Polarforschung 55 (1): 49—54, 1985

Lichen-Habitats as Micro-Oases in the Antarctic — The Role of Temperature

By Ludger Kappen*

Summary: The existence of lichens in the Antarctic depends on sufficient moisture supply as well as heat in its natural habitat. From a comparison of diurnal courses of the microclimate of lichen habitats in the maritime Antarctic with those of the desertic continental Antarctic it is apparent that temperature conditions are in the same range (6°—8° C) in all habitats during days, when lichens are soaked and active. This similarity of the temperature levels and water conditions can be maintained under the more severe conditions of the polar desert only in particular localities or aspects of rocks similar to hot deserts. Thus by a convergent situation oases where lichens can exist are formed in deserts.

Zusammenfassung: Die Existenz von Flechten in der Antarktis hängt sowohl von ausreichender Befeuchtung als auch von der Temperatur an ihrem natürlichen Standort ab. Vergleiche von Tagesgängen des Mikroklimas an Flechtenstandorten in der maritimen Antarktis mit solchen in der wüstenhaften Kontinental-Antarktis zeigen, daß die Temperaturbedingungen (6°—8° C) tagelang an allen Standorten übereinstimmen, wenn die Flechten eingequollen und stoffwechselaktiv sind. Diese Übereinstimmung des Temperaturniveaus und der Einquellungsbedingungen kann unter den extremen Bedingungen der Polarwüste nur in bestimmten Nischen oder Felsexpositionen aufrechterhalten werden. Es läßt sich ein Konvergenz solcher gemäßigter Kleinnischen in heißen Wüsten und in Kältewüsten finden. Die Flechtenbesiedlung in Wüstengebieten hat damit Oasencharakter und ist auf mikroklimatisch jeweils ähnliche Standorte beschränkt, bei großklimatisch extrem divergierender Umgebung.

In extreme habitats such as deserts or high mountain regions lichens are very frequently the representatives of a most resistant and pioneering vegetation. This is for physiological reasons because these poikilohydric plants are highly tolerant of desiccation, cold and heat. Similarly, there are also ecological reasons. In extremely arid regions lichens can exist, however, in sharply limited areas such as mountain slopes of a certain aspect, in the shadow of rocks, or regularly distributed over the tops of outcropping rocks. Such restricted habitats have to be considered as oases, because the moisture factor in all of them is higher in contrast to the surrounding area. Lichens are able to efficiently use fog, dew and high air humidity for photosynthetic production. In hot deserts it is remarkable that such oases provide moderate temperature conditions and that the lichens in the active state are beyond their optimum temperature above 20° C (LANGE, 1969; KAPPEN et al., 1980). Thus, besides moisture, temperature is an important part of the oasis conditions.

For this overview the role of temperature for the lichens in climatically extreme habitats as can be found in the Antarctic shall be analysed. Lichens, like in many deserts of the world, form the main element of vegetation in Antarctica. Antarctica can be divided into two phytogeographical regions (PICKARD & SEPPELT, 1984, Fig. 1). The maritime Antarctic is comprised of Palmer Peninsula down to 68° S and the South Shetland and South Orkney Islands. Continental Antarctic means phytogeographically the sum of all ice free areas of the continent, which may be about as large as the area of the Federal Republic of Germany.

Lichens show the greatest abundance and species richness in the maritime Antarctic. For instance, the fruticose lichen genus *Usnea* forms a heather-like vegetation on ridges and coastal terraces. Precipitation is about 400 mm per year and fog is frequent. Day temperatures in summer may vary between 0 and +10° C. Coastal rocks are densely covered by about 30—40 lichen species. However, species selection and density varies with aspect: On the more westerly and southerly exposed rock sites rich lichen associations like the Ramalinetum terebratae (FOLLMANN, 1965) are developed; whilst on northerly and northeastern sites only xerophilous species such as *Caloplaca* and *Xanthoria* are found. Micrometerological

*Prof. Dr. Ludger Kappen, Institut für Polarökologie und Botanisches Institut der Universität, Olshausenstr. 40, D-2300 Kiel 1.

