Chapter 30
General Conclusions – Sand Dune Deserts, Desertification, Rehabilitation and Conservation

S.-W. Breckle, A. Yair, and M. Veste

30.1 Sand Deserts and Sand Dunes

Moving sand dunes represent a natural phenomenon in most arid and hyper-arid sand deserts, such as the Sahara, Namib, Taklamakan and Rub'al Khali. The preconditions for large sand dunes or even extensive "sand seas" are, on the one hand, the geological situation with a large source of sand provided by the weathering of parent rocks and, on the other hand, the climate, which is normally very arid and exhibiting typically strong wind systems. These dune systems – e.g. in the Gobi, the Rub-al-Khali and the Namib – are typical sand deserts. The water regime of these sand deserts is rather favourable in comparison with that of adjacent rock, gravel or clay deserts. The biomass resulting from 1 mm of rainfall on sandy soils is 2.5 times higher than that produced on fine-texture soils (Le Houérou 1986). This can always be seen in some specific stands of plants, mostly in the stable dune valleys where eventually sometimes even water can be found. The mobility of these dune systems is controlled by the specific wind regime, which may cause different types of dune morphology and dune types (Bagnold 1941; Besler 1980; Lancaster 1982; Tsoar 1984; Tsoar and Møller 1986; Cooke et al. 1993).

There are also less arid deserts. These are found along desert margins or in the form of semi-deserts, where fixed sand dune systems start to become mobile for various reasons (Wang et al. 2006), mainly by overgrazing and trampling, together with firewood collection. In geological timescales, climate change can be a trigger for the reactivation of stable sand dunes (Lancaster 1987; Littmann 1988).

The Nizzana dunes are an example of dunes at a desert margin, more or less stable during the last centuries. They are very small in comparison with other sand dune areas but nevertheless a good example of where, on the one hand, the dynamics of desert ecosystems (as shown in previous chapters) and, on the other hand, the vulnerability of these systems and the problem of desertification as well as the necessary measures of rehabilitation can be studied. Thus, some comparisons with other, selected sand dune ecosystems, with their specific dynamics and threats, can be made but also some general conclusions can be drawn.

30.2 Desertification – the Degradation of Sandy Desert Ecosystems and Threat to Adjacent Areas

Desertification is a major threat for the world's drylands. Especially desert margins and semi-arid areas are affected by land degradation as a consequence of inappropriate land use and over-exploration of natural resources. The United Nations Conventions to Combat Desertification (UNCCD) defines desertification as "the degradation of the land in arid, semi-arid and dry sub-humid areas caused by various factors, including climatic changes and human activities". Dryland ecosystems and especially desert margins are very vulnerable to over-exploitation and inappropriate land-use practices and climatic changes. Various aspects are involved in the initialisation and acceleration of desertification (Mainguet 1999; Breckle et al. 2001; Müller et al. 2006), e.g. overgrazing, deforestation, lumbering, overuse of water resources, salinisation, mining, erosion, sand movement, and climatic drought. Land degradation leads to a dramatic decrease in soil fertility, water availability, net primary production, plant cover and biodiversity. The ongoing climate change and climate fluctuations will accelerate these desertification processes. In many affected countries, the remobilisation of sand dunes and enhanced sand mobility are a major threat for villages, buildings, roads, railways and technical infrastructures. The Sinai-Negev sand field is a perfect example of how grazing and land use has destroyed the vegetation cover to a great extent (see Chap. 6, this volume). Already in the 1970s, the desertification

Fig. 30.1 Sand dunes near Nizzana are converted into agricultural fields for the production of flowers and vegetables in greenhouses

problem of the Sinai-Negev sand dunes was indirectly recognized on satellite images (Otterman et al. 1975).

Nowadays, agricultural cultivation along the northern and southern margins of the sand field is increasing, and large areas are covered by greenhouses for the production of flowers and vegetables (Fig. 30.1). The sandy soils of the Negev are very suitable for drip irrigation (Tsoar 1990). The increasing water demand for irrigation is affecting the coastal aquifer, and brackish water is moving into the wells (Tsoar 1990).

