

Diversity and ecology of soil lichens in the Knersvlakte (South Africa)

LUCIANA ZEDDA

Rheinische Friedrich-Wilhelms-Universität, Institut für Nutzpflanzenwissenschaften und Ressourcenschutz (INRES), Abt. Geobotanik und Naturschutz, KarlRobert-Kreiten-Straße 13, D-53115 Bonn, Germany
e-mail: luciana.zedda@uni-bayreuth.de

GERHARD RAMBOLD

Lehrstuhl für Pflanzensystematik, NW I, Universität Bayreuth, Universitätsstraße 30, D-95400 Bayreuth, Germany
e-mail: gerhard.rambold@uni-bayreuth.de

ABSTRACT. The lichen vegetation forming biological soil crusts is described for the first time for a semi-desert area of the Republic of South Africa (Knersvlakte, Namaqualand). Thirty-five terricolous lichen taxa were recorded. Fifty-two percent of the lichens are endemic to Namaqualand according to current knowledge. Squamulose and crustose lichens were the most common (over 60% of taxa) and most contained green algal photobionts. Three main communities were distinguished: 1) a widespread community composed by *Collema coccophorum*, *Psora* aff. *crenata*, *Placidium tenellum* and *P. squamulosum*; 2) a rare community characterized by foliose lichens belonging to *Xanthoparmelia*, *Neofuscelia* and *Paraparmelia*; and 3) a rare, crustose community formed by *Caloplaca* sp. (“*C. sp. 1*”), *Toninia* sp. (“*T. sp. 1*”), *T. ruginosa* and *Buellia* sp. (“*B. sp. 2*”). The lichen taxa and vegetation of the study area are unique and are threatened by land management practices and changing climate.

KEYWORDS. Lichens, biological soil crusts, vegetation, digital photography, Knersvlakte, Namaqualand, Republic of South Africa.



Soil-growing lichens are an important component of arid to semi-arid ecosystems where they contribute, together with bryophytes, algae, bacteria, cyanobacteria and non-lichenized fungi, to the formation of biological soil crusts. Biological soil crusts mostly cover the open space between higher plants, and ecologically function as a protective layer for the soil surface against wind and water erosion by binding soil particles together. They also contribute to soil formation by building up organic matter. In

addition, the lichenized and non-lichenized cyanobacterial components fix atmospheric nitrogen. Biological soil crusts are frequently used as indicators of ecological health of a given environment, and as indicators of long-term environmental shifts, such as climatic change. Moreover, these crusts are very sensitive to disturbance, and therefore suitable indicators of physical impact by livestock, human foot traffic or motorized vehicles (Belnap & Eldridge 2001; Belnap et al. 2001a, b). The indicator value of

lichens in desert and semi-desert environments has been recognized increasingly in the recent years. Most studies have focused on rangelands in Australian, North American and Near East regions where the emphasis has been on soil crusts dominated by lichens in rangeland evaluations.

In the Southern African region, there have been few detailed studies of soil-growing lichens. Several lichen species from the Knersvlakte (Namaqualand, Republic of South Africa) have been considered in recent taxonomic revisions, mainly members of the genera *Buellia* (Grube et al. 2005), *Catapyrenium* (= *Placidium*) (Breuss 1993), *Diploschistes* (Guderley & Lumbsch 1996), *Rinodina* (Matzer & Mayrhofer 1966), *Siphula* (Kantvilas et al. 2003), *Toninia* (Timdal 1991) and various genera of the Parmeliaceae (Elix 1997, 1999a–c, 2001, 2002; Esslinger 1977, 1986, 2000; Hale 1990). Among terricolous lichens from the Knersvlakte, a new type of squamulose growth-form with the thallus semi-immersed into the soil, called “Fensterflechten” (i.e., “window-lichens”) was described for the first time by Vogel (1955). These specially adapted taxa belong to the genera *Buellia*, *Diploschistes*, *Placidium*, *Endocarpon*, *Toninia*, *Eremastrella* and *Heppia*. A first list of species occurring on soil in the study area was given by Zedda and Rambold (2004), and is being completed in the present paper. Currently, ecological studies on lichens have been restricted to the Namib Desert and do not include the Western Cape Province. For instance, Schieferstein (1989), Schieferstein and Loris (1992), Wirth and Heklau (2006) and Wirth et al. (2007) investigated lichen soil communities in the Namib Desert along climate gradients, and Lalley and Viles (2005) explored communities of soil-growing lichens in the northern Namib. The floristic composition and structure of the lichen fields in the southern Namib Desert was described by Jürgens and Niebel-Lohmann (1995).

