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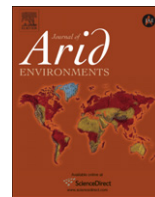
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Short Communication

Distribution patterns of soil lichens across the principal biomes of southern Africa

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ABSTRACT

The present study was undertaken to assess baseline distribution patterns for soil lichens occurring in the principal biomes of southern Africa, and to analyse their relationship to selected environmental parameters. Among the lichen species found across our survey sites, four distinct groups could be delineated, each as distinct consortium of lichen species sharing particular morphological characters (e.g. growth-form, pigmentation and type of photobiont kind). These groups are largely correlated with specific environmental parameters. These findings suggest that lichens may serve as valuable bio-indicators for evaluating climate and soil change in this region of Africa.

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1. Introduction

Biological soil crusts are a significant part of the biodiversity of many ecosystems in arid to semi-arid regions of the world. They play an important role in soil stabilization and contribute to soil fertility and formation (Belnap et al., 2001; Hammond, 1995). Lichens are a considerable component of biological soil crusts and their diversity is potentially threatened by global climate change, especially in species-rich regions of the world, such as southern Africa (Evans et al., 2001). Understanding and predicting the response of species to climate change is essential for devising long-term conservation strategies (Hannah et al., 2002). Since the water status of lichens varies passively with surrounding environmental conditions, lichens are closely associated with climatic conditions and can be affected by changes in atmospheric moisture and temperature (Ellis et al., 2007). Numerous studies carried out in the Northern Hemisphere demonstrate the value of lichens as indicators of climate shifts, especially in temperature and precipitation

(Cezanne et al., 2008; Insarov et al., 1999; Insarov and Insarova, 2002; Insarov and Schroeter, 2002). Soil texture and chemistry are also known to strongly influence lichen species composition in North America and Australia, where more stable, fine-textured soils support greater cover and biodiversity (Eldridge, 2001; Rosentreter and Belnap, 2001). For most lichen species or communities in southern Africa, the most important drivers of diversity are largely unknown and accounts of lichen distribution patterns across biomes or climatic gradients are limited. In the past, most biodiversity investigations focused on isolated case studies, the results of which cannot be extrapolated to other ecosystems (Jürgens and Niebel-Lohmann, 1995; Schieferstein and Loris, 1992; Lalley and Viles, 2005; Wirth et al., 2007; Wirth and Bungartz, 2009; Zedda and Rambold, 2009). Extrapolations are, however, indispensable for understanding ecosystem processes which promote and maintain biodiversity (Colwell and Coddington, 1994; Schmiedel and Jürgens, 2005). A preliminary overall study comparing the diversity of lichens in the main biomes of southern Africa was provided by Zedda and Rambold (2004).

The study reported here was undertaken to assess distribution patterns for soil lichens occurring in the principal biomes of Namibia and western South Africa, and analyses the relationship among lichen species and selected environmental parameters (climate, soil, altitude) in order to understand ecological preferences of lichens in

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the study area. This work is a first contribution to knowledge of the distribution and ecology of lichens forming biological soil crusts in southern Africa, and provides baseline information for future monitoring of ecological changes associated with global climate changes.

2. Material and methods

Investigations were carried out in Namibia and in the western part of the Republic of South Africa along a climatic transect which covers the Fynbos, Succulent Karoo, Nama Karoo, Savannah (including tree and shrub Savannah, i.e. the Kalahari woodlands) and Desert biomes (Fig. 1). These biomes were described by Rutherford and Westfall (1994) and also investigated by other authors (Desmet and Cowling, 1999; Graz, 2006; Jürgens, 1991;

Mendelsohn et al., 2002; Mucina and Rutherford, 2006; Walter, 1986; Werger, 1986). Their occurrence is related to latitude and to the distance from the Atlantic coast.

Investigation sites (“observatories”) were set up along a north-south climatic transect of about 1800 km, in the context of the BIOTA project (www.biota-africa.org). These are 1 km × 1 km (1 km²) in size and are subdivided into 100 1-ha plots for biodiversity monitoring at different scales (Krug et al., 2006; Schmiedel and Jürgens, 2005). For the assessment of lichen diversity, 29 sites were investigated (Fig. 1). The methods for sampling and compiling community data were previously described by Zedda and Rambold, (2004). Briefly, the plots were surveyed and all lichen species found were identified. From these data, a community matrix was assembled that indicated the presence/absence of each lichen species across the plots sampled (Table 1).

