LICHENS

AND THEIR IMPORTANCE FOR THE MONITORING OF ENVIRONMENTAL CHANGES IN

SOUTHERN AFRICA

WITH SPECIAL REFERENCE TO SOIL-INHABITING LICHENS

LUCIANA ZEDDA • GERHARD RAMBOLD

BIOTA Subproject S04

University of Bayreuth, Germany

BIOTA Southern Africa

Address of authors:

Dr Luciana Zedda, Prof. Dr Gerhard Rambold

University of Bayreuth, Chair of Plant Systematics & Ecology, NWI
Sect. Mycology, Universitätsstraße 30, 95440 Bayreuth, Germany
Tel: +49 921 552455
Fax: +49 921 552567
luciana.zedda@tiscali.de
gerhard.rambold@uni-bayreuth.de

Project financially supported by BMBF (Federal Ministry of Education and Research)

Federal Ministry
of Education
and Research

Project Management Agency: DLR (Deutsches Zentrum für Luft- und Raumfahrt e.V.)

pt
Projektträger im DLR

Brochure available in print format and as PDF-file from the authors

Contents

1. Introduction

Lichens are the object of investigation within the framework of the BIOTA Southern Africa project, subproject S04 (http://www.biota-africa.org). This interdisciplinary research project, installed in 2000, focuses on the analysis of biodiversity and its changes along climatic and vegetation gradients (transects) in Namibia and in the Republic of South Africa. In the context of this project, studies on the diversity of lichens are carried out. Special reference is given to the monitoring of lichens growing on soil, which form the so called biological soil crusts. Lichen diversity is assessed and analysed with respect to its spatial and temporal changes. These are related to various abiotic and biotic factors such as climate, soil features and land use. The indicator value of certain terricolous lichen taxa and/or lichen groups (communities) is investigated for the study area, and it is intended to use it in a future long-term monitoring programme in the region. In this brochure, we whish to explain what lichens are, how do they live and where do they grow, and why they are so important as bioindicators in arid and semi-arid areas of the world. The activities of the S04 subproject along the BIOTA transect are described, as well as the methods used for monitoring environmental changes in Southern Africa using soil-inhabiting lichens.

2. What is a lichen?

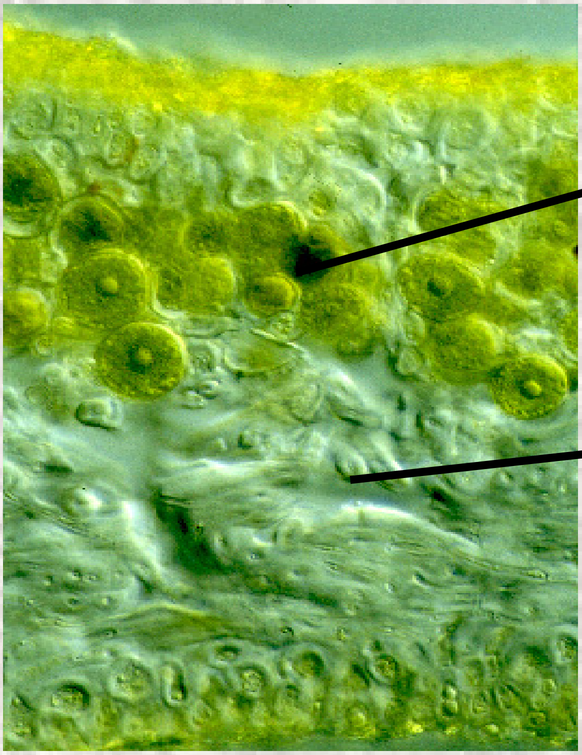
Lichens are commonly considered to be plants or are often mistaken as mosses. Actually, they are unusual, since they do not represent single organisms, but rather a combination of two or more organisms living together in a so-called symbiotic or mutualistic relationship. The participating bionts of the system are one species of a fungus (i. e. the mycobiont) on the one hand, and a green algal and/or a blue-green algal species (cyanobacteria) (i. e. the photobiont), on the other hand.

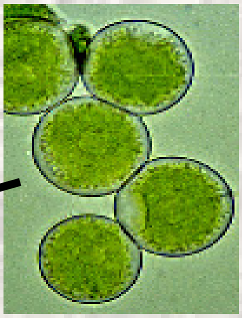
Each partner contributes in different ways to the symbiosis:

The mycobiont protects the photobionts from intense insolation and dehydration, and absorbs mineral nutrients from the sub-stratum and the atmosphere.