30.3 Designing Shelterbelts

Stabilisation and rehabilitation of mobile sand dunes is a major task for combating desertification. A key challenge is the reduction of surface wind speed as the source of sand transportation. Chemical products have been often used to stick sand grains together and to prevent saltation (Veisov et al. 1999). Such methods are unacceptable from an environmental viewpoint. They alter or even damage ecosystem functioning. Mechanical and biological barriers are a useful tool to increase the surface roughness and to decrease wind speed. Biological methods for sand dune stabilisation are increasingly and successfully being used in many deserts (Mainguet 1999; Veisov et al. 1999; Gao et al. 2006).

In the first stage of stabilisation, straw checkerboards are often used to reduce surface wind speed (Fig. 30.2). An efficient straw checkerboard of 10 to 20 cm in height and 1×1 m in size decreases sand flow by more than 99.5% up to wind speeds of 6 m s^{-1} (Qiu et al. 2004). In the second stage, the development of natural or planted vegetation takes place. Only re-vegetation is a permanent solution for sand dune stabilisation. An efficient shelterbelt depends on the regional wind field and on average as well as maximal wind speeds. The spacing depends on wind velocity and wind direction. It is recommended to space windbreaks at a distance of 5–25 times their height (Mainguet 1999). For the establishment of an effective shelterbelt, therefore, detailed information about the local wind field is needed but, unfortunately, there is commonly an important lack of knowledge in this respect. Species used for plantations have to be selected according to their growth, structure and water consumption. Soil water availability limits vegetation density and the biomass of perennials (see Chap. 26, this volume). Therefore, only local plants should be selected for shelterbelts. Indeed, plants from foreign regions have sometimes been introduced for the reclamation of sand dunes and as wind-breaking shelterbelts. Various *Populus* species are used, sometimes together with fruit trees, such as *Morus*. In fact, this is a rather old tradition in many parts of Central Asia (Fig. 30.3).

In South Africa, *Acacia* species from Australia were taken to stabilise the sand dunes in the Cape Flats. These alien plants invaded other sensible ecosystems in the country and are nowadays a major threat for the indigenous biodiversity and ecosystem functioning in many regions of South Africa (Bromilow 2001). Also in China, several tree species originating from Europe, North America and Australia

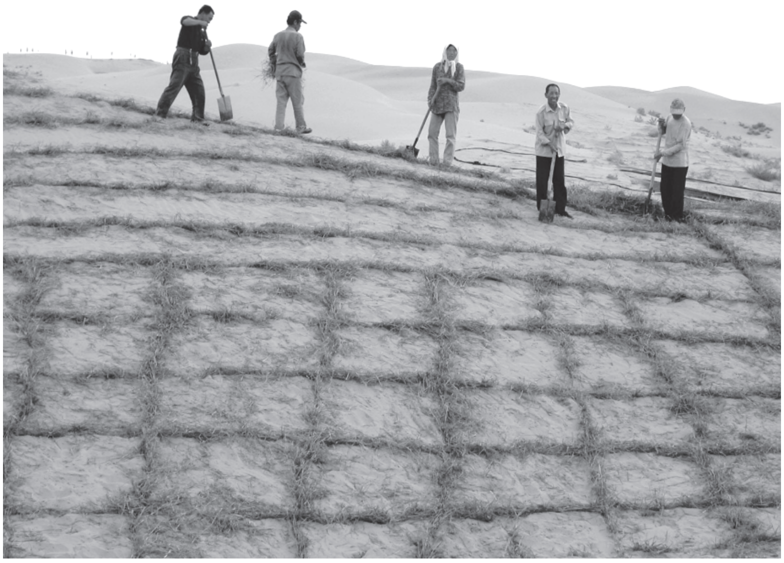

Fig. 30.2 Straw checkerboards decrease surface wind speed and stabilise the surface. The construction is very labour-intensive but is now used in many countries

Fig. 30.3 *Populus* trees are planted extensively in many parts of Central Asia, serving as shelter-belts and wind-breaking walls, here in Khoreshm (Uzbekistan)

are used in reforestation projects (Gao et al. 2006). Many species were tested for the rehabilitation of the Loess Plateau with its extreme erosion problems (Ichizen et al. 2005). The effects of these introduced plants on biodiversity, ecosystems functioning and genetic diversity are still unknown.