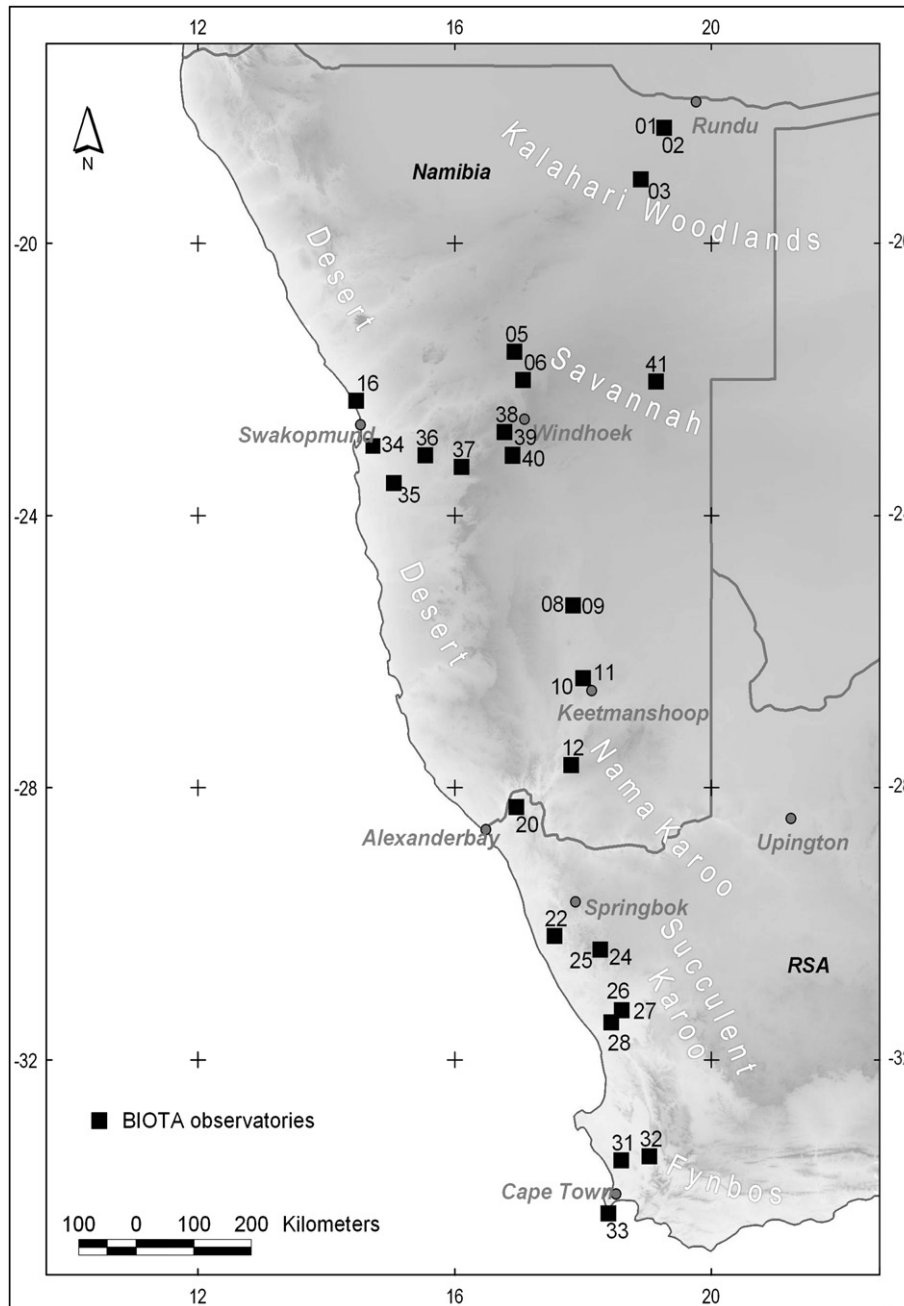


Fig. 1. Map of study area with location of investigation sites.

For soil analysis, 25 1-ha plots were chosen randomly in the different strata and surveyed with one profile each, 4 m south of the centre point of each 1-ha plot. Soil samples were air-dried and sieved to < 2 mm. Soil pH was analyzed by adding 0.01 M CaCl₂ with a 1: 2.5 relation (10 g dry weight + 25 ml solution) with a pH-electrode after 1 h with repeatedly stirring of the suspension. The electrical conductivity of the soil solution was measured using aquademin as solvent (Reeuwijk, 2002). Average values for soil pH and EC were calculated for each investigation site.

Most of the climate data were gathered by the BIOTA project at each site during the period 2001–2009. Monthly and annually average values of rainfall, temperature and air humidity were calculated for the same period, and the climatic datasets of Schulze (1994) and of Mendelsohn et al. (2002) were consulted for South Africa and for Namibia respectively, when BIOTA data were not available.