The present work represents a first contribution to the study of the diversity and ecology of lichens forming biological soil crusts in the Knersvlakte. It was carried out in the context of the BIOTA Africa project (www.biota-africa.org), with the main aim of assessing the diversity of soil lichens and their spatial and temporal shifts at selected sites. Special emphasis is given to the distribution of certain lichen characters

such as growth-form, chorology (geographical distribution of species) and photobiont type, which are known to be related to environmental parameters. Lichen communities were characterized for the first time, and their occurrence and richness examined under different micro-environmental conditions.

STUDY AREA

The Knersvlakte region is situated in the northwest of the Western Cape Province, in southern Namaqualand (Fig. 1). It is a moderately undulating coastal plain bordered by the Atlantic Ocean to the west, the Olifants River Valley to the south, the step scarp of the Cape Folded Belt to the east and the granitic-gneiss uplands of the Namaqua Metamorphic Province to the north. The area is underlain by shales, phyllites and limestones, and streaked by quartz gravel, sometimes covering as much as 100% of the ground surface. It has an elevation of about 150–250 m. The climate is semi-arid with long dry summers. The area receives an annual average winter rainfall (May–August) of 100–175 mm, and the annual mean temperature is 18.4°C (Schmiedel 2002; Schmiedel & Jürgens 1999).

The area belongs to the Succulent Karoo Biome which forms part of the Greater Cape Flora (Jürgens 1991; Werger 1978). The Knersvlakte quartz field flora comprises 67 obligate quartz field plant taxa, 94% of which are endemic to the area, and represents one of the richest centers of succulent plant diversity in the world. The vegetation within the quartz fields shows a clear pattern of small-scale mosaics of vegetation units, which are typically dominated by a single taxon, this being associated with different soil conditions (mainly soil conductivity and pH). The vegetation of the quartz fields differs considerably from its surroundings by its short stature, sparse cover and species composition dominated by leafy succulent vascular plants of the Aizoaceae. Many succulents are confined to the white quartz gravel, which reflects sunlight and is therefore cooler than the darker rocks and soil. Many of the succulents are dwarf and compact (Schmiedel 2002, 2004; Schmiedel & Jürgens 1999, 2002). The typical land-use type of the area is low intensity, rotational grazing with sheep and goats, at a recommended stocking rate of 12 ha per stock unit.

