine's physical footprint. For instance, drainage by large mining pits and groundwater extraction may impact survival of adult plants and water availability for people and other animals downstream in ephemeral river beds. Many of these species survive only because they have a reliable source of underground water (Seyfried et al., 2005).

The impacts of mines on biological and ecological integrity are therefore likely to be many and varied. To what extent will ecological restoration be able to compensate for these, and how?

3. A brief introduction to ecological restoration

The restoration of mined land is a field where widely different disciplines meet: natural resource management, engineering and geology. Opportunity for confusion is large, and it is valuable to examine the meanings behind restoration and the related terms rehabilitation, reclamation and remediation (all commonly used in the mining industry to refer to broadly similar pursuits).

Restoration *sensu stricto* means to bring something back to a former condition, or to an unimpaired or perfect condition, or to a healthy or vigorous state (implying a very specific endpoint) (Allen, 1990). In its ecological sense it refers to the return of an ecosystem to a close approximation of its condition prior to disturbance (Bradshaw, 2002), and was defined by the Society for Ecological Restoration as “the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed” (SER, 2004). It is most commonly used in a broader, ecosystem perspective to indicate the recovery of structure, composition and function (processes involved in the flow of resources and energy among ecosystem compartments) of a degraded ecosystem (SER, 2004). It is an intentional activity that initiates ecological processes and places the degraded ecosystem on a pathway towards a specified target, which may be an undisturbed state (SER, 2004; SER and IUCN, 2004) or any other acceptable ecological state (Hobbs, 2007; Hobbs and Norton, 1996; Hobbs et al., 2006; Seastedt et al., 2008; Whisenant, 1999).

In contrast, the meaning of rehabilitation is less specific, which is perhaps why the mining industry sometimes struggles to deal with it (Wassenaar and Yates, 2008). Its interpretation according to the Oxford English Dictionary is close to that of restoration: "the action of restoring a thing to a previous condition or status" (Allen, 1990), but in common usage a rehabilitated thing is not expected to be in as healthy a state as if it has been restored (Bradshaw, 2002). It highlights the repair of ecosystem function – with less emphasis on recovery of structure and composition – with an aim of raising productivity for the benefit of people (Aronson et al., 1993). Ecologically, rehabilitation implies that an ecosystem is not yet fully restored, but may become so.

In the mining context however, rehabilitation is mostly used interchangeably with the terms reclamation and remediation in the sense of removing human-made structures and making an area safe for human occupation or other land uses. Here there is little or no reference to natural properties like resilience, resistance or biological diversity. In the current paper we use the term rehabilitation more in its mining sense, and, following the interpretation of Aronson et al. (1993) and Tongway and Ludwig (2011) refer to the broader activity and discipline of reinstating ecological structure, composition and function as restoration.

As a scientific and practical discipline ecological restoration is relatively young, but it has grown tremendously in scope and expertise over the last 30 years (Jordan et al., 1987; Ormerod, 2003; Perrow and Davy, 2002a, 2002b; Roberts et al., 2009; Young et al., 2005), in response to accelerating levels of degradation and desertification of a range of ecosystems (Millennium Ecosystem Assessment, 2005b, 2005c, 2005a; Roberts et al., 2009). It has often been called an "acid test" for our knowledge of ecology, and has strong links with theoretical ecology (Bradshaw, 1987, 2002; Young et al., 2005).

Restoration is done for many reasons, ranging from a technocratic need to satisfy institutional mandates, to an idealistic expression of concern for human-caused environmental degradation (Light and Higgs, 1996). Philosophers of restoration sometimes get mired in arguments about the two widely contrasting viewpoints that, on the one hand, restored nature is inferior to "real" nature and that, on the other hand, pristine nature is an idealistic phantom (Light and Higgs, 1996 and references therein). The consequence of all this discourse is that ecological problems may be reconstituted in terms that avoid the technical challenges and miss the obvious and basic necessity to ensure viable land use for future generations.

