Practical measures in arid land restoration after mining – a review for the southern Namib

Antje Burke*

THE PRINCIPLE OF ECOLOGICAL RESTORATION offers opportunities to re-vegetate disturbed areas cost-effectively after mining. The southern Namib is the northern tip of one the world's 25 biodiversity hotspots and is under pressure from mining and exploration activities. This paper provides a review of methods available for arid land restoration and assesses their applicability in the context of southern Namib restoration ecology. The techniques available are discussed under the headings: (a) provision of suitable landform and substrate and (b) facilitating natural processes. Landscaping man-made landforms to match their surroundings, the provision of rough surfaces and small water catchments as well as applying fresh topsoil are the main aspects to be considered. Growth-impeding soil properties such as toxicity, and acidic, saline and sodic conditions will require treatment to ensure natural plant re-establishment is feasible or replanting areas is successful. Seeding and relocating native plants are feasible options to accelerate natural plant succession that merit further development in the southern Namib. Apart from the involvement of mining and exploration companies, the use of these techniques will require good planning, a small team of dedicated staff, limited training and some very basic facilities to become a reality.

Introduction

To fulfil obligations to future landowners and generations, land that has been mined will need to be made useful again after mining.[1] The contemporary guiding principle is the reinstatement of the pre-mining land capability and restoring natural biodiversity as far as possible. While this concept is widely accepted around the globe, achieving this goal in developing countries is a long way from accomplishment. In Namibia, rehabilitation after mining is at best restricted to removing infrastructure, remediating pollution and securing potentially dangerous situations (such as mining voids). In many instances the land remains in a state unsuitable for any other use.[2]

A brief definition for clarity: rehabilitation encompasses all endeavours that attempt to make land useful again after disturbance. This ranges from planting pastures where there used to be shrubland, to creating artificial lakes from mine voids, and to restoring the pre-mining landscape and vegetation. Ecological restoration 'is the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed'.[3] In the mining context, this applies to restoring the pre-mining landscape and vegetation to a state 'when it contains sufficient biotic and abiotic resources to continue its development without further assistance'.[3] In many arid countries the concept of re- establishing self-sustaining, natural ecosystems is considered impractical and too expensive. This notion has to be challenged.[4]

To assist with collating the necessary information systematically, I provided a research framework for ecological restoration in the southern Namib in a previous review.[5] In the meantime some progress has been made and the purpose of this article is to review and discuss practical aspects applicable to the southern Namib and comparable arid lands. I focus on restoration after mining, largely with reference to the Succulent Karoo Biome,[6] which has been identified as a global biodiversity hotspot[7] where many parts are under pressure from mining.[5]

The southern Namib encompasses the northern tip of the Succulent Karoo Biome and extends along the Namibian coast approximately from Lüderitz, south to just beyond the Orange River.[8] The Namibian section of the southern Namib includes the restricted Diamond Area 1 (Sperrgebiet). At present approximately one-third of the Sperrgebiet comprises active mining licence areas; but within these, mining is restricted to a small portion along the coast, ancient terraces of the Orange River and a small area west of Rosh Pinah. Diamonds and zinc are won by opencast mining. Both mining operations create open pits, mine spoils, industrial and domestic wastes and cleared areas necessary for infrastructure. The zinc ore is processed on site and creates acid mine spoils. The remaining Sperrgebiet has been assigned as prospecting licence areas and drilling is undertaken systematically in many parts of the region. In the remaining southern Namib, outside the Sperrgebiet, mining operations include small-scale diamond mining along the Orange River and quarrying for dimension stone. The main problems to address during rehabilitation are man-made landforms, loss of unique habitats, vehicle tracks and potentially toxic substrates.

Reinstating pre-mining land capability requires that landforms, substrate and plant cover are restored. Ecological restoration provides the tools to accomplish the desired land capability. Two main aspects need to be addressed: (1) provision of suitable landform and substrate, and (2) facilitating natural processes.

Provision of suitable landform and substrate

In order to re-establish vegetation, landform and substrate conditions must be right.[9] The following tools are available to obtain substrates that support plant growth in areas that have been stripped or are man-made landforms.

Landscaping

Landforms and soil surface should mimic the natural environment. Apart from reducing unsightly appearances, landforms present in the natural environment are also likely to facilitate the establishment of the indigenous plant life in an area. Considering the main wind directions and creating small catchments[10] to support water infiltration, seed and nutrient deposition and incorporating the natural 'flow' of landforms (K. Pitcher, pers. comm.), collectively help to provide a suitable backdrop for plant growth. On a smaller scale, roughening the surface, providing furrows[11] and loosely scattering stones, rock fragments and dead wood can help to channel water and provide 'safe sites' for seed germination.[12,13] Simulating the natural surface in the undisturbed surroundings nearby is likely the best model.