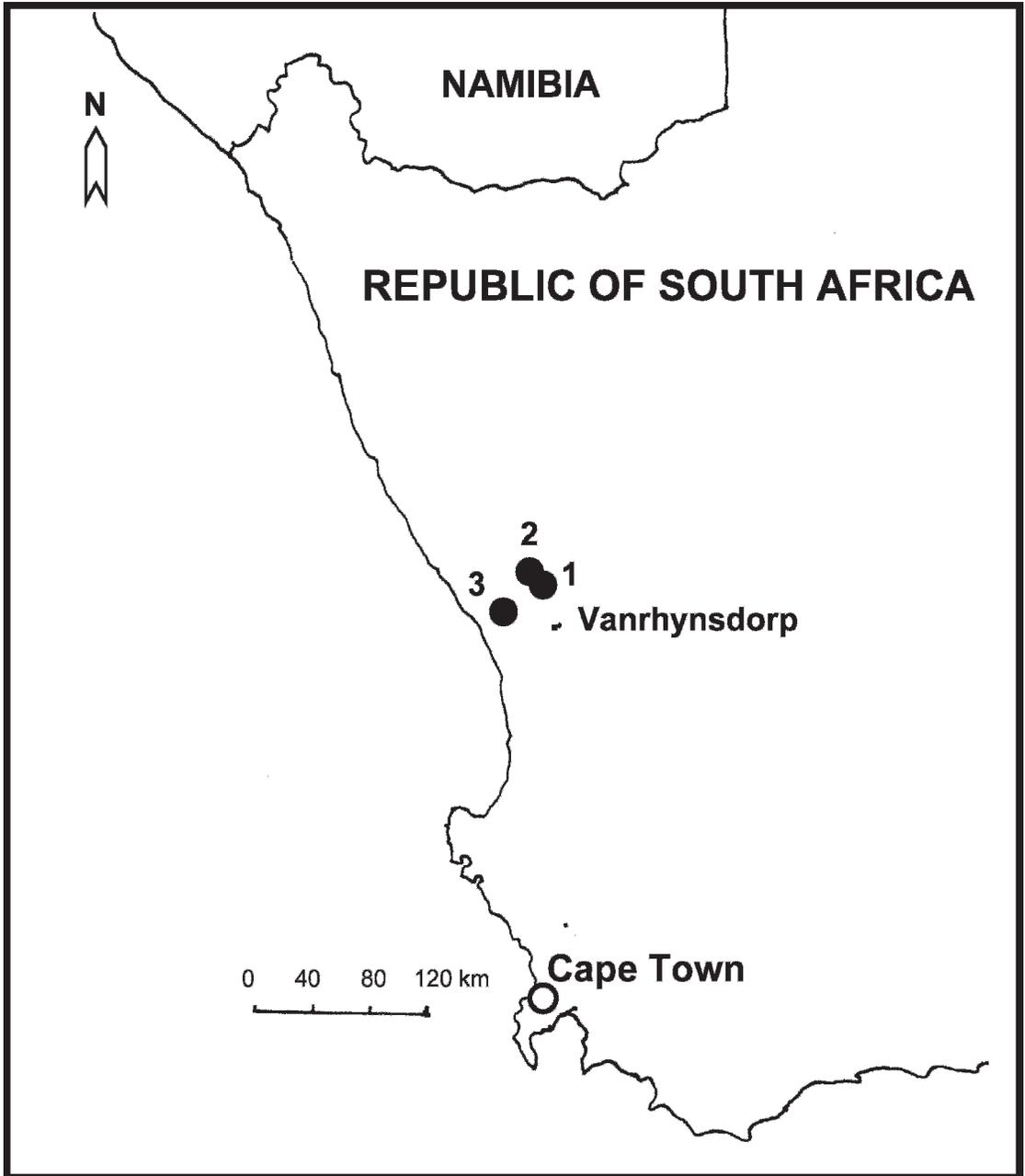


Figure 1. Map of southern Africa with location of study sites.

The following three sites were investigated lichenologically in the quartz field of the Knersvlakte (**Fig. 1**):

Site 1 (= BIOTA Biodiversity Observatory 26): Farm Flaminkvlakte 111 (also called Goedehoop), 31°17'S, 18°36'E. Vegetation type: mosaic of quartz field vegetation. Management: very extensive

rotational sheep farming with summer grazing in the Bushmanland.

Site 2 (= BIOTA Biodiversity Observatory 27): Farm Luiperskop (Ratelgat), 31°17'S, 18°36'E. Vegetation type: mosaic of quartz field vegetation. Management: rotational sheep farming with an average stocking of ca. 25 ha per small stock unit.

Site 3 (= BIOTA Biodiversity Observatory 28):
Farm Moedverloren 208, 31°27'S, 18°26'E.

Vegetation: mosaic of quartz field vegetation.

Management: Nature reserve without domestic animals since 2001; heavily grazed by sheep before 2001.