From our perspective an important rationale for restoration is practical: much of the value of biodiversity to humanity lies in its ability to supply ecosystem goods and services (e.g. clean air, water, and stable, productive soil) (Díaz et al., 2005). A recent analysis (Benayas et al., 2009) has shown that restoration actions focused on enhancing biodiversity could indeed successfully support increased provision of ecosystem services. By way of example, in the Namib a critical service is that provided by intact ecosystems to the tourism industry.

However, success in restoration is by no means guaranteed (Lockwood and Pimm, 1999), with the odds (strict financial limits, short time frames, and a lack of acceptance or understanding by the industry) often stacked against the restoration practitioner. It is therefore imperative that we understand what makes good restoration.

4. Good restoration

Good restoration requires an expanded view that includes ecological, historical, social, cultural, political, aesthetic and moral aspects. Milton (2001) lists a number of general ecological and management principles that emerged from accounts of successful rehabilitation projects, and Burke (2003a, 2008), identified several measures, ecological and otherwise, that will improve restoration practice in Namibia. However, success may depend largely on the level of commitment made by companies to repair the damage their activities may have wrought. In this regard, a common theme in successful restoration projects has been the acceptance of industry best practice as a guiding standard, and the application of systematic planning principles linked to mine closure planning. To this we can add that, similar to management of any natural system, restoration should follow adaptive management principles (Allen et al., 2002; Cummings et al., 2005; Murray and Marmorek, 2003).

A number of responsible players in the mining industry subscribe to best practice in environmental management (ICMM, 2006), including restoration management. By this is meant the benchmarking of performance against industry peers and relative to agreed standards, with the aim of finding techniques and methods that are most effective at achieving a particular goal (Camp, 1989). Industry standardisation is not infallible; e.g. the biodiversity guidelines in best practice principles such as the Equator Principles (available at http://www.equator-principles.com/principles.shtml), which now accounts for 85% of global project finance capacity and have been widely accepted as a standard by mining companies (Langdon, 2007), are generic and broad, leaving much room for interpretation by policymakers and authorities. Nevertheless, best practice incorporates an implicit commitment to using all the technology and knowledge at one's disposal to ensure success.

The linkage of restoration with mine closure planning is obvious. However, in practice restoration is still most often seen as part of the decommissioning phase in the mine's life cycle, placing an unfair responsibility on managers to recreate in a year or two ecological properties that normally take many decades to recover. Ideally restoration should form part of environmental management planning from the conceptual phases of the mine to the very end (Burke, 2003b). In this way problems can be solved, lessons can be learned along the way, costs are spread and ecological processes are allowed to play out over a more realistic time frame.

Much of what constitutes best practice in restoration can be summed up by the adaptive management approach. Ecosystems are inherently complex, challenging the manager in many novel and usually unpredictable ways. Adaptive management is a systematic scientific approach: management actions are devised as hypotheses and then implemented, and outcomes are monitored. Management actions are subsequently adapted on the basis of the results from monitoring. In addition, implicit in the adaptive management approach are (i) a clearly articulated vision, (ii) quantifiable objectives that offer unambiguous milestones for measuring progress, and (iii) thorough scientific investigation of both the ecosystem's natural dynamics and its response to disturbances (Allen et al., 2002; Christensen et al., 1996; Lindenmayer et al., 2008). The latter is especially important for restoration because natural processes such as succession can often be construed as restoration tools (Prach et al., 2001). Importantly, because adaptive management forms an explicit link between research and management, it allows the development of policy in a structured framework.

5. Current restoration initiatives in the Namib

Diamondiferous gravels and sands have been mined on the southern Namib coast for more than a century (Schneider, 2010). A strategic-level restoration plan, including agreed goals and an implementation schedule, has been drafted and some trials have commenced (Burke, pers.comm.). In addition, Antje Burke and colleagues (Burke, 2001a, 2001b; Burke et al., 2008, 2003), have investigated ecological aspects of recovery in this winter-rainfall area that is also part of the biologically diverse Succulent Karoo. Restoration work through Namdeb has focused on planting vegetation in raked and blocked off mining vehicle tracks, drill lines and old waste rock dumps (Burke and Cloete, 2004). To all accounts these efforts have largely been successful, at least in the short term, probably partly because the company understood the size of the problem and consequently committed enough resources to it. The methods developed by Namdeb and other Namib mining companies for rehabilitation of vehicle tracks have also been applied elsewhere in the Namib (Daneel, 1992), so far with unknown results as the study areas where known impacts and restoration were tested need to be re-assessed.