The photobionts synthesise organic com-pounds by the photosynthetic process (green algae as well as cyanobacteria) and produce organic nitrogen compounds by nitrogen fixation (cyanobacteria).

The vegetative layer (i. e. the thallus) of most lichens is composed of fungal filaments, between which algal or cyanobacteria cells are embedded. Occasionally, the fungal and algal species, which usually build up the lichen jointly, may each be found living in nature without their partner, but a fungus without capabilities to survive on its own is involved in most lichen associations, due to its strong dependency on the algal partner.





Cells of a green-algal photobiont

Fungal hyphae

Microscopical view on section through the complex thallus of a (foliose) lichen species.

The lichen partnership enables both partners to survive under extreme conditions in which other organisms usually can not live, such as in hot and cold desert environments. In all cases, though, the appearance of the fungus in the lichen is morphologically quite different in comparison to separately growing individuals. Also we can better define a lichen as a “lichenised fungus” with a highly specialised nutrition system. Around 20% of all fungi are lichenised and can usually not live without the algal partner.

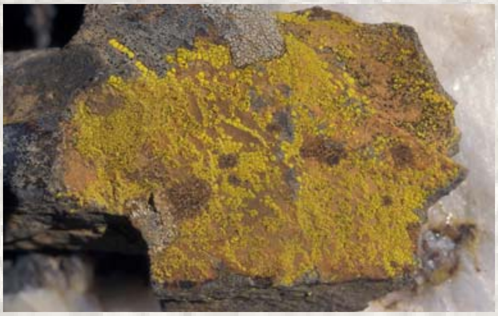
Thin sections of the vegetative layer of the lichen under the light microscope may either reveal a simple association of fungal hyphae and algal cells, with little structural differentiations, or well-defined and complex structures. In the latter case, different layers may be distinguished: the upper cortex, composed of closely packed fungal cells, the algal layer with algal cells and mycobiontal hyphae, the medulla, formed by loosely packed hyphae, and the lowest part of the thallus, called the lower cortex.

Lichens can have root-like structures, so-called rhizoids with the function to attach the thallus to the substrate. Some species are covered by cilia, which are fibrillar outgrowths from the margins or the upper surface of the thallus.

3. What do lichens look like?

Lichens are very variable in shape, size and colour. The various lichen species are distinguished by different and characteristic shapes, i. e. '**growth-forms**'. The appearance of lichens is usually determined by the fungal partner, the resulting structure being called a "**thallus**". Three main growth-form types are normally distinguished: the crustose, the foliose, and the fruticose one. Lichens of different growth-forms often differ in their ecological preference (e.g. with respect to the micro- or macroclimatic conditions). Therefore, it is very important to record this information on lichens of a given area during tha monitoring work.

Toninia lutosa. – a crustose species growing on soil and widespread throughout the Succulent Karoo.

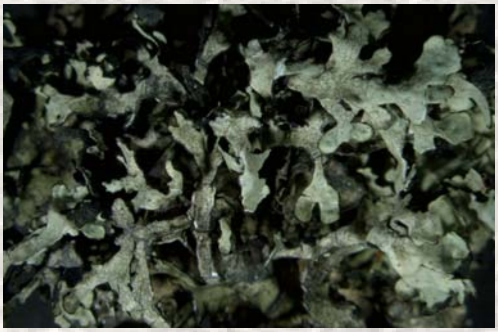


Acarospora sp. – a crustose species growing on rock.

Psora aff. *crenata* – a squamulose species growing on soil and widespread throughout the Succulent Karoo.

Crustose lichens are tightly attached to the substrate with their lower surface, e.g. a piece of rock or a stone, so that it is not easy to remove them without destructing the substrate. Lichens with this growth-form often tolerate extreme habitats such as bare, exposed rock surfaces or arid soils. When growing on inclined rock surfaces, they may profit from surface water flow. Among the various species, a wide range of subtypes can be observed within this major growth type however. For instance, crustose lichens can have a powdery surface, or present squamulose or peltate structures, or may exhibit no structures at all due to their growth inside soil, rock or bark. Lichens with overlapping scale-like squamules (squamulose) or presenting a more or less central attachment area on the lower side of the thallus (peltate) are characterised by thalli with partially detached undersurface and, often occurring in hot and arid regions of the world. A special form of crustose lichens is given by the so-called "window lichens" ("Fenster-flechten" in German), which grow more or less completely immersed in the soil, exposing only their flat upper surface. This form is also very common in semiarid to arid regions of the world.