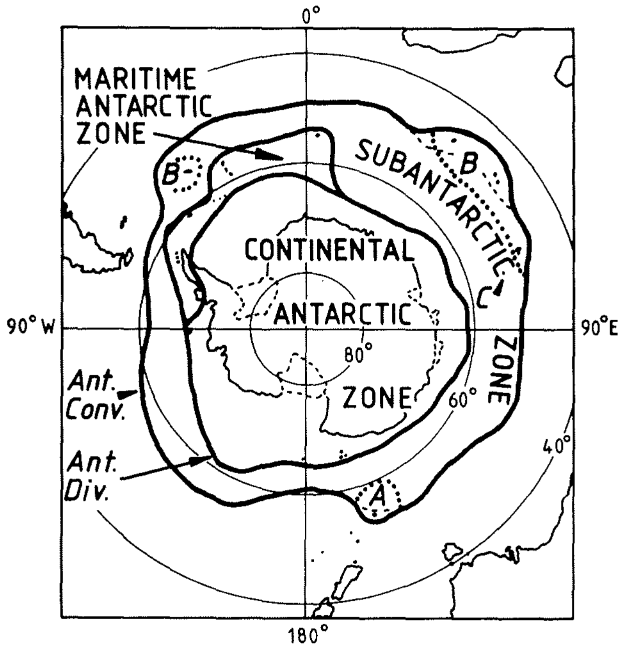

Fig. 1: The Antarctic region divided into three main zones (from PICKARD & SEPPELT, 1984); Antarctic Convergence is the oceanographic boundary of Antarctica; Antarctic Divergence is the circumpolar boundary between prevailing easterly continental winds and westerly oceanic winds.

Abb. 1: Einteilung der antarktischen Region in Hauptzonen (nach PICKARD & SEPPELT, 1984). Die antarktische Konvergenz bildet die ozeanographische Nordgrenze der Antarktis; die antarktische Divergenz ist die zirkumpolare Grenze zwischen vorwiegend östlichen und vorwiegend westlichen Winden.

measurements confirm that those sites receive more sun radiation and are significantly drier (KAPPEN & REDON, 1984). On damp or rainy days when lichens become extensively soaked, thallus temperatures are heated up to a maximum of 9 ° C. All warmer thalli were found to be dry or drying out.

Precipitation on the continent is much lower (so far known to be below 100 mm/year). Climatic conditions at the coast of Northern Victoria Land (Birthday Ridge, 72 ° S) resemble those of a polar desert. Further south and inland as e. g. in the Ross Desert („Dry Valleys", Linnaeus Terrace; 77 ° S) drought is extreme. At Birthday Ridge only a north exposed granitic mountain slope is free of ice. Superficially all of the rock is devoid of any vegetation. However, in the gentle part of the slope covered by a granitic block field lichens of all growth forms can be found growing exclusively in gaps between the pebbles (KAPPEN, 1985a). Among the 40 species a macrolichen such as *Usnea sulphurea* is frequently found.

Rock surfaces in the continental Antarctic were frequently found to be heated up to more than 30 ° C. At Birthday Ridge exposed pebbles reached more than 22 ° C at a quantum flux density (Licor sensor) of 2000 $\mu Em^{-2}s^{-1}$. Lichens do not grow on such apparently prosperous sites but they can be found at rock surfaces which are more sheltered and cooler (Fig. 2). Only here can lichens make use of the scattered moisture sources in this area. Besides infrequent fog, snow is the only source of water for the lichens. During the summer snowfall is joined by strong wind, thus, snow cannot accumulate on the rocks but is drifted into the gaps between the bolders and accumulates on the lichen thalli. The lichens being mostly dark pigmented melt the snow very quickly and become soaked. It was estimated that the thalli may be more or less soaked during one third of the summer period. Basing on this assumption *Usnea sulphurea* may need 200—300 years to reach a dry weight of 500 mg (KAPPEN, 1984). The lichen habitat at Birthday Ridge resembles small oases in the dry rock desert, providing the lichens with a particular microclimate and sufficient moisture. In the glaciated inland about 70 km south of the coast lichens were found on small isolated mountain slopes. For instance they were growing in a belt immediately above the water table of a small melting pool which reached 11 ° C water temperature during the day.