6. Systemic constraints in the successful restoration of mined land

The incentives for a mining company to restore environmental damage caused during exploration and mining in Namibia are small (Wassenaar and Yates, 2008), which in itself limits the opportunities for successfully applying restoration as a tool to mitigate impacts. However, apart from that inherent limitation, there are effectively three major constraints to successful restoration planning and implementation in Namibia, namely a lack of capacity, a lack of knowledge and a lack of clear legal guidance. Below we expound on these.

6.1. Lack of capacity

Capacity to implement effective restoration programmes is lacking in three basic departments: within the mining industry itself, in government, and in science, both basic and applied (SAIEA, 2010). The first refers to the fact that successful restoration requires appropriate people to be appointed in positions where restoration plans are developed and implemented (restoration knowledge is required by all involved or by those who could influence its implementation). This gap is currently partly being filled through outsourcing. Consultants, usually associated with environmental firms, are tasked to develop once-off rehabilitation plans (sometimes called restoration plans) as part of closure plans, but such consultants are not associated with the process for long enough to manage the long-term ecological issues. On the whole, the industry has not created a niche for what is mainly an ecological problem within what is mostly an engineering industry (Wassenaar and Yates, 2008).

Government institutions tasked with supervision and reviewing of environmental assessment procedures also tend to be uninformed about technical details regarding arid ecology, and seldom put environmental management plans out for review by specialists. They also do not have the capacity and expertise to monitor restoration programmes or to assist with the setting of restoration objectives.

Finally, only a handful of scientists have done or are doing any research into restoration in arid systems in Namibia. The only significant restoration research has been done by Antje Burke in southern Namibia, although the same biome (Succulent Karoo) in South Africa has been the focus of much more restoration research (Carrick and Kruger, 2007; Milton, 2001). Furthermore, there are few scientists in Namibia sufficiently familiar with specifics of desert ecology to be able to provide expert advice on restoration. With only one Namibian institution – Gobabeb Research and Training Centre – actively involved in ecological research on Namib systems, there are also not enough new scientists being trained in this specific field.

6.2. Lack of knowledge

Although the Namib is one of the best researched true deserts in Africa (Seely, 1990; Seely and Pallett, 2008; see bibliography at www.gobabeb.org), hyper-aridity brings a specific set of challenges (Didham and Watts, 2005; SAIEA, 2010), particularly for restoration (Aronson et al., 1993, 2002; Bainbridge, 2007; Milton, 2001; Suding et al., 2004; Tongway et al., 2003). There is still limited knowledge of the response of these arid ecosystems to severe disturbances such as mining and the best management techniques to recover their integrity. As an example: personal observations have shown that restoration in Namibia is still commonly regarded as planting vegetation on waste rock dumps. However, for many species it may be better to approach the problem as one of "assisted colonisation", where the options could be to increase the rate of dispersal (i.e. seeding (Wijdeven and Kuzee, 2001; Montalvo et al., 2002)), the rate of germination (i.e. creating safe sites for germination (Isselstein et al., 2002)), the rate of early survival (through irrigation or hydrogels for instance (Lucero et al., 2010), or through instigating natural symbiotic processes such as mycorrhiza (Jacobson, 1997)), or a combination of these. This approach should not be confined to plants with the assumption that "animals will follow naturally". It will be important to similarly assist the colonisation by animals, particularly focusing on keystone species and ecological engineers. Only research into species' functional roles in undisturbed ecosystems and the response of species and assemblages to natural disturbances will identify these key species and elucidate the best strategy.