MATERIAL AND METHODS

A floristic survey was carried out in Mar–Apr 2001, and vegetation sampled in Nov–Dec 2002. All different lichen taxa occurring at the above listed sites (Biodiversity Observatories), having a surface of 1 km², were collected for identification. According to the monitoring approach followed by the BIOTA project, Biodiversity Observatories were divided into 100 one-hectare plots (Schmiedel & Jürgens 2005). Investigations of lichen vegetation were carried out at the center point of selected one-hectare plots of the three sites. Altogether, 65 vegetation plots having a surface of 2000–2500 cm² were examined applying the method described in Zedda and Rambold (in prep.). The following microhabitat types could be distinguished within the plots: 1) a mosaic of stony and bare soil with cover of quartz pebbles less than 50%; 2) hills and ridges with quartz pebble cover greater than 50%; 3) “river” beds with or without tall shrubs; and 4) a schist habitat, present at sites 1 and 2, with very sparse quartz cover. Plots were marked with metal pegs and coordinates taken in order to relocate the sites. Samples were examined in the laboratory using morpho-anatomical and chemical analyses, using descriptions and keys in Zedda and Rambold (2004), and with the help of experts for certain genera or groups. Lists of taxa occurring at the sites and at the selected plots are given in **Tables 1 and 2**.

The occurrence of lichen taxa in the examined 65 vegetation plots is reported in a matrix (**Table 2**). Binary data were sorted manually on the base of decreasing percentage occurrence of taxa (traditional vegetation analysis methods). Plots with similar species composition of their terricolous lichen-mycota were pointed out in this way. Data of the same matrix have been submitted to cluster analysis, using the freeware Biodiversity Pro V. 2 (McAleece et al. 1999). The similarity among groups was measured using the Bray-Curtis coefficient and the Complete

Link algorithm. Differences in cover among the sites were not analyzed in the present work. A correlation analysis was carried out with data from **Table 2** using Statistica V. 7. in order to point out the influence of microhabitat on lichen diversity. Results, reported in a correlation matrix, were considered significant at $p < 0.050$ (**Table 3**).

RESULTS

Lichen diversity. A total of 35 terricolous lichen taxa were recorded from the three sites. The highest alpha-diversity was found at site 1 (29 taxa), while sites 2 and 3 presented lower diversity (15 and 18 taxa, respectively). The most common lichens were *Collema coccophorum* (recorded in 62% of the plots), *Psora crenata* (40%) and *Placidium tenellum* (38%). As shown by the correlation analysis (**Table 3**), lichen diversity, expressed both in term of species richness and community richness, was most positively related to microhabitats 1, where quartz cover was lower than 50%. It was also favored by microhabitat 4 characterized by stable soil in a schist habitat. Microhabitats 2 and 3, on the contrary, had strong negative influence on lichen diversity, especially microhabitat 2, having high quartz cover.

Fifty-two percent of taxa were endemic to Namaqualand, 39% were widespread in both hemispheres (e.g., *Collema coccophorum*, *Heppia adglutinata* and *Placidium* spp.) and only 9% in the Southern Hemisphere (e.g., *Diploschistes hensseniae*, *Neofuscelia imitatrix* and *Toninia australis*). To the endemic group belonged species of the mainly foliose *Xanthoparmelia* and *Paraparmelia*, and so far undescribed taxa of *Acarospora*, *Buellia* and *Caloplaca*.

Squamulose lichens were the most abundant in the entire lichen-mycota of the three sites (38%), followed by foliose (31%), crustose (25%) and subfruticose (6%) lichens. Squamulose and crustose lichens (related growth-forms) comprised together over 60% of the lichen-mycota. Only 17% of lichens had cyanobacteria as their photobiont, while most of the species (83%) had green algae as a photobiont.

The terricolous lichen communities. Only 24 of the recorded 35 taxa occurred at the 65 plots in which vegetation sampling was carried out. By sorting data reported in **Table 2**, different groups of

Table 3. Correlations of species richness and community richness with the four microhabitats.