Topsoil application

Fresh topsoil on disturbed areas provides the best growth medium for plants. Hence a widely practised measure in mining rehabilitation is the preservation and storage of topsoil. Once an area is mined out, the soil is then reapplied.[14] Biologically active soil (that is, topsoil — usually within the upper 10 cm) is an extremely valuable commodity for rehabilitation. These top layers of soil contain microorganisms, fungi and most importantly the plants' seed bank.[15] However, time is a critical factor to facilitate success.

*EnviroScience, P.O. Box 90230, Klein Windhoek, Namibia. E-mail: antje.burke@enviro-science.info

If topsoil is stored, the timing of its re-application needs to ensure that the soil is replaced shortly before the most favourable conditions for germination, such as after the fire season[16] or just before the start of the growing period. Even more critical is time with regard to length of topsoil storage. The biological health of topsoil degrades quickly once moved out of its natural position. Anaerobic or otherwise adverse conditions gradually kill most of the biologically active components of the soil[17] and the germination of seeds, if the soil is stored over several seasons, removes a large portion of, and eventually the entire, seed bank.[18] What remains is, at best, a substrate with better soil properties than the bare areas usually remaining after mining. However, if the provision of suitable substrate for plant growth is the sole objective, more cost-effective methods can be used (for instance, applying sand derived from overburden removal elsewhere in sandy environments). Studies in winter rainfall, coastal strandveld in South Africa showed that topsoil should ideally not be stored more than one month, as even after only five months of storage the species richness of the seed bank declined rapidly.[19] Given these problems, in most arid habitats topsoil storage and reapplication is only successful if the soil can be relaid immediately in similar disturbed habitat nearby.[20] In addition, if topsoil is stored over long periods it may also supply a 'nursery' for weedy species.[21] In wind-swept areas, where soil is continuously re-deposited, topsoil and subsoil properties likely do not differ markedly and both could be used for rehabilitation.

Where topsoil can be used for rehabilitation immediately, it is an extremely important commodity for restoration. Where it cannot be used promptly, storing topsoil needs to be evaluated on a case-by-case basis, taking the above constraints, the site condition and growing periods into account.

Ameliorating substrate problems

Tillage and chemical treatments can help to counteract the physical and chemical properties of unsuitable soil. Disturbed areas are often compacted, and mines can produce spoils containing substances toxic to plants or that are highly acidic or alkaline. The right chemical properties are critical to ensure that re-vegetation of disturbed sites is successful.[22]

The mechanical preparation of the site to provide suitable physical conditions is called tillage.[23] The objectives of any form of tillage are to provide soil aeration, reduce compaction and prevent erosion. These are management interventions applied in agriculture, and similar types of machinery are used. For small areas manual means are more applicable, and people using rakes, shovels and spades can achieve as much as most machinery. Mulching (that is, laying a loose cover of organic material) adds organic material to the soil and helps to reduce evaporation and soil erosion.[24]

Acid and alkaline spoils are frequently associated with mining operations. Acid-mine problems are encountered in association with base-metal production, while alkaline spoils are characteristic of arid regions, where rains are insufficient to leach out salts.[25] Hence even mines that do not use chemicals during the processing of ore (as in diamond mining) may encounter problems with tailings and overburden dumps.[26] Saline and sodic soils are both alkaline and require treatment (salinity refers to the total salt content, whereas sodicity to the sodium content of the soil). Salinity is usually reduced through irrigation and adding organic matter.[30] Sodic soils require adding a soluble calcium salt or an acid-former (such as sulphates).[27] Acidic soils are most commonly treated by adding lime or other calcium-containing substances such as ash and coal residues.[28] If problems with soil conditions are encountered, the appropriate treatment will need to be determined and applied. Acidic and probably alkaline soils are a problem in the southern Namib.

Facilitating natural processes

Using natural processes to accelerate the establishment of natural, self-sustaining plant and animal communities is one of the main objectives of ecological restoration. There are various ways that natural processes can be used to speed up plant establishment. Learning from the basic principles of succession,[29] we know that pioneer plants usually help to ameliorate soil conditions by adding organic matter, loosening the soil and perhaps removing elements toxic to later successional species. Some may act as nurse plants for other plants[30] and attract insects, soil organisms and small animals that further help to loosen the soil and add important nutrients.[31] As in many shrub-dominated communities,[32] cyclic succession occurs in the Succulent Karoo Biome.[33] This means that vegetation naturally undergoes changes from bare areas (that may be caused by die-offs during drought periods or disturbance by animals) to herb- and later shrub-dominated communities. These processes are aided by animal activities, such as burrowing animals and herbivores that help initially with seed dispersal and soil nutrient enrichment;[34,35] in the case of herbivores these may eventually destroy the vegetation. Animals or droughts cause die-off and the process starts again with the colonization of bare areas. This can happen within a span of a few decades in the Succulent Karoo Biome.[36] Whether or not this ecologically rapid turnover is applicable to the southern Namib is not known at present.