Foliose lichens have a leaf-like shape of the thallus, are flat and only partially attached to substrate. The upper and the lower surfaces of thallus typically differ one another. The leaf-like thallus is often divided into subunits called 'lobes' with various degrees of subdivision. Also foliose lichens develop a great range of thallus size and subforms. A special type for instance is the umbilicate form, the more or less circular thalli being attached to the substrate by a central umbilicus of the lower surface.



Xanthoparmelia walterii. – a foliose species growing in the Namib desert.

Xanthoparmelia spp. – foliose lichens growing on soil in the Succulent Karoo.

Fruticose lichens are hair-like, strap-shaped or shrubby and subunits (or ramifications) may be flat or cylindrical. They are attached to the substrate by the morphologically basal part of the thallus. Upper and lower surfaces can be distinguishable or not. Fruticose lichens usually require higher air humidity to survive and are mainly restricted to sites where fog and dew are frequent events. Along the BIOTA transect, they are mostly found close to the Atlantic coasts, due to the effect of the Benguela flow.

Teloschistes capensis. – a fruticose species growing in the Namib desert.

Shrubs of *Teloschistes capensis* on soil in the lichen fields of the Namib desert.

The **size** of lichens is very variable; some species only have a diameter of a few millimeters, others can reach a few meters length.

The lichen thallus is often brightly coloured, and can be more or less dark or pale, black, brown, grey, green, yellow, orange. The **colour** is due to a various kinds of secondary metabolites (pigments), which are produced by the lichen in order to protect itself mainly against insolation. The colouration of the thallus is often specific at species or genus level and can therefore be used for identification purposes.

Acarospora sp. – yellow, crustose thallus growing on rock in the observatory Numees (Richtersveld National Park).

Peccania subnigra – black, small fruticose thallus growing on soil in the observatories of the Succulent Karoo.

Caloplaca namibensis – orange, crustose-placoid thallus growing on pebbles in the observatory Wlotzkasbaken (Namib Desert).

Haematomma sp. – whitish-brown, crustose thallus with red apothecia growing on twigs in observatory Roscherpan.

Ramalina celastri – Fruticose, yellowish-green thallus, growing on twigs in the observatory Roscherpan.

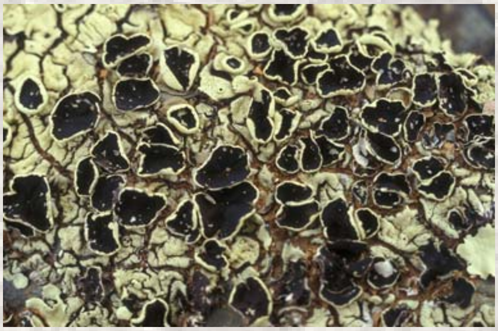
Crustose lichens with differently coloured thalli on rocks in the observatory Wlotzkasbaken (Namib Desert).

4. How do lichens reproduce?

Many lichens reproduce **sexually** by fruiting bodies. These are of different shape in the different relationships, and may either be flattened, semi-globose or elongated (apothecia), flask-shaped (perithecia), or more or less stalked.

Apothecia are spore-bearing fruiting bodies that are cup- or disk-shaped. Two main morphological types are distinguished. Apothecia with a margin originating from the thallus are called “lecanorine”. In other cases, where the margin develops from the tissue of the fruitbody, it is called either “lecideine”, when the margin is dark pigmented (carbonised), or “biatorine” when it is pale.

Perithecia are globose to flask-shaped fruiting bodies, which are more or less immersed in the thallus layer or into the substrate, and open with a small pore- or tube-like ostiolum. In a number of genera, its wall structures are heavily pigmented (“carbonised”).