N=65	Correlations			
	significant at $p < 0.0500$			
Variable	Microhabitat type	Microhabitat type	Microhabitat type	Microhabitat type
	1-Quartz pebbles cover <50%	2-Quartz pebbles cover >50%	3-River beds	4-Schist habitat
Species richness	0.568	-0.516	-0.387	0.144
Community richness	0.556	-0.521	-0.416	0.194

lichens frequently occurring together could be pointed out. The first group (C1) was formed by crustose and squamulose *Collema coccophorum*, *Psora crenata*, *Placidium tenellum*, *P. squamulosum*, *Toninia lutosa* and *T. australis*. This corresponded well to Cluster 1 separated by cluster analysis at a similarity of 25% (Fig. 2). This group was defined as Soil Lichen Community 1 and was present in 65% of the sampling plots. The second group of species highlighted in Table 2 was composed of foliose *Xanthoparmelia leonora*, *X. simulans*, *X. sp. 1* (provisional name), *Neofuscelia* aff. *imitatrix* and *Paraparmelia prolata*, which also clustered in a separated group (C4) by the cluster analysis. This was named Soil Lichen Community 2 and occurred in 14% of investigated plots, usually together with Soil Lichen Community 1. A third group (C3) was characterized by *Diploschistes hensseniae*, *Toninia ruginosa* and by undescribed taxa of the genera *Acarospora*, *Buellia*, *Caloplaca* and *Toninia*, and corresponded to cluster 2 and 3 of the cluster analysis. This was called Soil Lichen Community 3 and it also occurred mostly with members of Soil Lichen Community 1. It was present in 20% of the plots. A large group of plots (28%) showed only one lichen species belonging to Soil Lichen Community 1 or no species at all.

DISCUSSION

Lichen diversity. The terricolous lichen-mycota of the three investigated sites is relatively rich in taxa when compared with other semi-arid areas. It is, for instance, much higher than in the well-investigated central Namib Desert, where 56 lichen species have been recently recorded along WE transects, on a much larger area than the one investigated in this work. However, only a small amount of these (6 taxa)

grows strictly on soil, while most of them are found on gravel or on quartz and dolorite pebbles and stones (Wirth & Heklau 2006; Wirth et al. 2007). Lalley and Viles (2005) reported 28 lichen taxa from biological soil crusts of the northern Namib Desert, eight of which grew on soil. In the southern Namib (lichen field of Alexanderbay, RSA), 31 taxa are reported by Jürgens and Niebel-Lohmann (1995), found on soil, pebbles and plants. Comparing data from other regions, 48 soil lichens are known from arid and semiarid Australia (Eldridge 1996). Considering that epiphytic and saxicolous lichens are also abundant in the Knersvlakte (pers. obs.), lichens therefore are a very important component of the ecosystem. Diversity is greatest at site 1, which is characterized by more extensive rotation sheep grazing in comparison with the other sites. Site 2 has the lowest diversity of soil lichens because of higher land-use impacts, i.e., higher average stocking rates. One possible explanation for the high lichen diversity of the study sites is the effect of fog and dew, due to the pronounced influence of the ocean system on climate. Soil features appear also to play an important role, since the greatest lichen diversity, both in terms of species and communities, is found in habitats with a lower cover of pebbles and a higher soil pH. According to Schmiedel (2002), stone cover is negatively associated with electrical conductivity (salinity) and positively with low soil pH in the quartz fields of the Knersvlakte. This could mean that soil-growing lichens prefer higher soil salinity and higher soil pH, which are also mostly positively correlated with higher soil carbonate content. These results are in agreement with data from other arid to semi-arid regions, e.g., southeastern Australia (Eldridge & Tozer 1997), and from other areas of southern Africa (pers. obs.). Also in the lichen fields

Bray-Curtis Cluster Analysis (Complete Link)

