Acta Oecologica 69 (2015) 35–45

Contents lists available at ScienceDirect

Acta Oecologica

journal homepage: www.elsevier.com/locate/actoec

Original article

Multiscale effects on biological soil crusts cover and spatial distribution in the Monte Desert

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A R T I C L E I N F O

Article history:
Received 13 April 2015
Received in revised form
21 August 2015
Accepted 23 August 2015
Available online 2 September 2015

Keywords:
Grazing gradient
Old riverbed
Aeolian plain
Microsites
Aspect
Landforms

A B S T R A C T

Biological soil crusts (BSC) play diverse roles in arid and semi-arid ecosystems such as increasing soil fertility and reducing soil loss due to aeolian and hydric erosion, but they are very sensitive to disturbances. These attributes point to the relevance of BSC for soil conservation and restoration. In order to use BSC for restoration of degraded soils, we need to understand the ecological drivers of BSC. In this study, we analyzed the effect of environmental factors on BSC cover at different spatial scales in the central Monte Desert (Argentina), including landform, slope, aspect, vascular plants, and disturbance intensity. We evaluated the effects of different factors with linear mixed effect models, comparing the adjustment of models of different complexity, which included different number of factors. First, at the landscape scale, we analyzed BSC cover in two geomorphological units with different soils, topography, and vegetation. BSC cover was higher in the old riverbed, which has a higher proportion of fine clay soil particles, than in the aeolian plain. Disturbance effects were apparent in the old riverbed, showing increasing BSC cover at higher distances from settlements, and BSC located both, under and outside plant canopies. At the mesoscale, we found no differences of BSC cover in dune flanks and inter-dune valleys of the aeolian plain. Finally, at the microscale, BSC patches of higher surface cover were found in association with vascular plants (*Larrea divaricata*, *Bulnesia retama*, *Lycium sp.*), on mounds, and in microsites of southern exposure and high slopes. Our findings suggest that BSC develop preferentially associated with vascular plants, which generate mounds and sloped microsites with southern exposure, where lower irradiances reduce desiccation in these extremely dry environments.

1. Introduction

Biological soil crusts are associations among mosses, lichens, cyanobacteria, eukaryotic algae, and soil particles. They are found in the surface soil of most arid and semiarid areas of the world (Bowker, 2007). They play important roles in the ecosystems where they live. For example, the atmospheric nitrogen fixed by cryptogamic covers, including cryptogamic species covering rocks, soils (BSC), and plant stems, as well as moss and lichen carpets, contributes half of the terrestrial nitrogen fixation worldwide (Elbert et al., 2012). Cyanobacteria secrete exopolysaccharides, which fix soil particles, preventing soil loss by erosion and runoff, and facilitating colonization by other microorganisms (Belnap and Gardner, 1993). Yet, BSC are sensitive to disturbances, such as trampling by humans and domestic animals (Cole, 1990; Eldridge, 1998; Williams et al., 2008; Gómez et al., 2012), off road vehicles, and fires (Kröpfl et al., 2007; Hilty et al., 2004). Disturbances may reduce BSC cover and diversity, and change their species composition, transforming complex BSC communities into associations of a few species of cyanobacteria (Belnap and Lange, 2003; Eldridge et al., 2006). Estimated recovery rates of BSC after disturbances can be slow (Belnap and Eldridge, 2001), but there are studies that show rapid recovery, from months, after experimental disturbance in the Karoo, South Africa (Dojani et al., 2011), 14–18 years in Utah (Anderson et al., 1982), to 20 years in Australia (Read et al., 2011), with recovery times decreasing with inoculation (Belnap, 1993). The biomass and functional loss created by destruction of BSC may affect site productivity, due to the loss of nutrients and soil particles

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http://dx.doi.org/10.1016/j.actao.2015.08.005
1146-609X/

through erosion (Williams et al., 2012).

Soil degradation and desertification in arid and semi-arid areas, including the Monte Desert is a worldwide problem, due to increasing land use pressures and population growth (Van de Koppel et al., 1997; Asner et al., 2003; Villagra et al., 2009). However, studies relating degradation to the ecology of BSC are scarce in South America, and particularly in Argentina (Castillo-Monroy and Maestre, 2011). In the Austral and Central Monte Desert, three studies have reported negative effects of livestock activity on BSC, reducing their cover and altering their spatial distribution (Bertiller and Ares, 2011; Gómez et al., 2012; Tabeni et al., 2014). In contrast, BSC recovering in degraded arid areas may contribute to soil restoration and reduce the risks of further degradation (Eldridge and Greene, 1994; Bowker et al., 2005). Additionally, BSC contribute greatly to biodiversity, representing a high number of species of cyanobacteria, eukaryotic algae, lichens, mosses, and liverworts (Belnap and Lange, 2003; Bowker et al., 2008, 2010; Flechtner et al., 2013). Still, soil crust biodiversity studies in South American drylands are scarce and floristic surveys are needed (Castillo-Monroy and Maestre, 2011). Functional approaches to classify BSC are also relevant, because different types of BSC may modify different soil properties and can be indicators of successional stages (Eldridge and Rosentreter, 1999; Koch et al., 2013). Squamulose lichens may be more efficient for fine soil particle retention, increase of soil roughness, and protection against wind erosion, while crustose BSC may be more effective for moisture retention (Eldridge and Rosentreter, 1999; Ghorbani et al., 2012; Leys and Eldridge, 1998). Gelatinous BSC may retain soil moisture and are effective at protecting the surface against water erosion (Eldridge, 1996). Lichens with cyanobacteria symbionts may fix atmospheric N, increasing N availability in the soil (Evans and Ehleringer, 1993), while lichens with green algae may be less susceptible to light stress (Demmig-Adams et al., 1990).

