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Soil-associated lichens in rangelands of north-eastern Patagonia. Lichen groups and species with potential as bioindicators of grazing disturbance

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Abstract: Soil-associated lichen species characteristic of north-eastern Patagonia are classified by cluster analysis into six groups using ecological and morphological characters. The constancy of species, the total number of species, the number of species per crust and the relative frequency of species are analysed at sites with different grazing levels: three non-grazed, three regulary grazed, and three heavily grazed. Using the results, the potential use of lichen groups as bioindicators of rangeland conservation and degradation are explored. Species of three lichen groups (group A: lichens growing on calcareous gravels, group C: terricolous lichens with pale, crustose non-areolate thallus, and group F: terricolous lichens with pale, areolate thallus) are identified as sensitive to grazing, and most of the species forming these groups are suggested as potential bioindicators of grazing disturbance. Thus, *Rinodina bischoffii*, *Caloplaca holocarpa*, *Catillaria lenticularis*, *Acarospora heppii* (group A); *Lecanora dispersa* and *Rinodina mucronatula* (group C); and *Psora decipiens* (group F) are the species most sensitive to grazing disturbance. Conversely, species of group D (terricolous lichens with dark, foliose thallus: *Collema coccophorum*), and group B (lichens growing on siliceous gravels: *Aspicilia contorta*) may be indicated as the most resistant to grazing disturbance.

Key words: cryptogamic crusts, saxicolous lichens, terricolous lichens

Introduction

Biological soil crusts are composed mainly of an assortment of lichens, bryophytes, cyanobacteria, algae and fungi. In arid and semi-arid ecosystems, these crusts are essential for the stability and functioning of soil since decomposition and mineralization processes and biological activity occur mostly in the top few centimetres of the soil profile (Eldridge & Tozer 1997). At the continental level, cryptogamic crusts influence soil carbon and nitrogen cycles, while at regional or local levels, they can have effects on vascular plant processes such as germination and nutrition, as well as on soil processes by increasing water infiltration or resistance to soil erosion (Eldridge 2001). Cryptogamic crusts and crust organisms can be used as bioindicators or biomonitors of environmental disturbance (Belnap *et al.* 2001). For example, Eldridge & Ferris (1999) showed that the lichen *Psora crenata* (Taylor) Reinke is a good indicator of disturbance in Australian ecosystems.

Grazing reduces both the cover and diversity of cryptogamic crusts (Eldridge & Koen 1998). Among the macroscopic crust organisms, lichens require greater environmental stability (Eldridge 2001) and are more sensitive to grazing by domestic livestock (Graetz & Tongway 1986; Memmott *et al.* 1998) than bryophytes. Normally, the consequence of continuous overgrazing is the dominance of pioneer lichens containing cyanobacteria that fix atmospheric nitrogen, mostly of the genera *Collema*, *Peltula* or *Heppia* (Eldridge & Tozer 1997). Under heavy grazing all crust components may be completely destroyed by trampling (Eldridge & Koen 1998).

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In dry ecosystems, lichens and bryophytes are usually difficult to identify due to their scarce (poor?) development or sterility. Consequently, the use of morphological groups is highly recommended for monitoring studies (Eldridge & Rosentreter 1999). In addition, identification of morphological groups requires less training and allows a greater number of sampling replications and more powerful statistical analyses of data than would be possible if assessments were based on identification to species level. It should be pointed out, however, that while monitoring based on morphological groups may be appropriate on a broad regional level, it may be too coarse for detection of rare or uncommon species and for documenting total species diversity. For this reason, when working in a new area or with unfamiliar species, it is recommended that identifications are made to the species level (Körner 1994). Furthermore, the use of morphological groups may have some shortcomings when certain species do not fit neatly within any one group (e.g. differences in colour which are environmentally induced) since this could result in assignment of the same species to different groups by different workers.

Although some attention has been paid to the importance of lichens concerning vegetation and soil processes in arid and semiarid regions of Australia and North America (Eldridge & Greene 1994; Belnap *et al.* 2001), these issues have been scarcely explored in similar areas of South America, where most studies have dealt with crusts dominated by algae (Büdel 2001). In the present study, groups of soil-associated lichens are defined using ecological and morphological characters of the dominant species in rangelands of north-eastern Patagonia, and the potential of these lichen groups as bioindicators for conservation and disturbance by grazing is explored.