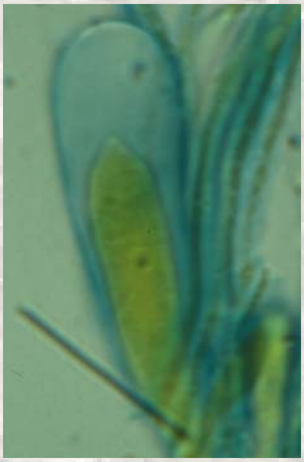


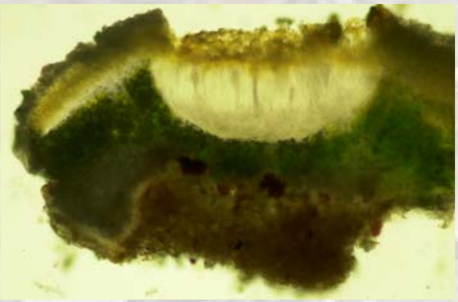
Lecanorine apothecia of *Xanthoaprmelia.*

Biatorine apothecia of *Psora.*

Perithecia of *Placidium.*

Spores (ascospores) are produced within spore-producing cells (sporocysts, asci), inside the fruiting bodies, and spread by wind or rain. When the spores germinate, they have to find the cells of a compatible algal partner to establish a new lichen thallus. On the one hand, sexual reproduction is important for retaining genetic variation; but on the other hand, it is risky in the case of lichenised fungi due to low likeliness for the fungal spores to meet an appropriate algal cell for relichenisation.





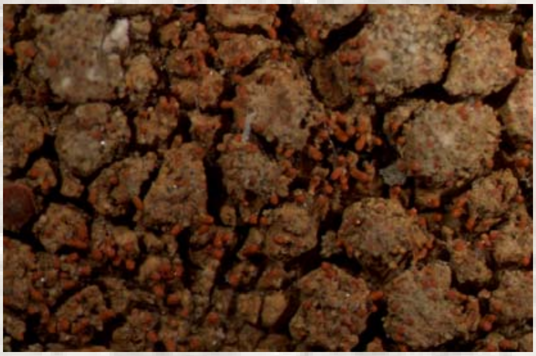
Section of apothecium and ascus of *Acarospora* sp. (BIOTA observatory Nu-mees).

The mycobionts of many lichen species reproduce asexually in a not lichenised form, by generating other kinds of fungal spores (conidia), different from ascospores. These are produced in structures called conidiomata. The most frequent conidiomata are pycnidia. Some mycobiont can have different types of conidiomata, producing also different spore types (macro-, meso- and microconidia).

However, many lichen species have increased their chance of success for dispersal by reproducing vegetatively, or asexually, in a lichenised mode (with both symbiontic partners). Such vegetative reproduction can occur through the simple fragmentation of the thallus. Especially when this is dry and fragile, fragments can easily brake off and be transported by wind or animals. In other cases, special propagules containing both symbiontic partners are produced. They can be poorly structured elements, called soredia, which are small globules consisting of fungal filaments and algal cells. Other propagules are peg-like, more or less branched, coral-shaped, round or flattened outgrowths, which are called isidia, and originate from the thallus surface. They break off for dispersal and show in microscopial section the same structure as the thallus, with distinguishable layers. Soredia and isidia are spread by wind, water and small animals, for example mites and birds, to new locations where, if conditions are favourable, a new thallus is established.

Pycnidia (conidiomata) on the lichen thallus of *Paraparmelia* in the Knersvlakte.

Soralia of epiphytic *Ochrolechia* (BIOTA observatory Roscherpan).

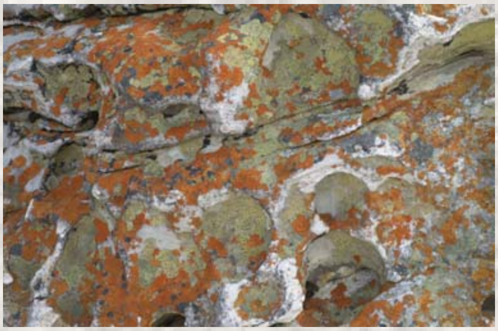


Isidia on the thallus of *Caloplaca testudinea* (Namib Desert).

Fragments of the thallus of *Xanthomaculina convoluta*, transported by wind in the Namib Desert.

