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Original Research

Non-rainfall water input determines lichen and cyanobacteria zonation on limestone bedrock in the Negev Highlands

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ABSTRACT

Lichen zonation on bedrock in accordance with the rock contours is a common phenomenon. This is also the case in the Negev Desert Highlands, where zonation along a continuum of lichens-cyanobacteria or different groups of lichens (epiliths-endoliths) within a distance of as short as <1 m can be observed. In an attempt to evaluate the factors responsible for the zonation, two plots with zonal distribution were demarcated in a north-facing slope and two at a south-facing slope, and their chlorophyll content and species composition were defined. In addition, rock properties, surface temperatures, dust input, rain amount, and the amount of non- rainfall water input, NRWI (dew, fog and high water vapor content) were measured. Whereas rock properties and aeolian input failed to explain the observed zonation, a clear temperature-induced NRWI gradient was found. The findings suggest that differential amounts of NRWI are responsible for the zonation observed, and subsequently for the clear gradient in chlorophyll content. The findings also suggest that lithobiont zonation may serve as a biomarker for subtle gradients in surface temperatures and subsequently in NRWI.

1. Introduction

Lichens cover many rock surfaces, playing an important role in contributing organic carbon and nitrogen input (Elbert et al., 2012). They also play an important role in rock weathering (Chen et al., 2000) and soil formation (Syers and Iskandar, 1973).

Lichen distribution or zonation, i.e., a parallel belt-like alteration in the lichen population was long noted. Regional distribution, occasionally termed zonation (Beefing, 1975) in the order of kilometers was mainly attributed to microclimate (Daniëls, 1975), and more specifically to variability in the amounts of rain (Rogers, 2006; Büdel et al., 2009), fog (Rundel and Mahu, 1976; Schieferstein and Loris, 1992) or dew (Kidron and Temina, 2013). Slope scale zonation (in the order of tens of meters, occasionally termed vertical zonation) was however reported on coastal rocks along the Ocean, lakes or rivers and explained by the time duration during which the lichens are immersed in water or subjected to wetting by water spray or splash (Fletcher, 1973a,b; Schneider and Torunski, 1983; Rosentreter, 1984; Hawksworth, 2000; Brodo and Sloan, 2004). Slope scale zonation was also reported inland.

Whether along cliffs or bedrock (Yarranton and Green, 1966; John and Dale, 1990), lichen or lithobiont zonation was attributed to variability in water and minerals. Availability of minerals may change due to differences in rock composition of the rocks and/or variable input of dust, i.e. nutrients (Hofman et al., 1974; Larson, 1980). Differences in water availability may stem from a moisture gradient, such as due to different inclination which affects evaporation (Larson, 1980; Matthes-Sears et al., 2000). Nevertheless, while variability in dew duration was found to be responsible for slope zonation in the Negev (Kidron et al., 2011), moisture measurements along slopes are not available, to the best of our knowledge, from other parts of the world.

Zonation at a micro-scale (<1 m) entails extra difficulties. Zonation was attributed to differences in water availability following capillarity from ponds (Wessels and Büdel, 1989), sea water (Brodo and Sloan, 2004), or from wet soil (Kidron, 2002). Variable water availability was also suggested for the zonation observed at the Niagara Escarpment (Matthes-Sears et al., 1999). Nevertheless, this assumption was not backed up by direct measurements, and the authors suggested that it may also result from random colonization.

Micro-scale lichen zonation is a common phenomenon on calcareous rocks in the Negev Desert Highlands. In many instances, belts of different colors, reflecting different lichen populations, or belts having a gradual change in composition from cyanobacteria to lichens or from epilithic lichens to endolithic lichens can

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be observed. These belts may coincide with the rock contours, or change in accordance with the rock angle. While water ponding and consequently capillary rise were not visible on the inclined rock surfaces, we hypothesized that variable non-rainfall water input (NRWI) may explain the differences observed in lichen composition. However, other variables such as dust (which may reflect nutrient input), rain or even variability of rock structure and mineral composition (which may affect the surface water-holding capacity and therefore water availability) should also not be ruled out. Exploring the factors responsible for lithobiont zonation was the aim of the current research.

2. The research site and methodology

The research was conducted within a first order drainage basin near Sede Boqer in the heart of the Negev Highlands (Fig. 1a). The drainage basin is ~500 m above sea level with Turonian limestone hills towering 40–50 m above the wadi beds. Vegetation consists of low shrubs which cover 10–20% of the slopes. Lichens (out of which >95% are chlorolichens) cover most of the bedrock and cobbles of the drainage basin (Lange et al., 1970; Friedmann and Galun, 1974; Danin and Garty, 1983).

The site lies within the extreme desert zone of the Negev. Average annual rain precipitation is 95 mm (Rosenan and Gilad, 1985) and average annual dew and fog precipitation, as measured in Avdat (9 km south of Sede Boqer) is 33 mm with 195 dewy days a year (Evenari et al., 1971). Average daily yield per dewy morning is 0.2 mm (Kidron, 1999). Average annual temperature is 17.9 °C. It is 24.7 °C for the hottest month of July and 9.3 °C for the coldest month of January (Bitan and Rubin, 1991). Average annual potential water evaporation is ~2600 mm (Evenari, 1981).

Four plots with lithobiont zonation were demarcated, two of which were located at the north-facing slope (PL1 and PL2) and two at the south-facing slope (PL3 and PL4). A description of the plots is given in Table 1.