30.4 Stabilisation of Sand Dunes in the Aralkum

The most conspicuous cases of desertification with visible effects in the wider vicinity can be observed within the Aralkum Syndrom (Agakhanjanz and Breckle 1993; Letolle and Mainguet 1996; Breckle 2003). The Aralkum Syndrom is a complex pattern of various kinds of desertification problems caused by increasing lack of water, mainly by overexploitation for excessive irrigation practices, and thus desiccation of lakes. Not only has the Aral Sea almost disappeared but also Lake Chad in Africa, Lobnor in Sinkiang, and the Dead Sea as well as the Great Salt Lake in the USA and the Lago Enriquillo in the Dominican Republic face strong water losses, and are becoming smaller and more saline. New salt flats develop, as well as new sand deserts.

From the desiccated seafloor, the Aralkum, salt-dust clouds are transported hundreds of kilometres and are contaminating irrigation fields in neighbouring countries (Uzbekistan: Amudarya river plains, Kazakhstan: Syrdarya river plains, Turkmenistan, etc., many examples; see NASA 2006). The huge stretches of salt deserts with puffy salt crusts (about 65%) need an urgent action for rehabilitation, which is possible only by means of phytomelioration (Fig. 30.4) through extensive halophyte plantings of *Haloxylon aphyllum* or *Halocnemum strobilaceum* (Fig. 30.5; Meirman et al. 2001; Breckle 2003; Wucherer et al. 2005a, b). Dust storms are a common feature in arid lands but are increasingly disturbing cultivated lands and settlements (Littmann 2006; Gao et al. 2007).

About 25% of the desiccated seafloor of the Aral Sea consists of sand deserts with newly developed aeolian activities. This area is threatening the adjacent regions by dust and sand storms (Youlin et al. 2001). Again, it needs a strong action of phytomelioration to accelerate the natural succession processes of invasion of psammophytes, e.g. *Calligonum* species, *Haloxylon aphyllum, H. persicum, Tamarix* species, in order to minimize sand storms (Fig. 30.6). The use of saplings of *H. aphyllum* in spring on sandy soils yields the best results. Nevertheless, even if saplings are taken and used in fall and on solonchak soils, there is still some success of rooting (Meirman et al. 2001; Wucherer and Breckle 2005).

A strict management system for grazing to prevent further degradation of sandy areas around villages and newly established "afforestations" is necessary, in combination with establishing shelterbelts around the villages (Figs. 30.7, 30.8). This also has been demonstrated in the Nizzana area for the sand dunes and their grazing intensity (see Chap. 6, this volume).

It has to be stressed that in the Aralkum, the sand desert is by far less dangerous for the adjacent regions than are the salt deserts (Wucherer and Breckle 2005).

Fig. 30.4 One row of a phytomelioration trial with cuttings of *Haloxylon aphyllum* (Saxaul) on the dry seafloor of the Aral Sea 1 year after planting. In the *background*: an annual plant cover by *Atriplex pratovii*

Fig. 30.5 A 1-year-old sapling of a well-growing *Haloxylon aphyllum*, and creation of a sand dune in the lee

Fig. 30.6 Various *Calligonum* species (Polygonaceae) occur in the sand deserts of the Aralkum. They are subject to sand covering or to sand deflation. The extensive root system is then visible

Fig. 30.7 Villages around the former coastline of the Aral Sea are in a desolate condition because of frequent dust and sand storms

Fig. 30.8 Creation of shelterbelts by planting resistant trees, e.g. *Ulmus pumila* around the village of Bugen

Salt-dust particles are small and can be transported for hundreds of kilometres. Sand grains are larger and are subject to saltation and short-distance transport only. Nevertheless, common sand storms (Bisqunaq) in the wider Aral Sea basin are also a threat for the health of local inhabitants and cause damage to equipment not only in the villages (Fig. 30.9).