5. Where do lichens grow?

Lichens occur in all the regions of the World. They are widespread in a range of habitats from extreme conditions of heat or cold, from deserts to tropical rain forests, from natural to managed environments, colonising very different substrates. A large number of species grows on rock and on soil, others on bark, leaves and wood of shrubs and trees. Lichens are also found on a range of man-made substrates like glass, rubber and roofing tiles. Several species have a wide ecology, which means that they are found on different substrates and under different ecological conditions; others on the contrary are restricted to certain habitat conditions. Some species are, for instance, well-adapted to aridity, and occur in desert to semi-desert environments, others prefer humid and cold conditions, and never occur in arid areas.



Different lichen species on rock at the BIOTA observatory Cape of Good Hope.

Xanthodactylon flammeum on twigs along the coasts of the Northern and Western Cape.

In general, lichens can colonise extreme habitats, such as cold and hot deserts, competing less with higher plants due to their strong adaptation to soil salinity, aridity and extreme temperatures. In arid and semi-arid regions where moisture deficit limits vascular plant cover, lichens are able to survive by utilising the narrow time spans of rain, fog and dew events for the gain of water being necessary for algal photosynthesis. Desert habitats with fog and dew favour the occurrence of those lichen species which have green algae as photobionts, whereas lichens with cyano-bacteria are found in areas lacking dew, with higher temperatures and less rainfall.

Lichen soil crust dominated by *Lecidella crystallina* in the Namib Desert.

Lichen soil crust dominated by *Psora crenata* in the Succulent Karoo.

Lichens growing on soil form biological soil crusts together with other organisms (e.g., free-living cyanobacteria and bryophytes), which occur in all hot, cool, and cold arid and semi-arid regions of the Earth. They play a very important role in these ecosystems, since they are able to retain soil moisture, to reduce wind and water erosion of the soil, fix atmospheric nitrogen, and to contribute to soil organic matter. One of the main factors conditioning lichen diversity in a given ecosystem is human activity. Air pollution, overgrazing, the use of pesticides, fire, trampling by domestic live-stock, and vehicle traffic are all factors limiting lichen growth. Moderate human disturbance, however, can even favour lichen diversity. For instance, more lichen species occur in open, not too much disturbed forests, where better light conditions are given, rather than in dense forests. Competition with higher plants may be lower under conditions of moderate disturbance, thus promoting the abundance of soil-growing lichens.

Lichen soil crust dominated by *Teloschistes capenis* in the Namib Desert (Wlotzkasbaken).

Lichen soil crust dominated by *Xanthparmelia* species in the Knersvlakte (obs. Goedhope).

6. Lichens as biological indicators

Changes in organisms can be reliably used to indicate a change in the environment. These changes may be physiological, chemical, or behavioural. A bioindicator can be defined as any biological species or group of species whose function, population, or status can be used to determine ecosystem level or environmental integrity. Lichens belong to the most frequently used bioindicators in terrestrial monitoring projects. They are long-lived organisms with high habitat specificity so that they can be used during the whole year for estimating species diversity and habitat potential. Since they grow on different types of substrata, they can be used as biological indicators of environmental conditions in different habitats, even in urban and rural environments. Certain lichen species are very sensitive to given environmental impacts such as air pollution NO_x (nitrogen oxides), SO_2 (sulphur dioxide), climatic changes, grazing, agricultural and forest activities. Others are not affected and even supported by such events.

Grazing at the BIOTA observatory Luiperskop 211 (Knersvlakte).

Destruction of lichen fields in the Central Namib by off road driving.

Lichens, together with bryophytes, are usually found in advanced succession stages of biological soil crust communities, on highly stable soils, and under rather undisturbed conditions, and are therefore important indicators for the degree of human impact and for environmental health in general. Unlike vascular plants, lichen growth appears not to be influenced by short-term climatic changes. This makes them ideal indicators for long-term environmental changes. In arid to semi-arid areas, many lichen soil crusts are good indicators of physical disturbance, such as by livestock, human foot traffic, or motorised vehicles. A severe problem for the unique lichen fields in the Namib Desert is the impact of off-road vehicles. However, land managers very rarely use lichens for rangeland evaluations, especially in Southern Africa. This is mainly due to the difficulty of identifying lichens without the help of specialists (so-called ‘lichenologists’). Identification problems can be reduced by grouping lichens according to functional types or by general morphological characteristics. For this reason, it is one of the aims of our project to elaborate morphological groups of lichens having a high indicator value to be used in monitoring programs and management activities by non-specialists.