The Ross Desert has been ice-free for about 5—10 000 years. The mountains reach heights of 2 500 m and

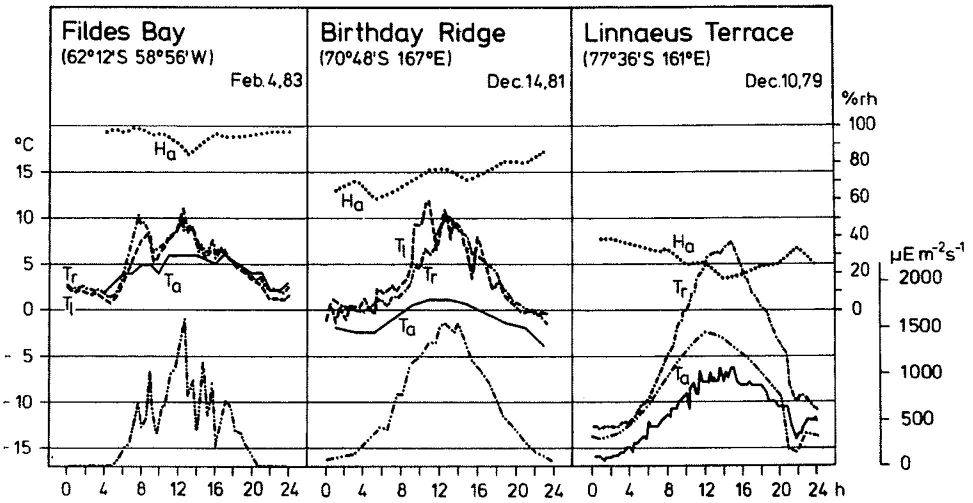

Fig. 2: Microclimatic situation in lichen habitats of three different areas in Antarctica. Diurnal courses of air relative humidity (H_a, rh%), air temperature (T_a, °C); Temperature of rock (T_r, °C), and of endolithic lichens (Linnaeus Terrace: *Buellia cf. pallida*), fruticose thalli of the genus *Usnea* (T_l, °C), quantum flux density (- ⩲ ⩲ -, $\mu Em^{-2}s^{-1}$).

Abb. 2: Mikroklima von Flechtenstandorten in drei verschiedenen Gegenden der Antarktis. Darstellung von Tagesgängen der relativen Luftfeuchtigkeit (H_a, rh%), der Quantenfluxdichte (- ⩲ ⩲ -; $\mu Em^{-2}s^{-1}$), Temperaturen der Luft (T_a, °C), der Felsen (T_r, °C), von endolithischen Flechten (Linnaeus Terrace: *Buellia cf. pallida*) und von strauchigen Thalli der Gattung *Usnea* (T_l, °C).

the valleys are absolutely desertic. However, some meltwater streams run through the bottom. Air temperature is mostly below the freezing point, air humidity falls below 50%, because catabatic winds from the polar plateau have a strong drying effect. Over wide areas only a very scattered microflora of cyanobacteria can be found.

The situation is changed by particular microclimatical conditions such as were investigated in the Asgard Range at a level of 1600 m (Linnaeus Terrace). Beacon-Sandstone is the material of the mountains and