Materials and Methods

The study area is situated in north-eastern Patagonia, west of Puerto Madryn (Chubut Province, Argentina). The mean annual temperature is 13·7°C (15 y series) and mean annual precipitation is 188 mm (Bertiller 1998). Winds are strong and blow predominantly from the west throughout the year (Bertiller *et al.* 2001). Soils are a complex of Typic Petrocalcids-Typic Haplocalcids (del Valle 1998), and vegetation is a shrubland of 'jarillas' (*Larrea divaricata* Cav.) and 'coirones' (*Stipa* spp.), typical of the southern region of the Monte Phytogeographical Province (Cabrera 1976). Nine sites each of 2 ha were selected within a homogeneous and floristic representative area of *c.* 2400 km^2. Three were non-grazed sites (*Laguna Blanca*, 42°48′S, 65°08′W; *Ea. Gallastegui*, 42°47′S, 65°05′W; and *Ea. El Ranchito,* 42°49′S, 65°36′W). The other six sites were grazed throughout the year. Three of the these grazed sites were located within paddocks (2500 ha each) with a regular stocking rate for the area: 0.11 sheep ha^{-1} in *Ea. El Ranchito* (42°49′S, 65°34′W), and 0·14 sheep ha^{-1} in *Ea. San Luis* (42°38′S, 65°22′W) and *Ea. El Amparo* (42°41′S, 65°38′W). The other three sites (*El Ranchito* (42°49′S, 65°36′W), *Ea. San Luis* (42°39′S, 65°23′W) and *Ea. El Milagro* (42°44′S, 65°38′W) were located near watering points. These sites were heavily grazed with a stocking rate ranging from 0·11 to 0·14 sheep ha^{-1} throughout the year and twice a year with a high stocking rate *c.* 50 sheep ha^{-1} for a few days (Bisigato & Bertiller 1997; Bertiller *et al.* 2002).

At each site, 100 m transects were delineated, each with 14 to 29 stations. At each station (4 × 1 m), the soil surface was examined in the field and all lichen species that formed either patches or carpets on the soil were collected. Crusts from beneath the canopies of shrubs as well as inter-shrub areas were included. Approximately 230 samples were collected and examined in the laboratory for identification of species (Scutari *et al.* 2003). A complete floristic list was constructed for each site and the number of lichen species per crust was recorded.

The lspecies ichen species were hierarchically classified by cluster analysis using Euclidean distances and average linkage, using three criteria: habit (saxicolous or terricolous), thallus type (crustose non areolate, areolate, squamose, or foliose), and colour (black, brown, grey, green, yellow, orange) (Norusis 1997). The photobiont and the type of sexual structure were also observed. The absolute constancy of each species was calculated as the number of sites in which a given species occurred (Mueller-Dombois & Ellemberg 1974). The relative frequency of each species was estimated at each site as the percentage of stations where a given species was present. The significance of differences among stations in mean number of total species, and mean number of species per crust was analysed by one-way ANOVA. The Kruskal–Wallis test was used to evaluate the significance of the differences among grazing levels in non-normally distributed means of relative frequency of each lichen group. Pair-wise comparisons were made by Mann–Whitney's test (Norusis 1997).

Results

Lichen groups

Seven lichen groups were defined (Table 1). Group A ('calcareous lichens'), made up of five saxicolous species, occurred only on calcareous gravels and included endolithic and epilithic species, the latter exhibiting either indistinctly areolate thalli or powdery or microscopic thalli. Group B ('siliceous lichens') consisted of only one species (*Aspicilia contorta*) with distinctly areolate thalli with contiguous areolae growing on siliceous gravels. All the saxicolous species have a green alga as photobiont, apothecia as sexual reproductive structures, crustose growth form and isolated hyphae as means of attachment to the substratum.