7. Why are lichens useful?

Lichens play an important role in the food chain of different ecosystems. Reindeers, moose, musk oxen of the cold areas of the Northern Hemisphere for instance, feed on soil-inhabiting *Cladonia* lichens during winter time. In several parts of the world, snails and mites nourish on lichens. Snails, especially, seem to use bitter lichen compounds as protection against antagonists. Several bird species use lichens to build their nests, since they are better masked in the environment and protected against predators. Some groups of moths and of beetles are known to feed on lichens as well. Surely, also in Southern Africa there are numerous organisms profiting from lichens as food or for protection. As demonstrated by photographs, taken at the BIOTA observatories, some animals camouflage themselves among lichens and adopt their colours. These aspects are unfortunately poorly investigated, and it will be a challenging task to study these interactions in the future.

Lizard showing the same pattern of colours as lichens on rock (BIOTA observatory of Cape National Park).

Grasshoper showing the same spots of colours as lichens on rock (BIOTA observatories of Namaqualand).

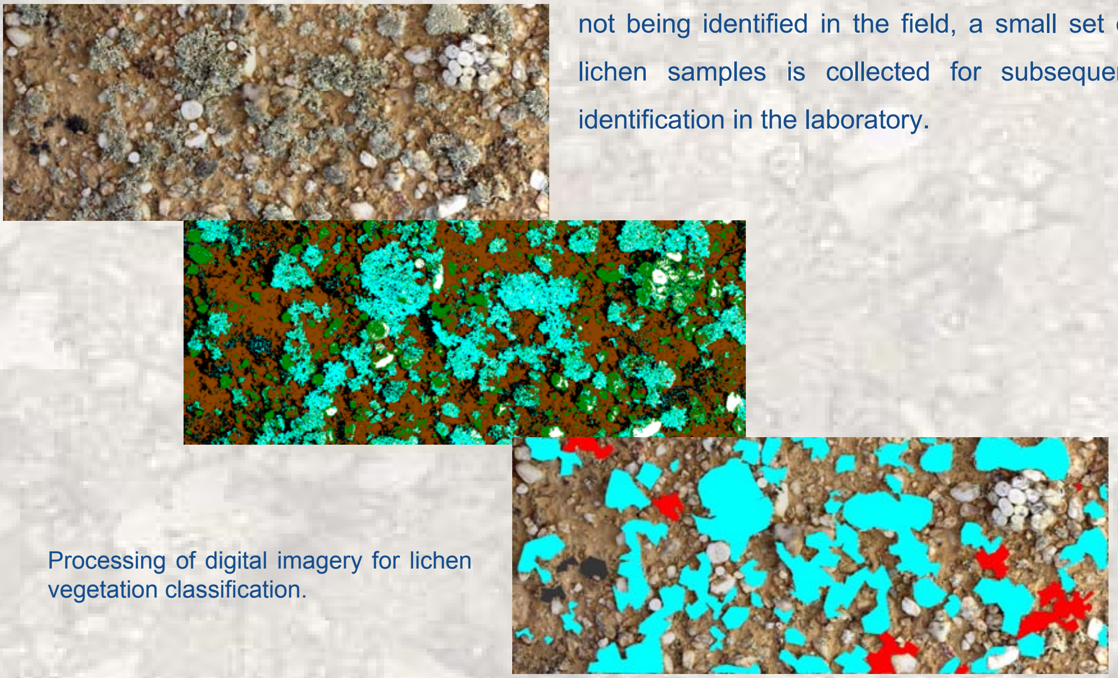
Grasshoper showing the same colour of *Caloplaca* sp. growing on pebbles at the BIOTA observatories of the Knersvlakte.

8. Monitoring lichens in Southern Africa: our activities

A method based on digital imagery was elaborated and applied during the work for the investigation of lichen communities forming biological soil crusts. Investigations are carried out in the BIOTA observatories. These have a surface of 1 km^2, and are located from Northern Namibia to the Cape Peninsula, along a climatic gradient. They were divided in 100 hectare plots, and a ranking was carried out in order to identify hectare plots representative for the area, having different habitat types, and higher priority of investigation (list of studied sites under http://141.84.65.132/UBT-Mycology/Biota/ProjectBIOTA-S04_Intro.html).