The productivity of the vegetation by natural succession is much stronger on sand dunes than in the salt desert. The relatively good water conditions in a sandy area (Yair 2001, and see Chaps. 18 and 29, this volume) under an arid climate are a good precondition for phytomelioration. Thousands of hectares are already "afforested" in several, mostly sandy parts of the new Aralkum in the south-eastern Uzbek sector (GTZ Project, Novizkiy, unpublished data).

Conservation and sustainable use of biological diversity has became a key issue in Kazakhstan (Karibaeva et al. 1998). Barsa Kelmes Island has been a nature reserve since 1939 but today, open access to the east via the dried-out seafloor has had a major impact (TERRA 2007). The totally flat seafloor, with a mixture of salt crust desert and, in the older parts, of sandy desert has enabled the fauna to occupy a much larger area. By enlarging the size (16,795 ha) of the Barsa Kelmes nature reserve considerably (59,884 ha), and by demarcating two additional core areas (Kaskakulan, 109.942 ha; Syrdarya Delta, 11,244 ha), a good step forward in nature

Fig. 30.9 Frequent sand and dust storms cause damages to equipment – here, a stranded ship

Fig. 30.10 The new sand desert in the Aralkum inhibits the establishment of a rich fauna, including reptiles – here, an *Agama* species

Fig. 30.11 Open *Artemisia* semi-desert with old *Haloxylon aphyllum* shrubs and small trees on Barsa Kelmes Island, now declared a core area of nature conservation

conservation with future developmental goals has been accomplished (Ogar and Geldeev 2007). The declaration by the Kazakh Government aims to activate the natural dynamics and to conserve remnant fauna (Fig. 30.10) comprising various reptiles, and also gazelles, Saiga antelopes and wild asses, as well as remnants of the open Saxaul desert forests (mainly *H. aphyllum*) with a rich biodiversity on the former Barsa-Kelmes Island (Fig. 30.11).

30.5 Stabilisation of Sand Dunes in the Tengger Desert

In the last decades in the northern provinces of China, large shelterbelts have been established to reduce sand erosion (Sun and Fang 2001; Ximing et al. 2001; Li et al. 2004b; Gao et al. 2006; Veste et al. 2006). Protective forest systems (Zhao et al. 2005) have been established in semi-arid regions, such as in the Horqin sandy region in northeast China. Here, an annual rainfall of between 315 and 490 mm can promote the growth of trees on the sand dunes. This is a major difference with the Nizzana area. The southern parts of the Tengger Desert along the Yellow River have only 180 mm of annual precipitation. High sand movement is common and is endangering the roads and railway lines along the river.

Fig. 30.12 Stabilised sand dunes in the Tengger (Shapotou) sandy region of Inner Mongolia, China