Whatever the time span, ecological restoration attempts to accelerate the process of plant establishment to obtain plant communities that can then undergo natural succession. There are various means to facilitate plant establishment. Providing the right landform and substrate as discussed above is reported to accelerate not only plant establishment[4] but also re-colonization by animals.[37] This method, however, will only be successful if adequate sources of seeds of natural vegetation are available in the vicinity. For quicker results, or if large areas are denuded, active intervention will be required. The methods range from inoculation of soil with mycorrhiza fungi, to seeding and planting with exotic or indigenous species. In most instances a combination of these methods will be appropriate.

Mycorrhizal fungi

Inoculation with mycorrhizal fungi has long been used to help with the re-establishment of vegetation after mining.[38] Interactions of mycorrhizal colonizers and their host plants influence soil development and through this the final composition of the vegetation.[39] Pre-inoculated grasses showed better survival, vegetative growth and reproduction on semi-arid plains[40] and the use of microorganisms associated with roots may accelerate restoration.[41] This symbiosis can be successfully applied during ecological restoration and enhances growth, nutrient and water uptake of the host plant. In the southern Namib, *Cladoraphis cyperoides,* an important dune grass, was found to be myccorhizal,[42] and other plants probably form mycorrhiza. However, even without sophisticated facilities that can provide pre-inoculated plants or soils for restoration purposes, following some simple guidelines will be adequate. Fresh topsoil supporting the same vegetation type nearby will possibly have all the required fungal spores. And, if transplants are undertaken in a way that all soil around the roots is kept, this will ensure that beneficial soil microorganisms are transferred to the site to be restored.

Seeding

Introducing seeds on rehabilitated surfaces will help to obtain some vegetation cover in a short time. This is particularly important where indigenous species have very short seed dispersal distances.[43] Various sowing techniques are available and a variety of species can be used. Seeding with nurse crops, often exotic species, to stabilize soil and improve soil conditions is widely applied. For example, legumes with nitrogen-fixing capability[44] or quick growing grasses are used for this purpose. In the context of ecological restoration, this method is acceptable, as long as no negative side-effects occur with the introduction of exotic species (for example, a change to undesirable soil conditions or risk of the introduced species becoming invasive and competing with native species). In South African succulent Karoo vegetation seeding with non-native *Atriplex* species prevented the establishment of indigenous plants.[19] These species should thus not be used.

It is important to obtain the correct seed mix for a particular site. Ideally, the mix should not only contain the native species that were present at the site before the disturbance, but should also include the genotypes adapted to the conditions on site.[45] Seeds need be collected from the same vegetation type in the vicinity, or even better from the vegetation that is to be destroyed beforehand. In Namibia seed collection is undertaken by the National Plant Genetic Resources Institute, but the institute focuses on single species preservation and does not supply seeds for commercial or restoration purposes. There are no commercial seed collecting enterprises in the country. However, all it takes is good planning, limited training and some basic storage facilities. If so provided, staff of the mining companies would be able to undertake the necessary seed collections themselves.

In a desert environment the timing of seeding is critical and should happen close to the onset of rains. Should these fail in a particular season, some initial irrigation at the time of natural rainfall may be required.

Replanting

Re-vegetating or replanting denuded areas with indigenous species is appropriate in areas where (a) natural recovery is slow, (b) the vegetation to be cleared has an important ecological function (such as water catchment management, dust suppression) and/or (c) vegetation types of conservation concern are affected.[46] Replanted native vegetation more likely provides self-sustaining plant communities and plant cover that matches the surrounding landscape in an aesthetically pleasing way.[47] Planting clumps of vegetation rather than neat rows, and following the terrain is most appropriate. The spacing of similar undisturbed, natural vegetation nearby is the best model to follow. Considering the terrain to be replanted in the southern Namib, most areas should probably be worked manually. This would avoid soil compaction associated with heavy machinery and would also facilitate a flexible planting pattern.

The most imminent constraint in Namibia is the availability of planting material. No southern Namib plant species have yet been cultivated on a large scale, other than for plant collectors, although many have horticultural potential.[48] Hence no species native to this area are available in commercial nurseries. One possible solution is discussed below.