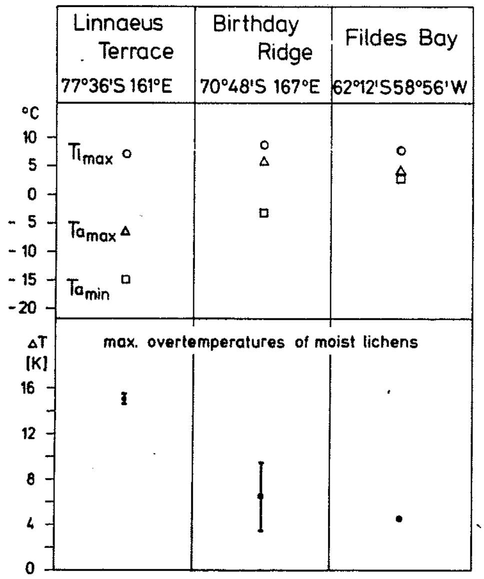

Fig. 3: Top: Ranges of maximum ($T_a$max) and minimum ($T_a$min) air temperature at three lichen habitats and level of the highest measured temperatures in naturally soaked lichen thalli in their habitat ($T_l$max).
Bottom: Ranges of maximum temperature differences between soaked lichen thalli and air temperatures during the day, when the thalli were warmed up to a maximum temperature (means of 2—4 days each).

Abb. 3: Oben: Maximale ($T_a$max) und minimale ($T_a$min) Lufttemperaturen gemessen an den Flechtenstandorten und die höchste Flechtentemperatur ($T_l$max) an Tagen, wenn die Thalli natürlich aufgesättigt waren.
Unten: Höchste Differenz zwischen Temperaturen natürlich eingequollener Flechtenthalli und den Lufttemperaturen, wenn die Flechten am stärksten erwärmt sind (Mittelwerte von je 2—4 Tagesgängen).

rock scree. Rocks are covered by a brown iron crust on the north side. Below this crust the rock is bleached over a profile of 1 cm inwards. In the relatively large porous space fungal hyphae, algae and microorganisms form a small ecosystem. The presence of apothecia on the rock surface indicates the existence of cryptoendolithic lichens (FRIEDMANN et al., 1980), which belong to the genera *Buellia* and *Lecidea* (FRIEDMANN, 1982).

The existence of the lichen in the rock periphery was essentially dependent on water availability. During the summer, snow falls more or less regularly for a period of a week or longer. Snow accumulates on the rocks under the mostly calm conditions. After 1—2 days the sky clears up. Snow on south exposed rock sites stays and evaporates slightly, whilst on the north exposed sites it melts rapidly and water trickles into the porous space of the rock. The moistened rock becomes heated up to 7 ° C at midday, while air temperature measures only —7 ° C or less (Fig. 2). The cryptoendolithic environment stays at above zero temperatures for 9—13 hours a day. Light is about 1% of the ambient. The rock surface dries out quickly, however inside relative humidity remains high for several days, thus providing extended periods of activity in the lichens.

Also the situation of the cryptoendolithic lichens resembles that of an oasis. Here in the polar desert water becomes available to the lichens under the influence of the heating sun. On the other hand, in the hot desert the lichens can profit from water under the relatively coolest conditions. Thus, the oases are formed by a convergent combination of environmental factors.

Until now we have analysed only very short periods of time in the maritime and continental habitats of the Antarctic, however our data show very apparently that the conditions in the oases are similar to each other which is a contrast to the great differences of the general environments. For the lichens those environmental conditions are most relevant which influence them in the soaked active state. Fig. 3 shows that during all 18 investigated moist days temperatures in all lichen habitats were in the same range and did not exceed 9 ° C, whilst air temperatures differed widely. The air—lichen temperature difference was greater the colder and drier the ambient conditions were. In the extreme cold Ross Desert this condition