Therefore, in 1957 a sand dune protection system was initiated. Since then, the vegetation protective system in Shapatou is 16 km long and 500 m wide on the northern, and 200 m wide on the southern side of the railway (Li et al. 2004b). In the first phase of stabilisation, straw checkerboards are used. In the centre of the checkerboards, mainly seedlings of *Artemisia ordosica, Hedysarum scoparium, Caragana korshinskii, Eragrostis poaeoides* and *Calligonum mongolicum* were planted. Other plants, especially annuals, established spontaneously, as did biotic crusts (Li et al. 2002). The degree of vegetation coverage in experimental plots with *A. ordosica* and *C. korshinskii* depends on plant density and mixture. In monocultures of *A. ordosica*, the maximum observed vegetation cover was 18.6% and, for *C. korshinskii*, 19.6%, whereas in mixed stands of both species the cover was up to 25.8% (Fig. 30.12) (Li and Shi 2003). The reasons for the higher vegetation cover in the mixed stands are the different root systems of the species. In contrast to *Artemisia, Caragana* can use water from deeper layers. Between the checkerboards, a biological soil crust develops (Fig. 30.13). As we could show for the Nizzana dunes (see Chap. 29, this volume), mosses have a negative impact on deep-rooting shrubs also in sand dunes at the Shapatou research site (Fearnehough et al. 1998; Mitchell et al. 1998; Li et al. 2004a). The number of shrubs declined on stabilised plots where mosses established (Fig. 30.14). Despite the climatic differences between northern China and the Negev, these sand dune ecosystems have some similarities (Fig. 30.15); in both regions, effects of climate change may be a risk (He 2001). Vegetation cover and plant functional types as well as ecosystem processes are comparable.

Fig. 30.13 Biological soil crusts developed between the straw checkerboards on stabilised sand dunes of the Tengger Desert at the Shapotou experimental site (Inner Mongolia, China)

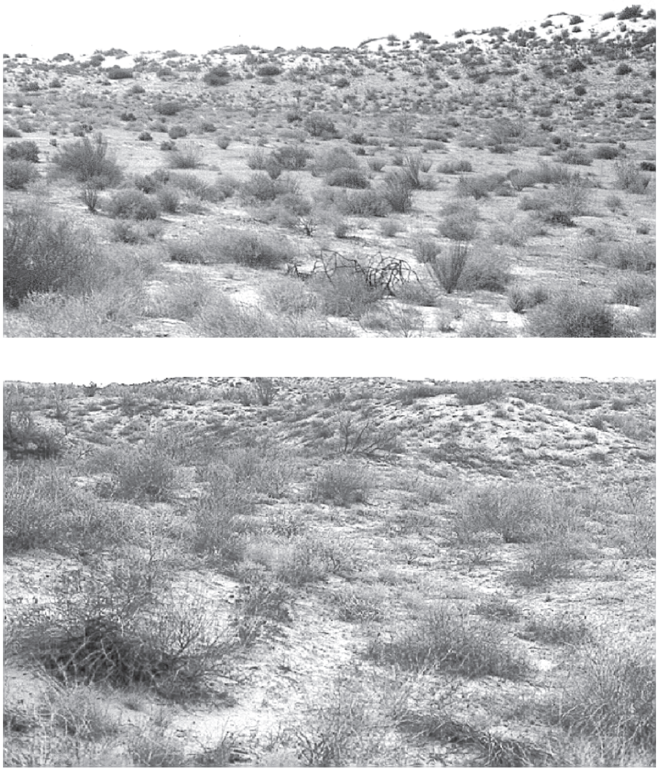

Fig. 30.14 *Top* Sand dunes in the Haluza sands in the eastern extension of the Sinai-Negev sand field, and *bottom* stabilised sand dunes of the Tengger Desert (Inner Mongolia, China)