The matrix with binary data on lichen presence/absence was sorted according to frequency and co-occurrence at the same sites, in order to identify groups of species. Correlations were analysed among single lichen taxa (presence/absence data) and environmental parameters characterizing the investigated sites, with the STATISTICA software package (Vers. 7) and using the non-parametric Spearman R coefficient. Results are reported in Table 1, where only species with an absolute frequency of at least 2 are shown. The most rarely occurring species (35) have been excluded from the matrix, but the entire list of species can be found in Zedda et al. (2010). The following parameters were considered for the analysis: rain (mm/y), altitude (m a.s.l.), temperature (°C), air humidity (%), soil pH and electroconductivity (EC) and rain system (winter vs. summer rainfall).

3. Results

Four main ecological groups of lichen species were determined by sorting the matrix of the most commonly occurring lichens (Table 1). Lichen species group **G1** is only represented by green algal lichens, having crustose, squamulose or foliose growth-form, and various pigmentation of the dry thallus. G1 is most common in the Succulent Karoo and some elements of it have been recorded also from the Fynbos biome (Table 1). Lichen species group **G2** is predominantly formed by cyanolichens, with peltate, squamulose or small foliose thallus, and in all cases is darkly pigmented. G2 is most frequent along the transect in the Savannah biome. Only two species of this group were found in the Succulent Karoo (*Collema tenax* and *Peltula patellata*). Lichen species group **G3** is most frequent in the Succulent Karoo, but was also reported from the Fynbos and from the Savanna biomes. G3 is formed by cyano- as well as green algal lichens having reduced growth-form (small foliose, fruticulose and squamulose). Thallus pigmentation is dark (brown to black), with the exception of *Psora crenata* with pinkish-brown thallus surface.

Another lichen species group (**G4**) was identified at two sites of the Namib Desert, and is formed by the species *Acarospora* sp. 2, *Lecidella crystallina*, *Toninia* sp. 1 and *Xanthoparmelia walteri*. These species have morphological affinities with those of G1 since they are also represented by green algal lichens, with crustose to foliose growth-form.

The globally distributed species *Cladonia symphycarpa* is only found at two sites of the study area (Fynbos biome). **G0** describes a condition without any soil surface lichens, a situation most frequently observed in the Nama Karoo, followed by the Savannah and the Fynbos biomes.

From the correlation analysis (Table 1), it is evident which topographical and ecological factors are most strongly related with the distribution of the various taxa. The majority of the species

forming G1 are found in winter rain areas and are related to elevated soil salinity and to increased air humidity, while they are in a few cases negatively related to higher temperature and to increasing altitude (which indirectly indicates increasing distance from the coast). Members of G2 are linked positively to increased altitude, while correlations with other factors are less significant. Similar to G1, the lichens of the group G3 are negatively related with increasing temperature and positively to EC, with a few species being positively related to higher air humidity. The species of G4 are positively related to air humidity, and negatively to rainfall. Some of the species are also negatively correlated with temperature and altitude, but relationships are weak, probably due to the low number of only two sites hosting this community. Occurrence of *Cladonia symphycarpa* is positively linked to increased air humidity and winter rain, but negatively to higher soil pH and elevation. The absence of lichens in given sites is associated with increased temperature, low air humidity and summer rainfall.

4. Discussion and conclusions

The considerable latitudinal extension of the investigated sites and the consequent macroclimatic differences result in strong floristic differentiation among the soil lichens of southern Africa. The main climatic factors relating to lichen species distribution are air humidity, temperature and the rainfall system. The results suggest that increasing rainfall is only positively related with a small number of species (e.g. *Cladonia symphycarpa* and cyanolichens), but that a strong reduction in rainfall corresponds with lichen absence, especially when other water sources like fog or dew are scarce. Well-defined ecological lichen groups can therefore be distinguished in the various biomes, and the lichens of the different groups share morphological similarities, even if represented by often phylogenetically unrelated species. The dominance of green algal photobionts and the presence of foliose growth in ecological group G1 are indicative of elevated air humidity, since green algal lichens are able to use extremely small amounts of water for photosynthetic activity in desert areas, and to use water vapour for reactivation, and foliose lichens are known to be bound to more humid conditions as well as the fruticose ones (Belnap et al., 2001; Nash, 1996). The species typical of the Namib Desert (G4) present also the same traits, but are found under a summer rainfall system.

Species of G3, sharing cyano- as well as green algal lichens, result to be more widespread than G1 along the transect and can also occur at higher elevation. They are negatively related to increased average temperature and appear to require certain air humidity to survive, or at least dewfall. Members of this ecological lichen group have also been reported as common and ubiquitous in dry inland sites of other semi-arid regions of the world (Belnap et al., 2001; Rogers, 2006).