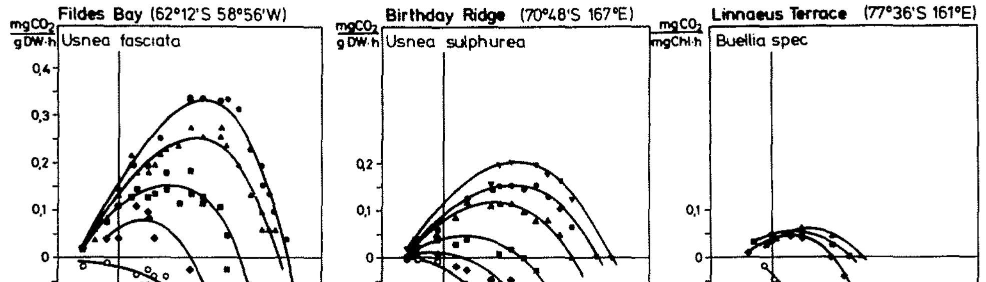

Fig. 4: Photosynthesis versus temperature and quantum flux density (black symbols) and dark respiration versus temperature (circles) of lichen species from different areas in Antarctica according to laboratory measurements. *Usnea fasciata* and *U. sulphurea* have an erect fruticose thallus and grow on rock, *Buellia cf. pallida* grows inside the porous space of sandstone (cryptoendolithic).

Abb. 4: Abhängigkeit der Nettophotosynthese von Temperaturen und Quantenfluxdichte (schwarze Symbole) und Temperaturabhängigkeit der Dunkelatmung (Kreise) bei Flechtenarten verschiedener Gebiete der Antarktis. Messungen unter Laborbedingungen. *Usnea fasciata* und *U. sulphurea* haben aufrechte, strauchige Thalli und wachsen auf Fels. *Buellia cf. pallida* wächst „kryptoendolithisch" im Porenraum von Sandstein.

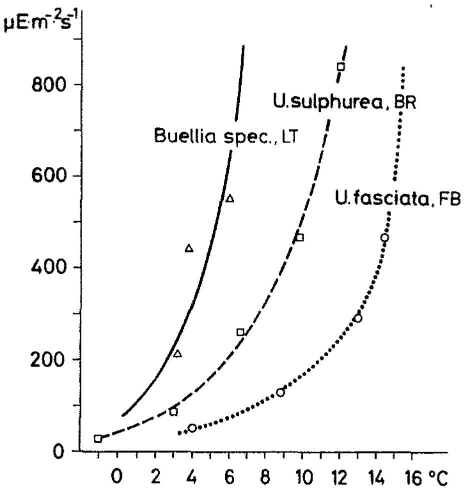

Fig. 5: Optimum of net photosynthesis versus temperature and quantum flux density according to laboratory investigations in the lichens from Linnaeus Terrace (LT), Birthday Ridge (BR), Fildes Bay (FB).

Abb. 5: Optimale Nettophotosynthese in Abhängigkeit von Temperatur und Quantenfluxdichte nach Labormessungen an den drei Flechtenarten von Linnaeus Terrace (LT), Birthday Ridge (BR) und Fildes Bay (FB).

can be generated only inside the porous space of rocks where overheating above air temperatures reached more than 16 K.

The difference in physiological performance of the lichens, which may be better correlated to the general ambient conditions, is in contrast to the similar habitat conditions (Fig. 4). All species are able to carry out photosynthesis at temperatures below zero. At low light intensities the optimum temperature for net photosynthesis ranges between 0 and 5 ° C, and between 10 and 16 ° C when quantum flux density is high. The highest upper compensation temperature is still below 30 ° C. Although *Buellia* from Linnaeus Terrace has not a fruticose growth form like the Usneas, it represents the largest lichen of its habitat. The upper compensation point of the latter is at only 16 ° C. The photosynthetic rate and thus production capacity obviously decreases the more desertic the regional climate is. Repiratory quotient is lowest in *U. fasciata* and highest in *Buellia (U. fasciata* 0,075 mg CO_2 $g^{-1}h^{-1}$; *U. sulphurea* 0,150 mg CO_2 $g^{-1}h^{-1}$; endolithic *Buellia* 0,225 mg CO_2 mg Chl. $^{-1}h^{-1}$ at + 10 ° C).