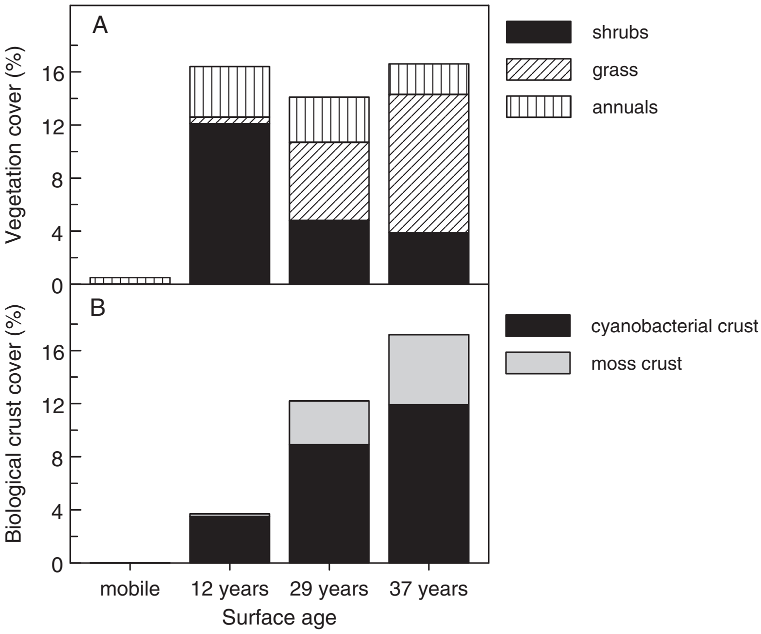

Fig. 30.15 Vegetation cover with shrubs, grasses and other annuals on mobile and stabilised sand dunes at the Shapotou experimental site in the Tengger Desert, Inner Mongolia, China (**A**) and a cover of cyanobacterial crusts and mosses (**B**), the plots representing different surface ages (0, 12, 29, 37 years in 1996; after Mitchell et al. 1998)

30.6 Restoration of Sand Dunes in Southern Africa

A major challenge for ecological restoration aiming to repair ecosystems with respect to their health, integrity and self-sustainability exists for arid and semi-arid areas, especially those of high biodiversity (Aronson et al. 1993). The Succulent Karoo and the Strandveld belong to the hotspots of biodiversity in arid regions, with a large number of endemic genera and species (Milton et al. 1997; Desmet and Cowling 1999a; Veste and Jürgens 2004). Sand dunes (Fig. 30.16) occur along the coastal belt of the Strandveld and up to 10 km inlands. The Strandveld receives 50–150 mm mean annual rainfall, the northern sand dunes between Port Nolloth and Alexanderbay 20–60 mm with rainfall predominantly in the winter months (Cowling et al. 1999). The vegetation consists mainly of succulent and non-succulent dwarf shrubs (Milton et al. 1997). Characteristic for the flora are the high numbers of Asteraceae, Mesembryanthemaceae, Crassulaceae, Eurphorbiaceae and other succulents. The conservation of this unique flora and fauna is a major task in recent South African environmental laws. Intensive livestock grazing leads to serious landscape degradation in the Strandveld. Furthermore, opencast mining for diamonds and other minerals is common in the sand dune areas of the Succulent Karoo and the southern Namib Desert ("Diamanten-Sperrgebiet").

Fig. 30.16 Succulent dwarf shrubs covering the sand dunes of the Succulent Karoo (photograph southeast of Alexanderbay, South Africa)

These mining activities have damaged vast areas of the sandveld succulent vegetation (Fig. 30.17), creating enormous dumping sites with overburden sands (Carrick and Krüger 2006). Huge-scale sand removal and relocation is characteristic for opencast mining. Mine pits produce unnaturally deep depressions. Strong southerly winds and intensive rain events are the main erosion forces in the Namaqualand lowlands. These extreme wind conditions, in combination with the low rainfall, prevent an autogenic recovery of the damaged sites (Carrick and Krüger 2006). Many of these disturbed sites are invaded by alien species. The consequences for the ecology of this unique biome have to date not been adequately assessed.

Since 1998, the Environmental Conservation Act limits environmentally damaging activities and requires that developers include the costs for ecological rehabilitation into their operational budgets. Natural vegetation has to be restored after mine closure. Positive experiences with seed collection and propagation of woody species were recorded in reclamation projects in the semi-arid fynbos. Often, technical approaches (cultivating, fertilizing, reseeding, irrigation) and exotic species were used in strip-mining restoration (Halbich 2003). However, such technical procedures failed in areas with rainfall below 200 mm year^{-1} (Milton 2001). For the conservation of biodiversity, the goals of restoration have to go beyond the stabilisation of damaged ecosystems, and the reestablishment of ecosystem services such as the control of sand movement and dust. The reestablishment of ecosystem function and self-sustaining vegetation cover in these sandy ecosystems is very important for biodiversity conservation. General principles for restoration