All plots were divided into three belts in accordance with the observed zonation: an outer belt (OB) at the outer boundary of the plot, an inner belt (IB) at the inner part of the plot, and a middle belt (MB) at the intermediate position between OB and IB. While an abrupt change in the rock angle characterized the OB of PL1 and PL2, PL3 and PL4 had the same surface angle for all belts. Yet, in order to avoid angle-induced zonation in PL1 and PL2, only the upper semi-horizontal surfaces of the OB, which had an identical angle to MB and IB, were included in the analysis.

In order to eliminate the possibility that local wind turbulence may result in differential inputs of rain and dust (Goossens, 1988; Sharon and Arazi, 1997; Blocken et al., 2006), transects of three small rain gauges and three dust traps were placed at all plots in accordance with the zonation observed (Fig. 1b). Rain and dust measurements were conducted during 2004–2006.

The rain gauges consisted of 1.5 cm-diameter and 10 cm-long tubes, attached with wooden bases to the rock surface. The dust traps (10 cm in diameter and 2 cm high) were attached to a $10 \times 10 \times 1\ cm^3$ wooden base that facilitated an easy separation of the trap during sampling. The traps consisted of a roughed-Plexiglas bottom (3 mm thick with 2 mm-high protrusions), underlying one layer of 3 mm diameter glass marbles, as previously described (Kidron et al., 2014b). A $1 \times 1\ cm^2$ metal net, pressed against the marbles, served to "anchor" the marbles onto the Plexiglas, thus guaranteeing a single layer of marbles throughout the trap (Fig. 1b). As for PL4, due to the steep angles, the rain gauges and dust traps were located horizontally (on pedestals) and the amounts that fell incident to the surface were calculated in accordance with the surface angle. Calculation was carried out with the aid of a pair of rain gauges and dust traps that were placed on the ground approximately 2 m from PL4: one placed horizontally and one tilted, mimicking the angles of PL4. The ratio of the amounts obtained at both rain gauges (or dust traps) on the ground served to calculate the amounts received at the different belts of PL4.

Owing to the fact that soil splash may enter the traps, dust measurements were confined to the rainless summer, while rain was

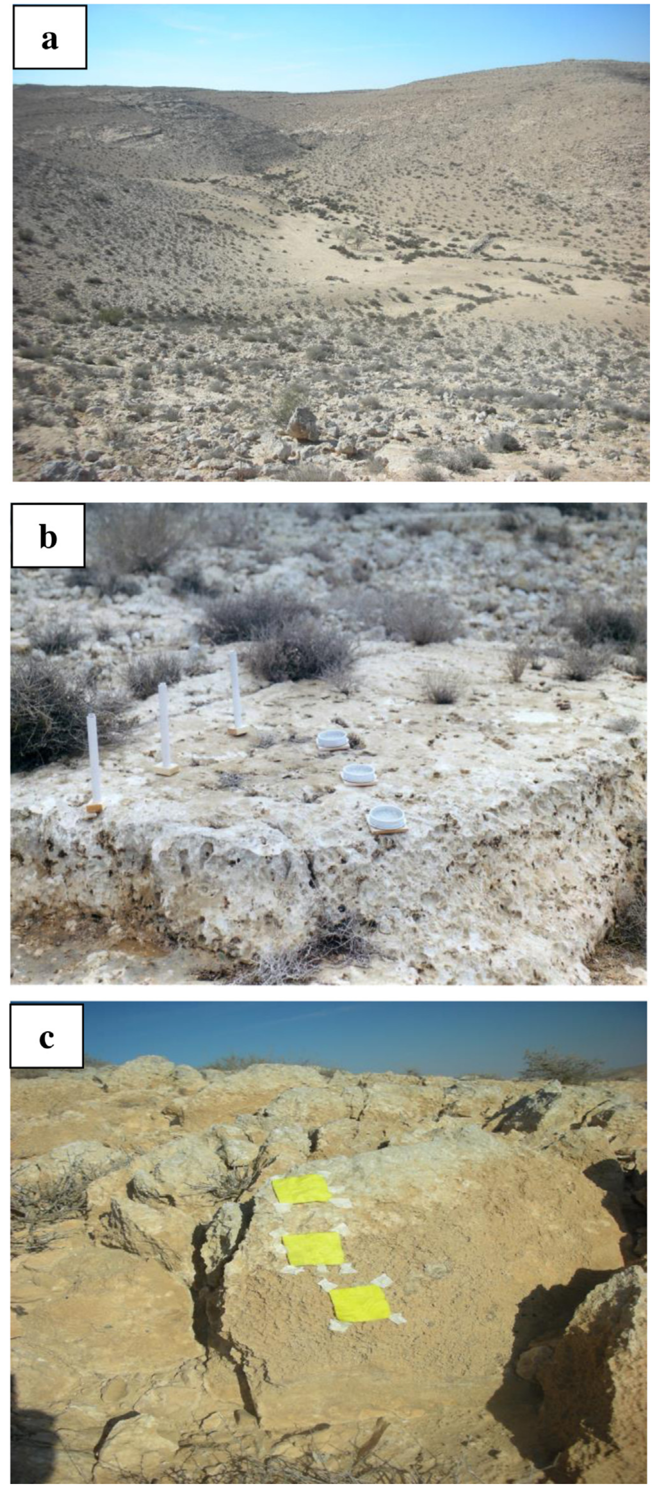

Fig. 1. General view of the research site (a), lichen zonation at PL1 at the north-facing slope (b) and PL4 at the south-facing slope (c). Note the rain gauges and dust traps at PL1 and cloths attached to PL4 for non-rainfall water input (NRWI) measurements. Note the pale whitish outer belt of PL1 at the edge of the rock and of PL4 at the top of the rock.