In Fig. 5 the relationship between optimum temperatures of net photosynthesis and quantum flux densities is shown for all three species. Light may rarely be a limiting factor during most of the day (cf. Fig. 2). By means of the functions in Fig. 5 it is possible to investigate whether temperatures become optimal with respect to light conditions. Days were selected when the lichens were soaked during most of the time by rain or snow. The temperature differences between measured thallus temperature and the optimum tem-

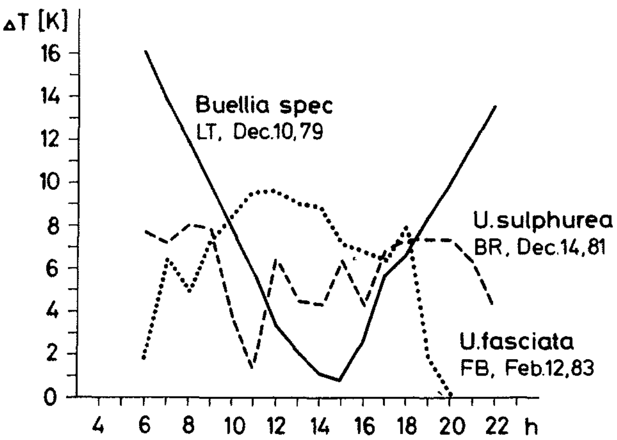

Fig. 6: Differences (ΔT) between potential optimum temperature of net photosynthesis versus natural quantum flux density (see Fig. 5) and actual thallus temperature in the diurnal courses at the three habitats in Antarctica.

Abb. 6: Tagesgänge der Differenzen (ΔT) zwischen potentieller Optimumtemperatur der Nettophotosynthese (s. Abb. 5) bei der jeweiligen Quantenfluxdichte und der aktuellen Thallustemperatur an den drei antarktischen Standorten.

perature of net photosynthesis according to the quantum flux density was always more than 1 K. This may illustrate that we have not yet found a diurnal course during which lichens have reached an optimum temperature range. Consequently the microoasis in the Antarctic is a habitat with sufficient (minimum?) water supply and sufficient but always suboptimal heat for the lichen.

References

Follmann, G. (1965): Una asociación nitrofila de liquenes epipetricos de la Antartida Occidental con *Ramalina terebrata* Tayl. et Hook. como especie caracterizante. — Publ. Inst. Ant. Chil. 4: 1—18.

Friedmann, E. I. (1982): Endolithic microorganisms in the Antarctic cold desert. — Science 215: 1045—1053.

Friedmann, E. I., Garty, J. & L. Kappen (1980): Fertile stages of cryptoendolithic lichens in the dry valleys of Southern Victoria Land. — Antarc. J. of U. S. XV: 166—167.

Kappen, L. (1984): Water relations and net photosynthesis of *Usnea*. A comparison between *Usnea fasciata* Torr., maritime Antarctica, and *Usnea sulphurea* (Koenig) Th. Fr., continental Antarctic. — In: D. Brown, ed., Lichen physiology and cell biology, 41—56, New York.

Kappen, L. (1985a): Vegetation and ecology of ice-free areas of Northern Victoria Land, Antarctica. 1. The lichen vegetation of Birthday Ridge and an inland mountain. — Polar Biol. 4: 213—226.

Kappen, L. (1985b): Vegetation and ecology of ice-free areas of northern Victoria Land, Antarctica. 2. Ecological conditions in typical microhabitats of lichens at Birthday Ridge. — Polar Biol. 4: 227—236.

Kappen, L., Friedmann, E. I. & J. Garty (1981): Ecophysiology of lichens in the Dry Valleys of Southern Victoria Land, Antarctica. Microclimate of the cryptoendolithic lichen habitat. — Flora 171: 216—235.

Kappen, L., Lange, O. L., Schulze, E.-D., Buschbom, U. & M. Evenari (1981): Ecophysiological investigations on lichens of the Negev desert VII. The influence of the habitat exposure on dew imbibition and photosynthetic productivity. — Flora 169: 216—225.

Kappen, L. & J. Redon (1984): Microclimate influencing the lichen vegetation on different aspects of a coastal rock in the maritime Antarctic. — Ser. Cient. INACH 31: 53—65.

Pickard, J. & R. D. Seppelt (1984): Phytogeography of Antarctica. — J. Biogeography 11: 83—102.