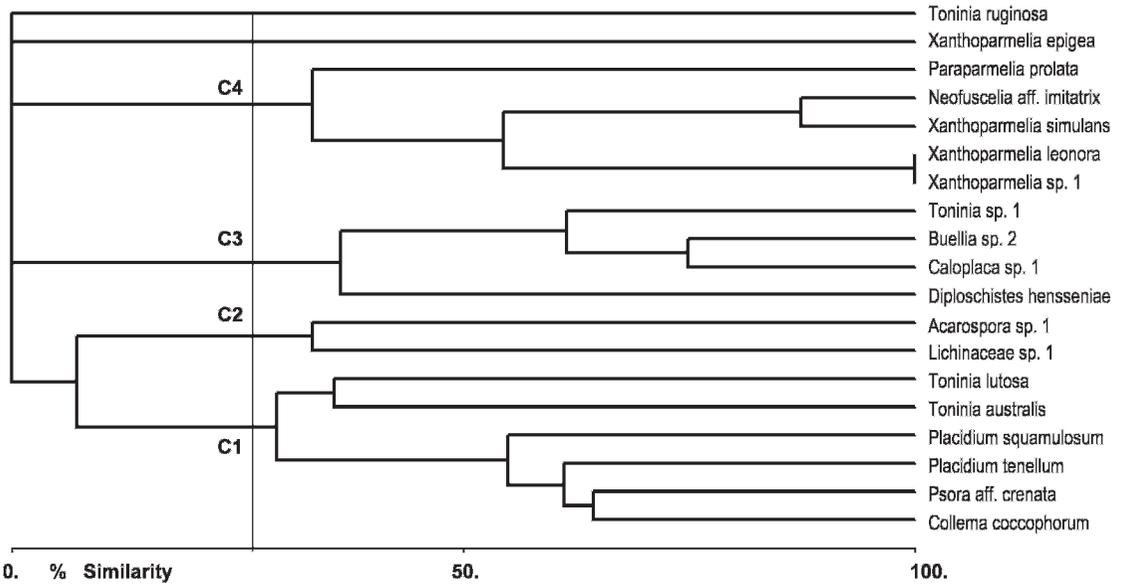


Figure 2. Cluster analysis of lichen taxa based on binary data of Table 2.

of Alexanderbay, soil salinity is positively correlated with lichen cover, while higher plants avoid these conditions (Jürgens & Niebel-Lohmann 1995). The lack of competition with higher plants could be therefore also an important driver of lichen diversity.

The level of endemicity in the sites of the Knersvlakte is very high in comparison to other areas of southern Africa. Wirth and Heklau (2006) found, for instance, about 27% endemism among the species in the terricolous and saxicolous lichen-mycota of the central Namib Desert. As reported by several authors for different regions, lichen taxa are, in contrast to flowering plants, usually widespread and only rarely endemic to a given area. The endemic component of the mycota treated in this study is restricted to Namaqualand, and—according to present knowledge—in some cases to the quartz fields of the Knersvlakte. Most of the collected taxa however have so far been collected in few samples, and/or have been described for the first time from the Knersvlakte. Thus, their true distribution is difficult to estimate and their range might be much wider within southern Africa.

The greater frequency of squamulose and crustose lichens suggests a tolerance of low precipitation and high temperature. Some taxa grow

partly immersed in the soil (“window-lichens”), others are considered as “pioneers,” as they are able to recolonize soil after disturbance more rapidly than foliose and fruticose lichens (Belnap & Eldridge 2001; Belnap et al. 2001b). The relative high percentage of foliose lichens is noteworthy for semi-arid areas, and can be related to the frequent occurrence of fog and clouds, especially in the early morning hours (pers. obs.). The high percentage of lichens with green algal photobionts also suggests the presence of a climate characterized by relative high air humidity and frequent fog events. Desert habitats characterized by fog and dew are thought to favor phycolichens, whereas lack of dew, less rain and higher temperature favor cyanolichens (Belnap et al. 2001b).