Relocation

Relocating or transplanting of plants directly from their natural habitat into freshly prepared sites is at present the only way to re-vegetate areas with indigenous vegetation in Namibia. However, there are problems with this approach. Little is known about which species tolerate such treatment, which techniques should be applied and how to time this intervention correctly. Without irrigation, for example, transplanting indigenous species, despite mulch treatment and testing of different planting techniques, gave poor results in the Mojave Desert.[49] However, the southern Namib vegetation is largely succulent and succulents retain their own water supply[50] and are thus less prone to suffer from desiccation.[51] As a result, relocation with succulents has been fairly successful, although there are differences between species, largely linked to growth form. For example, survival of leaf succulents in the lowland Succulent Karoo Biome in South Africa was more successful than that of soft-stemmed succulents,[19] a pattern we also observed in the southern Namib.[48] Compact leaf succulents showed the best results.[52] A further constraint is that, due to the high number of endemic plant species, many with an extremely limited range,[5] ideally no species should be removed out of their natural habitat. Thus transplants need to originate from areas that are going to be mined.

This is not impossible. Good planning, some basic storage facilities and a few dedicated staff to oversee and undertake the restoration activities are needed. Our preliminary results show that there is merit in further developing appropriate transplanting techniques. Since the southern Namib's succulent vegetation has mostly limited seed dispersal abilities and seed retention,[53] even if not all plants survive transplanting, dead plants will still facilitate succession. These will provide the seed bank and a natural structure to catch seeds, soil and litter and hence become a starting point to initiate natural succession. So nothing will be lost.

Setting a practical framework for the southern Namib

So far only few methods have been tried in the southern Namib. Initial interest to gain a better understanding of ecosystem components of relevance to restoration ecology resulted in a preliminary investigation of mycorrhiza associations of plant species in the coastal area,[42] setting up vegetation plots on mine dumps to study natural recovery, and a few trials to test the relocation potential of some indigenous plant species.[48] Unfortunately, the initial interest died quickly and many opportunities to make a truly valuable contribution to biodiversity conservation in the southern Namib are lost, if there is no commitment from mining companies in future. It is not necessary to understand every facet of local plant ecology to apply restoration ecology principles. Adaptive management[54] calls for applying practices according to best knowledge at the time and improving measures through continuous re-assessment. At present there are five main actions that would facilitate the further development of best practices for ecological restoration in the southern Namib:

1. Understanding the rates and sequences of natural recovery of vegetation after disturbance;
2. testing relocation potential of native species;
3. developing practical procedures and techniques that would ensure that seed and plant stock of vegetated areas that are going to mined are available for later restoration;
4. good documentation and monitoring of restoration costs, failures and successes; and
5. information sharing between all relevant parties.

These are elaborated on below.

1. Knowing the natural sequences and rates of recovery of plant communities will help to determine whether or not intervention is desirable or necessary. For example, should cyclic succession occur in southern Namib plant communities, and short turnover periods are observed, no active intervention to re-establish plant cover may be required. Should intervention be necessary to speed up the recovery of plant cover, knowledge of natural sequences of recovery will help to collate appropriate seed mixtures, use pioneer communities to prepare substrates and determine species that could be used in transplants that facilitate the establishment of others.
2. Knowing which plant species tolerate transplants and under which conditions is important to avoid (a) elimination of plant species with a limited distribution range, (b) selection of the right species, and (c) unnecessary effort and costs, if the species in question have proved unsuitable for transplants.
3. To integrate mining with rehabilitation planning will facilitate implementation of the necessary procedures to rescue plants and seed stocks for later rehabilitation.

4 and 5. These are critical issues in the pursuit of adaptive management. We should not only learn from possible mistakes, but also learn to intervene, should the restoration process not take the desired course (for instance, by invasion of weedy species or problems with soil properties, such as crust formation). Since the evidence of restoration is supposed to be visible within one to 10 years[55] and reaching the restoration goal should not take longer than 10 to 50 years,[56] monitoring and record keeping will be essential. Continuous adaptation according to successes and failures will allow the refinement of restoration methods and will lead to the implementation of the most cost-effective and best practice at the time.

What are the constraints?

There are no legal requirements for habitat restoration after mining in Namibia, so that rehabilitation depends on the goodwill of the mining companies.[57] Excessive costs, scepticism about the success of the proposed methods, and a lack of restoration guidelines are often cited as obstacles by the industry. There are cost implications, yet these could be reduced through efficient planning. And whether or not the costs justify the expense can never be established without at least trying on a small scale.

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