BSC have interesting relationships with vascular plants, depending on plant functional groups (Berkeley et al., 2005; Eldridge, 1993; Thompson et al., 2006), the presence of livestock (Gómez et al., 2012) and microclimate (Belnap, 2006; Mager and Thomas, 2011). Livestock activity may directly or indirectly affect biological soil crusts, and their relationship with vascular plants. Domestic animals destroy aggregated crusts, or bury them by trampling, representing a negative effect (Eldridge, 1998; Concostrina-Zubiri et al., 2013). However, these animals also consume litter, grasses, or shrubs, which may relieve competitive interactions between vascular plants and soil crusts. A well-developed shrub layer may increase litter burial and decrease light intensity, limiting BSC development (Berkeley et al., 2005). Grasses may compete with BSC for resources in the Monte desert (Tabeni et al., 2014), while fine leaf, thorny shrubs may protect them from trampling, and allow enough light to reach soil spaces for crust development (Thomas and Dougill, 2006, 2007). BSC effects on seedling emergence varied in different deserts. Moss, cyanobacteria and algal dominated BSC facilitated survival and growth of two annual plant species (*Eragrostis poaeoides* and *Bassia dasyphylla*) in the Tengger desert (Li et al., 2005), while cyanobacteria dominated BSC inhibited seedling emergence of several perennial plants in the Negev desert (Prasse and Bornkamm, 2000). Topography and substrates, which can be modified by vascular plants, may affect BSC, interacting with microclimatic conditions such as radiation, temperature, humidity, and soil moisture (Eldridge and Tozer, 1997; Jiao et al., 2008; Li et al., 2010; Zhang et al., 2007). Consequently, these complex relationships among vascular plants, BSC, disturbances, and substrates, including BSC species composition, need to be analyzed in each region, in order to plan BSC conservation and soil restoration strategies.

In this study, we analyzed the abundance (% cover) and distribution (occurrence at three spatial scales) of BSC in an area of the Monte Desert used for extensive livestock production. The region is at risk of degradation because of population growth and changes in land use rights, but is located in a Natural and Cultural Reserve, having the potential to become a refuge for BSC. The balance between land use and conservation is especially delicate in this area because aboriginal land rights and conservation laws apply to the same area, without a knowledge of the effects of traditional land use on different organisms, or ecosystems.

The first objective of this study is to find areas where BSC reach maximum development at the landscape scale, in the old riverbed and aeolian plain. The second objective is to identify different factors that control BSC community abundance and distributions at the meso (dune landform) and micro (shrub versus shrub interspace) scale, including vascular plants, slope, and aspect. The analysis at each of the three scales includes the effect of livestock activity on BSC cover. The third objective is to start the taxonomic identification of BSC organisms in the region.

Because of the capacity of BSC to adhere to fine particles (Rozenstein et al., 2014), and the negative effect of crust burial by sand grains where soils are moved by winds, we expected to find a higher cover of BSC in the old riverbed, where soil particles are finer. We also expected higher BSC cover in inter-dune valleys than in dune flanks, because of higher soil movement, burial of BSC, and soil particle size in dune flanks. We expected to find a pattern of increasing BSC cover with lower grazing intensities, as in previous studies, because of the destruction of BSC by trampling (Concostrina-Zubiri et al., 2013; Williams et al., 2008). Finally, we expected significant effects of microenvironmental conditions, such as the presence of fine-leaved woody vascular plants, because they protect BSC from trampling and desiccation. Shrub mounds, aspect and slope were also expected to modify BSC cover, because they affect soil radiative and water balances.

2. Materials and methods

2.1. Study area

The study sites are located in the Telteca Reserve, approximately 120 km northeast of Mendoza city, Argentina (Fig. 1). The study area is within the Central Monte Desert, which is comprised of vast sandy aeolian plains with dune-interdune systems and old riverbeds. The sediments of dune-interdune systems are fine and very fine sands, with 90% of these sand classes, and 4–7% of silt and clay (Gomez et al., 2014). The old riverbed has higher proportions of fine particles, with 23–69% of fine and very fine sands, and 15–71% of silt and clay (Table S1, Supplementary online material). The climate is arid with hot summers (48 °C absolute maximum) and cold (−10 °C absolute minimum), dry winters (Meglioli, 2015). The mean annual temperature is 18.2 °C and mean annual precipitation is 156 mm, with precipitation occurring almost exclusively during the spring and summer (from October to March). This climate data were determined during a discontinuous period of 43 years (1971–2014), using the meteorological stations located as close as possible (<25 km) to the study sites. The meteorological stations were: “El Retamo” (32° 35′ S, 67° 28′ W), “Encón” (32° 15′ S, 67° 47′ W), “El Mateo” (32° 14′ S, 67° 41′ W) and “El Pichón” (32° 22′ S, 68° 03′ W) (Meglioli, 2015).

Characteristic plant communities of the Central Monte include the shrubby steppe dominated by *Zygophyllaceae* and the open woodland dominated by *Prosopis flexuosa* (Rundel et al., 2007). *P. flexuosa*, growing as either a tree capable of reaching 10 m in height, or a large shrub, is a facultative phreatophyte. It has an extended root system which acquires water from deep groundwater resources (Alvarez and Villagra et al., 2009), and dominates the tree