Fig. 30.17 Opencast diamond mining in the sand dunes between Alexanderbay and Port Nolloth damages the fragile desert vegetation of the sandveld

were adapted to the arid winter-rainfall areas (Table 30.1). After the failure with alien plants (cf. above), locally adapted indigenous plant species (e.g. Burke 2003; Anderson et al. 2004) have been successfully used for the restoration of sand dunes of the fynbos, Strandveld and southern Namibia. The re-vegetation of sand dunes can be based on a seed bank and seed dispersal. Therefore, different planting experiences were conducted to evaluate different planting designs for indigenous perennials (Burke 2003; Mahood 2003). Succulents were successfully relocated from pre-mined to post-mined areas. The reconstruction of vegetation structure is also important, and planting in multispecies clumps is recommended to increase survival under the environmental conditions prevailing in the Succulent Karoo (Blignaut and Milton 2005).

The approaches used by South African ecologists for the restoration of these ecosystems are focused on the reestablishment of ecosystem processes and functions (nutrient cycling, dispersal, recruitment). Animals also play an important role in supporting various rehabilitation processes. Indeed, they are the major pollinators, and import seeds and organic matter into the ecosystems. Burrowing rodents and insects improve soil fertility and soil permeability, with a positive effect on re-vegetation (Desmet and Cowling 1999b).

The South African experience emphasises also the importance of involving local communities in the planning, decision making and execution of successful projects (van Rooyen 1998; Milton 2001). The indigenous knowledge of local inhabitants can be useful to understand processes leading to desertification and also in selecting

Table 30.1 General principles for ecological rehabilitation in the arid and winter rainfall regions of southern Africa (after Milton 2001)

General principles
1. Set clear and ecologically and economically feasible goals for rehabilitation
2. Salvage living components of the ecosystem
3. Use locally adapted, indigenous plant and animal species
4. Retain and capture resources (organic matter, nutrients and water)
5. Mimic the original uneven shape of the landscape
6. Enable plants and animals to assist in the rehabilitation process
7. Do not rely on traditional agricultural and horticultural approaches
8. Keep good records of what works and what does not work
9. Budget sufficient time and money for rehabilitation

appropriate techniques for resource management. New scientific hypotheses can be based on such information. This will also promote public acceptance of rehabilitation measures and changes in land-use management.

30.7 Conclusions

The establishment of sustainable rehabilitation measures in sandy drylands requires the understanding of the main ecological processes governing these ecosystems. The Nizzana case study, as an excellent example, can here provide useful information about these ecological processes and their interrelations with vegetation patterns.

In this volume, various chapters on the geology, geo-ecology, geomorphology and land use, climate, flora, vegetation and fauna, as well as the formation of biological crusts give a sound basic knowledge of the Nizzana Sands system. The application of various remote-sensing techniques and many other methods to reveal ecosystem patterns and processes, such as topo-climate and micro-climate, including evaporation, transpiration and dew effects, to reveal aeolian sand transport and atmospheric input of dust, and to understand salt dynamics in soil, nitrogen input pathways, and runoff and erosion processes on dune surfaces and in dunes is a precondition in unravelling successional stages in the recovery processes of dunes on the crust and on the vegetation level, as well as interrelations between vascular plants and the crust and its spatial and temporal dynamics. This can also be seen in assessing plant water status, biomass distribution, and the vegetation patterning of perennials and annuals, as well as their heterogeneity and competition. Dynamic processes have to be seen in various temporal and spatial scales; extrapolation of observations and measurements along environmental gradients is an additional tool for a synthesis, and provides hints for sustainable management measures in such sensitive arid regions under climate change conditions. Thus, sand dune ecology has a strong importance for various applications in drylands.

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