A number of other issues need to be understood before informed restoration decisions can be made. For instance, even though there has been some research on biological soil crusts, an important component of landscape stability (Belnap et al., 2001; Lalley and Viles, 2005; Lalley et al., 2006), the critical variables that determine the rate of their recovery after disturbance, particularly on the diverse gypsum plains, are poorly known (Kaseke, 2009; Lalley and Viles, 2008; Warren-Rhodes et al., 2006). Basic empirical information on lichen and other soil crust organism transplant options (e.g. Cole et al., 2010) will be invaluable in designing strategies for soil crust recovery, yet essentially no work has been done on this in the Namib.

Knowledge gaps exist concerning the physical properties of the Namib's soils and the relative importance of different nutrients required for plant establishment and growth. It has been shown that nitrogen and phosphorus limit the growth of plants in deserts (Whitford, 2002). However, different from soils in more mesic areas, Namib soils have low levels of these nutrients as well as of organic matter and carbon (Abrams et al., 1997; Henschel et al., 2005; Seely, 1978). Their patchy spatial distribution and natural enrichment processes are probably key drivers affecting biomass and community patterns (Abrams et al., 1997; Gallardo and Schlesinger, 1992; Jacobson, 1997; Jobbágy and Jackson, 2000; Schaeffer et al., 2003; Whitford, 2002). The value of application of fertilisers (a standard rehabilitation technique elsewhere) is therefore unknown in the Namib, and techniques such as the use of nursery plants or micro-organisms to mimic natural spatial and temporal variability of soil chemistry need to be developed and assessed (e.g. Pueyo et al., 2009). Likewise, geohydrological properties and processes of soil near the surface (e.g., Kaseke, 2009) and deeper need to be taken into account, and manipulated so as to enable the soil to support viable communities.

On an ecosystem level, understanding resource distribution and flow and their relationship to species in terms of food webs is essential to manage impacts. Yet, there have been few food web studies in the Namib (Louw and Seely, 1982; Seely, 1991; Polis and Hurd, 1996). The complexity of trophic structures may be a useful indicator of the recovery of ecosystem function (Polis et al., 2004), but unless we understand Namib food webs and their response to disturbance, this will remain a theoretical option. Likewise, we need to know much more about a range of other kinds of relationships, such as facilitation, competition, or niche diversification, between different organisms, and how these are affected by abiotic factors such as episodic resource pulses (Ostfeld and Keesing, 2000; Yang and Naeem, 2008; Yang et al., 2008).

There is a lack of knowledge relevant to restoration about even well-studied high profile species of ecological importance such as *Welwitschia mirabilis* (Henschel and Seely, 2000). This species may perhaps be dependent on groundwater (Soderberg, 2010), and it is not known whether it may survive in areas with only vadose-zone moisture if groundwater levels drop due to mining.

The Husab Sand Lizard (*Pedioplanis husabensis*), a reptile endemic to a small range in the core of the central Namib uranium province (Berger-Dell'mour and Mayer, 1989), will experience habitat loss as a direct result of mining activities. However, despite being vulnerable, its natural history, let alone its population dynamics and survival mechanisms have never been investigated, considerably limiting the ability to manage the threat to this species. The same holds for numerous other restricted-range Namib endemics.

The ubiquitous presence of inselbergs in the Namib (Burke, 2002a,b,c; Burke et al., 1998) and other island-like habitats (e.g. Marsh, 1990) as well as linear corridors formed by drainage lines, implies a strong likelihood of metapopulation dynamics, at least for some species. Henschel et al. (2005) postulated that the extreme spatio-temporal variability of rainfall in the Namib, its distribution following the idiosyncratic pathway of each separate thunderstorm, can have similar implications for metapopulation dynamics and could affect the extraordinarily high biodiversity in some insect groups (e.g. Koch, 1962). This has obvious implications for restoration, yet no studies on landscape-level colonisation or extinction rates, or the factors that most likely affect these have been conducted.

The implications of unpredictable rainfall and other critical climatic events in relation to planning and timing of restoration of ecosystem processes at landscape levels are inadequately known. Even though such events may be fundamental ecological drivers in the Namib, it is currently not yet understood how restoration planning should consider these. This also goes for other long-term and large-scale processes that underlie desert ecology (see reviews elsewhere in this volume).