Species in group G2 are most common in the northern part of the transect and are associated with increased altitude, since the Savannah sites, where these species are frequent, are located on the elevated inner African plateau. Altitude may also have an indirect positive influence on dewfall occurrence, due to lower temperatures during the night. To date, no dewfall data are available from these sites, but the phenomenon was frequently observed in the field at early morning hours. According to Rogers (2006), dew formation may also occur beneath the upper surface of arid soils by vapour transport from deeper soil layers, which is likely to be a significant process for the survival of soil lichens. Dewfall appears to be an important water source in the Savannahs, which have no fog events and low air humidity. Squamulose and peltate lichens are more frequent in this lichen ecological group thanks to the evolution of a more or less concave growth-form, which is expected to substantially absorb more water during rainfall or dew

precipitation (Vogel, 1955). The darker pigmentation, most frequent in these species, apparently gives greater resistance to higher temperature and to intensive solar radiation (Gauslaa and Solhaug, 2001; McEvoy et al., 2007). Similarly, more prostrate lichens with cyanobacterial photobionts have a higher rate of species in the less humid parts of subtropical Australia (Rogers, 2006). The globally distributed species *Cladonia symphylicarpa* is typically found only in the Fynbos biome in the study area, probably because of greater rainfall and sandy soils in this biome. But its occurrence is considered as ecologically important, as *Cladonia* spp. usually grow on soil types and in climatic conditions, that differ from those of other above-listed species.

Unsuitable climatic conditions tend to correspond with lichen absence, as it is evident in the Nama Karoo where air humidity is reduced and temperatures are greater than in other regions. Similarly, species are lacking in other dry regions of the world with similar climatic conditions (Eldridge, 2001; Rogers, 2006). The absence of lichens in other biomes along the transect, which because of the suitable climatic conditions could potentially host lichens, is to be related to the unfavourable soil conditions.

Except for a few species, the calculated relationship of lichens with soil pH is weak but the relationship with soil salinity is significant for lichen ecological groups G1 and G3. There are several possible explanations for this positive correlation. 1) The relationship could simply be indirect due to the particular climatic conditions of the sites investigated in the Succulent Karoo, which are close to the coast and have saltier soils and low rainfall (Schmiedel, 2002; Petersen, 2008). 2) The occurrence of lichens may be related to the high calcium carbonate content and EC of salty soils, both of which result in reduced clay dispersion and thus greater stability of soil aggregates. 3) The preference of lichens for soils with high salinity could also be explained by a reduction of the competitive pressure of higher plants and by their higher salt tolerance (Nash and Lange, 1988). 4) A direct use of salts in aerosols for water capture may be possible as demonstrated by Follmann (1967).

The relationship among climate and soil features, and distribution patterns of lichen soil crusts observed in southern Africa is noteworthy. Other studies carried out in the same study area showed that lichen species' richness and cover, measured at hectare plot level, are also positively related to lower temperature, higher altitude and increased water availability (Zedda et al., 2010, Zedda et al., in press). As pointed out by different authors, currently winter rain dominated arid areas of the world are predicted to receive increased summer rain in the future as a consequence of global climatic change (Belnap et al., 2001). This change will most likely also affect southern Africa, where climate simulations indicate progressive extension of wetter summer rainfall and drier winter rainfall regions accompanied by winter drying along the coast (Mackellar et al., 2007). Shifts in soil lichen composition and diversity can therefore be expected, and will most probably lead to a dominance of common, globally distributed taxa, since these are more common in summer rainfall sites of the study area. In the same sites a decrease of biological soil crust diversity and cover may be caused by changes in vascular plant cover (Belnap and Lange, 2005). A loss of rare endemic species from the foggy coastal sites can be predicted by increasing aridity.

Nature conservation efforts may benefit from the examination of lichens, previously often neglected in predictive modelling of environmental change scenarios. In particular, the ecological effects of changes in air humidity, dew conditions, rainfall system and temperature could be monitored by using lichens as bioindicators. As changes in temperature or water availability will potentially lead to shifts in lichen communities, the investigated sites could be periodically monitored to analyse changes in lichen species richness, cover and composition. The advantage of a permanent sampling of

lichens in contrast to climate monitoring is that: 1) no daily measurements are needed; 2) lichens are long-living, stationary and widespread organisms; 3) lichen monitoring may be a cost-effective way to compensate for gaps in direct measurements at climatic stations and for the poor spatial coverage of stations, particularly evident in sparsely populated arid regions (Mackellar et al., 2007; Insarov and Schroeter, 2002).

Long term monitoring of lichen groups could therefore easily provide an early warning of ecological responses to climate change in southern Africa.

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