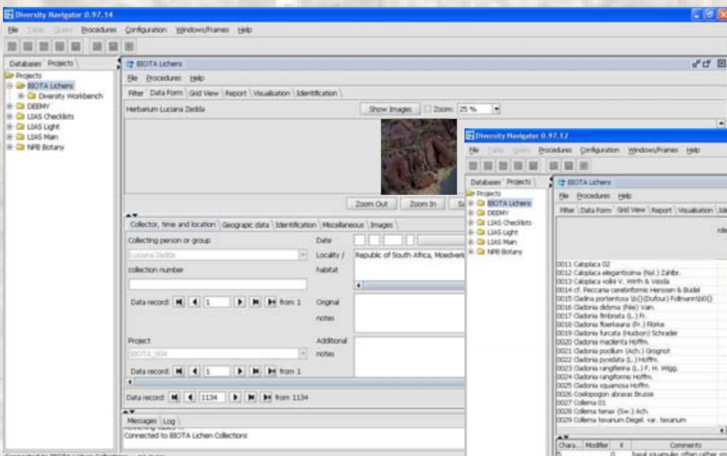
Digital sampling of lichen soil crust at Numees (Richtersveld N. Park).

Digital vegetation sampling of soil-growing lichen communities is carried out at the centre point of each hectare plot by means of digital photography. An aluminium frame construction allows to take several image sequences of the soil surface, fixing the camera in parallel to the soil surface. 36 images of a size of about 15 cm × 10 cm plus an overlapping of at least 10% are taken using a movable guide-rail adjusted on the top of the frame, which makes it possible to move the camera in steps of 10 cm along both axes of the frame. Images are mounted subsequently in order to reconstruct an entire image of the selected soil surface. Within this area, a sampling area of 20 cm × 50 cm (1000 cm^2) is delimited and further elaborated. In the case of certain species can not being identified in the field, a small set of lichen samples is collected for subsequent identification in the laboratory.

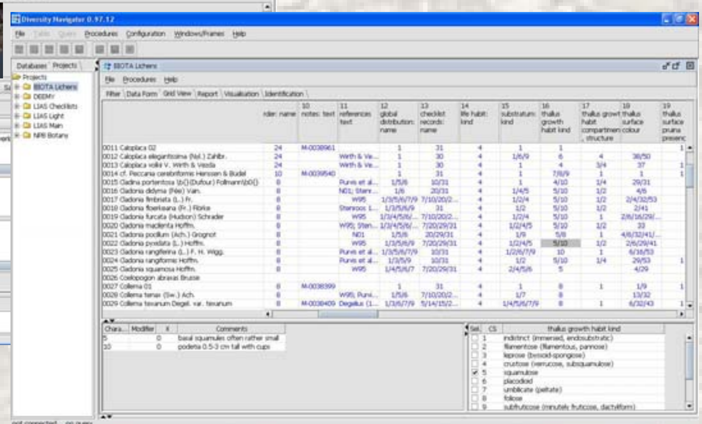


Processing of digital imagery for lichen vegetation classification.

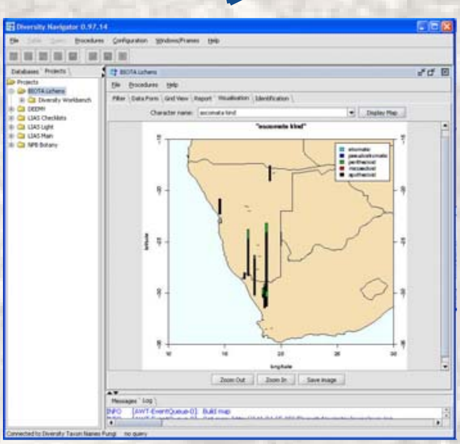
Data on collections as well as descriptive data on lichens occurring in Southern Africa are stored in databases. Digital images of the macro- and micromorphological characters of the lichen species are taken and stored together with vegetation images in an Internet server. All data is accessible via the Internet (Zedda & Rambold 2005). In order to quantify the coverage degree of lichens, the digital images are processed by using various software packages. This method allows to study lichen species in detail, assessing lichen diversity and cover, lichen vegetation dynamics, with special reference to inter- and intra-specific competition effects, and lichen population dynamics, by determining the growth-rate of different species. Lichen communities (vegetation) can be characterized and the indicator value of species, communities, and morphological groups estimated. Data on lichens can then be correlated with data gathered by other scientists, in order to analyse the influence of different factors, such as climate, soil type and land use, on lichen diversity.