In summary, the restoration ecology research that Burke and colleagues have started in the southern Namib (Burke, 2008), needs to be greatly expanded and applied on larger spatial and temporal scales, particularly in the central Namib. This will require both academic research, to fill the knowledge gaps, and applied research, to fill the knowhow gaps.

6.3. Policy and legal shortcomings for restoration

Namibian mining regulations and legislation do not refer to ecological restoration per se. A number of acts do refer to or imply rehabilitation (in the sense of removing human-made structures, making an area safe for human occupation or other land uses, and removing pollution) of some sort (Table 1). One of the reasons for the general lack of reference to ecological restoration within the legislation is that this is a relatively new concept in Namibia whereas most of the Namibian legislation was written a number of years ago.

At present the law that has the most explicit commitments for ecological restoration is the Minerals (Prospecting and Mining) Act, No. 33 of 1992, where there are a number of references for the need to rehabilitate the environment, particularly post closure (Table 1). The most recent piece of legislation making mention of rehabilitation is the Environmental Management Act, Act 7 of 2007 (EMA). The respective regulations were promulgated in 2012 and the post of Environmental Commissioner created. This act is likely to place the term rehabilitation within the context of sustainable

Table 1
Relevant Acts and Policies for restoration in Namibia.

Laws and policies	Reference to rehabilitation
The Environmental Management Act (2007)	• "…proponents shall as far as is reasonably practicable, take measures to rehabilitate the environment affected to its natural or predetermined state or to a land use which conforms to the generally accepted principle of sustainable development."
The Minerals (Prospecting & Mining) Act, No 33 of 1992	• In various sections, it requires the mining or prospecting licence holder to remove objects and structures, to remediate and "rehabilitate the land" and to minimise the effect of operations on land adjoining the mining area. It further requires licence holders to apply "good mining practices" with respect to environmental protection and natural resource conservation. • Failure to rehabilitate a mined area properly is an offence carrying a penalty of N$100 000 or five years imprisonment. • Licence holders have a general duty of environmental care, and are expected to practice continuous rehabilitation at own cost. Rehabilitation must be to the reasonable satisfaction of the Ministry of Mines and Energy (MME).
Minerals Policy of Namibia, 2002	• Stipulates that the government will investigate the establishment of mandatory mechanisms for the funding of final mine closure plans (including rehabilitation), and it will monitor industry compliance with these mechanisms. • Government will ensure compliance with national policies and guidelines during rehabilitation and applicable, with global best practice; with relevant stakeholders. • It will investigate the established financial mechanisms for environmental rehabilitation and aftercare.
The Environmental Investment Fund Act 13 of 2001	• The Fund is intended as an endowment that can allocate income to activities aimed at promoting: ○ The sustainable use and management of environmental and natural resources; ○ The maintenance of the natural resource base and ecological processes; ○ The maintenance of biological diversity and ecosystems for the benefit of all Namibians; ○ Economic improvements in the use of natural resources for sustainable rural and urban development.
Water Act, 54 of 1956	• Amongst other stipulations, allows the Minister to recover any costs from the licence holder to prevent the pollution of public or private water (including ground water) that occurs after mine closure as a result of seepage or drainage from mining or industrial activities

development, which brings it more in line with ecological restoration.

Thus whilst there are pieces of legislation that support the need for rehabilitation, the strongest legal instrument to enforce ecological restoration is to include it as a condition of an environmental clearance certificate. In terms of the Minerals Act, mining companies have to conduct an EIA, and Mining Licences are issued only once an environmental clearance certificate has been obtained. Therefore, at present, a commitment to ecological restoration lies very strongly with the proponent and its environmental consultant, who make a commitment to restoration in their EIA.

A number of the recommendations made in the strategic environmental management plan (SEMP) of the U-SEA (see also Section 1) highlight shortcomings in the institutional environments that will contribute to negative impacts on the environment, including the lack of effective restoration. As the benefits associated with the "uranium rush" are numerous, it is hoped that the government in particular will implement the recommendations made in the U-SEA, e.g. exercising the precautionary principle, enacting certain key pieces of legislation and improving capacity in a number of key ministries. All of these will go a long way to strengthening the legal environment for restoration.