The terricolous lichen communities. Soil Lichen Community 1 is the most frequent community at the investigated vegetation plots. It is formed by species which are common and widespread in southern Africa (Zedda et al., in prep.) and is probably the first community to colonize soil after disturbance. However, the process is expected to be relatively slow, and cyanolichens, which are pioneer, ubiquitous species, dominant on degraded or recovering sites where crust cover is sparse (Eldridge 1998; Eldridge & Koen 1998), could be the first lichens colonizing the area after cessation of

disturbance. As shown in the results, in several plots, only the cyanolichen *Collema coccophorum* is found. This might be indicative of greater or more recent disturbance in comparison to plots which are more rich in lichens. Green algal species, on the contrary, need longer ecological stability. It is known, for instance, that *Psora crenata* tends to be more common on relatively undisturbed sites (at least 60 years without human disturbance), and absent from disturbed sites of arid South Australia (Eldridge & Ferris 1999). In the Knersvlakte, Soil Lichen Community 1 is mostly present in the mosaic of quartz-open soil where the cover of quartz pebbles is sparse, and is bound to relative high soil pH, calcium carbonate content and salinity (pers. obs.). It could be therefore regarded as an indicator of these particular soil conditions. This community has affinities with the widespread *Collema-Placidium-Psora* communities reported from other arid to semiarid regions (e.g., Eldridge 1996). The range of some of the species forming these communities (e.g., *C. coccophorum*, *Placidium squamulosum* and *Psora decipiens*) is wide as reported by Belnap et al. (2001a, b). Most of them prefer sites with gypsiferous soil or soils with high calcium carbonate content, high pH and sparse vascular plant cover in arid North America and southern Australia (Rogers 1977).

Soil Lichen Community 2 is characterized by rare foliose lichen species which are endemic to Namaqualand. It can occur together with Soil Lichen Community 1, and is also restricted to sites with sparse quartz cover and relative high soil pH. This community may represent a later stage of the former one, since it is composed of taxa with relatively slow growth-rates (Eldridge & Koen 1998; Eldridge & Rosentreter 1999). It appears to be restricted to less disturbed conditions, since it is rarely found at site 2, which is characterized by more intensive land use. This finding is in accordance to that of Eldridge and Koen (1998) and Eldridge and Rosentreter (1999), who reported that soil-inhabiting *Xanthoparmelia* communities of arid to semiarid areas of eastern Australia are found associated with stable sites under extensive rangeland conditions, with a low rate of trampling by animals. Being dominated by foliose species, this community relies heavily on higher humidity, and is therefore most threatened by global climate changes.

Soil Lichen Community 3 is also rare and formed by several species new to science, whose ecology is not much known so far. It is restricted to soils with very sparse quartz cover (1–5%), being composed of fine-grained material originating from schist. This community is therefore indicative of very particular soil conditions, and consequently sensitive to any changes of soil, which can be caused by increasing grazing or by global climate change.

The large group of plots which had no lichens or only *Collema coccophorum* are situated on hill slopes and ridges having a high cover of quartz pebbles (51–100%) or in dry river beds, where the cover of quartz pebbles is sparse but disturbance is greater, due to floods during the rainy season.

CONCLUSIONS

The Knersvlakte has an extraordinary and peculiar diversity of lichen taxa and communities which is even greater than the one of the lichen fields of the Namib Desert. This diversity is supported by the unique climatic and soil conditions of this area, in particular the high relative humidity and frequent fog events, the high soil pH and soil salinity, and appears not to be threatened by very extensive farming such as at site 1. The occurrence and diversity of the recorded lichen species and communities give therefore important information on environmental conditions and stability.

The main impacts which are likely to have negative influence on soil lichens of the Knersvlakte are climatic changes and modification in land use intensity. Global climatic change will likely cause a shift in the composition and distribution of the soil lichen taxa, and we expect the main effects to be: 1) reduction of lichen richness, with a loss of the those morphological types being most sensitive to aridity, i.e., the foliose lichens; 2) loss of endemic taxa caused by changes in air humidity and 3) colonization by globally widespread cyanolichens typical of community 1. Increasing land use (i.e., stocking rates greater than the recommended ones) is also expected to reduce lichen cover and species richness.

The great number of species occurring and the extent of endemic taxa, including several undescribed species, make this area unique and provide incentives for giving it special conservation status.

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