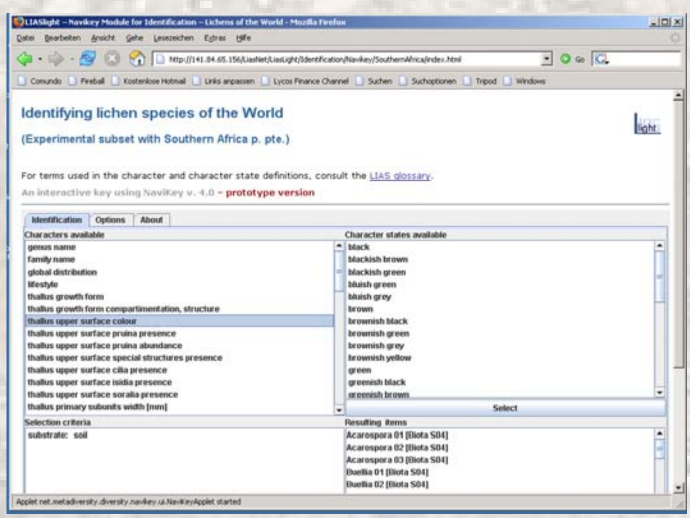
Database with collection data.



Database with descriptive data.



Georeferenced distribution of lichen species and of their characters.



Dynamic identification keys.

9. References

Belnap, J. & Lange, O. L. (eds.) 2001. Biological Soil Crusts: Structure, Function and Management. Ecological Studies, Springer Verlag Berlin, Heidelberg 150.

Belnap, J., Kaltenecker, J. H., Rosentreter, R., Williams, J., Leonhard, S. & D. Eldridge 2001. Biological Soil Crusts: Ecology and Management. USDI, Bureau of Land Mangement. Technical Reference 1730-2. Denver.

Kantvilas, G. & S. J. Jarman 1999. Lichens of rainforest in Tasmania and south-eastern Australia. Australian Biological Resources Study, Flora of Australia Supplementary Series No. 9.

Nash III, T. H. (ed.) 1996. Lichen biology. Cambridge University Press, Cambridge.

Nash III, T. H., Ryan, B. D., Gries, C. & F. Bungartz (eds.) 2002. Lichen Flora of the Greater Sonoran Desert Region. I. Lichens Unlimited, Arizona State University, Tempe, Arizona.

Nimis, P. L., Scheidegger C. & P. A. Wolseley (eds.) 2000. Monitoring with lichens – monitoring lichens. Nato Science Series. IV Earth and Environmental Sciences, Vol. 7.

Schmiedel, U. & N. Jürgens 2005. Biodiversity observatories. A new standardised monitoring tool for biodiversity studies. Basic and Applied Dryland Research 1: 87-91.

Zedda, L. & G. Rambold 2004. Diversity change of soil-growing lichens along a climate gradient in Southern Africa. Bibliotheca Lichenologica 88: 701–714.

Zedda, L. & G. Rambold 2005. LIAS light – subset BIOTA Southern Africa – Identifying lichen species of Southern Africa . http://liaslight.lias.net/Identification/Navikey/SouthernAfrica/index.html

10. Web links related to the project or to lichens in general

- http://www.biota-africa.org
- http://biota-africa.uni-bayreuth.de
- http://www.lias.net
- http://www.gbif.org

11. Acknowledgements

Thanks go to the Ministries of Environment and Tourism (MET) and of Agriculture, Water and Forestry (MAWF) in Namibia, The Northern Cape Nature Conservation, the Western Cape Nature Conservation Board, the Richtersveld National Park, and The Cape Peninsula National Park in the Republic of South Africa, as well as land-owners and communities in Namibia and RSA, for permitting research and for assistence during field work. A special acknowledgement is directed to all BIOTA colleagues and to the BIOTA coordination office at the University of Hamburg, especially to I. Fähnders for linguistic review, and to I. Homburg and N. Jürgens for their comments and suggestions. U. Sukopp (Bonn) and K. Hentschel (Bayreuth) are kindly thanked for some of the pictures shown in this work. The BIOTA Southern Africa project was sponsored by the German Federal Ministry of Education and Research under promotion number 01 LC 0024A.