7. What is required for successful ecological restoration in the Namib?

A short answer to this question would be that the gaps we identified above need to be filled. However, it is not clear how this should be accomplished. Six years after Burke (2003b) identified similar constraints for restoration and defined four main actions that need to be taken to place restoration high on the agenda, these gaps remain. In our opinion the shortcomings as defined above, and the main reasons why Burke's gaps remain unfilled, are all related to the fact that there is no strong proponent of ecological restoration in Namibia.

Developing on Burke's (2003b) paper, we here propose a number of steps that need to be taken to further the general aims of responsible and legally mandated environmental management principles in general, and of proper ecological restoration of mined land in particular.

A key part of the solution lies in the creation of a mechanism or programme that can champion restoration as an important management tool, as an economic activity, and as a theme for education and training. Such a programme will go a long way towards relieving the pressure on single mines to interpret the wide range of guidelines and legal requirements, and conduct their own research. This programme should have the following components:

- Champion the concept and use of ecological restoration of mined land as a valid environmental management tool,
- Support and develop scientific investigations into the ecology and socio-economic issues relating to restoration of degraded arid lands, drawing on a wide range of disciplines and knowledge,
- Develop a monitoring programme through which agreed indicators of environmental quality, with an emphasis on restoration, can be measured and evaluated,
- Develop a training programme through which capacity can be built to serve the needs of industry, private sector and government with regard to ecological restoration,
- Develop an information platform about best practices in restoration, and actively facilitate access to this information on a broad front, and
- Develop and facilitate development of restoration by putting pressure on environmental policy makers.

To achieve this, during April 2012 the Namib Ecological Restoration and Monitoring Unit (NERMU) was established at Gobabeb. NERMU is academically independent, has a strong scientific basis, and actively develops links with universities and other research institutions in Namibia and abroad, hosting researchers from partner institutions. It will be able to draw heavily on the extensive knowledge accumulated thus far on the environment of the Namib Desert, especially at Gobabeb, and help to guide the future quest for knowledge. Its core funding may in future at least partly be obtained from the mining industry itself as a component of their environmental management responsibility. For the initial stage, core funding required to develop the programmatic framework during 2012 and 2013 has been granted by an international donor, the German Ministry of Cooperation. NERMU addresses some of the objectives of the Namibian Environmental Investment Fund (EIF), administered by the Ministry of Environment and Tourism, comprising endowments and a range of local and international sources of revenue dedicated towards protecting and maintaining the environment. There is therefore obvious potential for the EIF to support this restoration programme in future. However, to ensure that it remains academically independent NERMU remains free to solicit grants and accept bequests from anywhere. The restoration programme will require philosophical and financial commitment from both the mining industry (as exemplified through the industry's support for the U-SEA and its SEMP) and government, and tight linkages with Namibian academic institutions.

The development in Namibia can call on experience in the development of ecological restoration in deserts of other continents, especially North America, South America, the Middle East and Australia, although none of the other deserts where restoration has been developed are as hyper-arid as the Namib. In particular, there is good potential to learn from the Australian experience, particularly because Namibian mining developments are frequently spearheaded by Australian companies. Faced with challenges of land degradation from agriculture and mining in Australia, ecologists have applied academic knowledge towards restoration (Dickman, 2010; McDonald and Williams, 2009) and developed it further towards ecological restoration as a discipline (Tongway and Ludwig, 2011). The commitment to restoration by a large bauxite mine (Gardner and Bell, 2007) provided good practical experience in Australia, both for the mine, as well as for restoration ecologists. These kinds of developments provide excellent background and useful case studies for the envisaged Namibian development.

Namibia is currently in the unique position that it can instil a culture of best-practice environmental management at the start of a new industrial boom, and NERMU was established as a strategic champion to take this initiative forward for the benefit of the mining industry and the region. Although there are likely to be numerous obstacles to the successful implementation of this initiative, none are insurmountable. In fact, the advantages of a programme focused on the restoration of the ecological integrity of degraded land in the Namib are many, and the disadvantages few.

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