The terricolous species clustered into four groups (C, D, E and F). Two crustose species attached by medullary hyphae made up group C ('pale, non-areolate lichens'). Group D ('cyanophyllic, foliose lichens') was comprised of a single species, *Collema coccophorum*, which was the most frequent and abundant lichen in the study area; this had a blackish foliose thallus and apothecia. The *C. coccophorum* specimens were mostly sterile and exhibited considerable morphological variation. Since *C. coccophorum* belongs to a species-group whose members are very difficult to identify except when fertile (Degelius 1954), all our material is currently under further critical examination. Group E ('brown, squamose lichens') included two squamose, brown pyrenolichens. Group F ('pale, areolate lichens') is composed of four species with apothecia and pale thallus (i.e. neither brown or black) mostly of an areolate growth form and included the terricolous form of *Aspicilia contorta*. As a result of the thallus colour and size, three of the four species in this group are the most conspicuous lichens in the study area: *Psora decipiens* (pinkish), *Acarospora schleicheri* (yellow, K −) and *A. contorta* (whitish grey). Except for *Fulgensia subbracteata* (a much smaller species with yellow, K+ purple, areolate thalli) all members of group F exhibited thin to thick, branched rhizinose strands as attachment/propagation structures. All species of groups C, E, and F have a green alga as photobiont.

Abundance of species and lichen groups at different levels of grazing

The number of species present varied between the sites (Table 1). The number of species present at non-grazed sites varied between 12 and 15 (considering *A. contorta* on soil and siliceous gravel as different species). At sites with regular grazing the number of species varied between 6 and 12, while in the heavily grazed sites, the number ranged from 0 to 4 (Table 2). *Collema coccophorum* (the only cyanophyllic, foliose lichen, group D) and *A. contorta* on siliceous gravels (group B) were the most constant species in the study being recorded at 8 of the 9 sites. In contrast, the least constant species were: *A. schleicheri* and *P. decipiens* ('pale areolate lichens', group F). Since *A. schleicheri* was only found in one non-grazed site it may be considered as rare in the study area. Moreover, all saxicolous species on calcareous gravels making up group A (*Acarospora heppii, Caloplaca holocarpa*, *Catillaria lenticularis*, *Rinodina bischoffii* and *Sarcogyne regularis*), species of group C (the two pale crustose non-areolate lichens: *Lecanora dispersa* and *Rinodina mucronatula*), two species of group F (*A. contorta* on soil and *F. subbracteata*), and the two species, *Catapyrenium squamulosum* and *Endocarpon pusillum,* of group E (brown, squamose lichens) showed intermediate constancy. Except for *S. regularis* (group A), none of the species belonging to groups A, C, and F were found in heavily grazed areas.

Mean species richness and the mean number of species per crust did not vary between non-grazed and regularly grazed sites, but both attributes were significantly lower in the heavily grazed sites (Fig. 1). Except for group B (*A. contorta*), the lichen group with the highest constancy of species showed the highest relative frequency, and this frequency was significantly reduced by heavy grazing (Fig. 2, Table 2). In the case of groups D, E, and F, the relative frequency did not vary between non-grazed

TABLE 1. *Groups of soil-associated lichens resulting from cluster analysis based on ecological (habit) and morphological characters (thallus type and colour)*

Habit		Thallus type	Colour	Lichen group	Species
Saxicolous	Calcareous	Crustose non-areolate	Black	**A**	*Rinodina bischoffii* (Hepp) A. Massal
			Orange		*Sarcogyne regularis* Körb
			Green		*Caloplaca holocarpa* (Hoffm.)A. E. Wade.
		Areolate	Brown		*Catillaria lenticularis* (Ach.)Th.Fr.
					Acarospora heppii (Nägeli ex Hepp) Nägeli
	Siliceous		Whitish/Green	**B**	*Aspicilia contorta* (Hoffm.) Kremp.(on gravel)
Terricolous		Crustose non-areolate	Green/Grey	**C**	*Lecanora dispersa* (Pers.) Sommerf.
			Grey		*Rinodina mucronatula* (Magn.)
		Foliose	Black	**D**	*Collema coccophorum* Tuck.
		Squamose	Brown	**E**	*Catapyrenium squamulosum* ((Ach.) Breuss
					Endocarpon pusillum Hedwig.
		Areolate	Yellow	**F**	*Acarospora schleicheri* (Ach.) A. Massal
			Orange/Pinkish		*Fulgensia subbracteata* (Nyl.) Poelt
					Psora decipiens (Hedw) Hoffm.
			Whitish/Green		*Aspicilia contorta* (Hoffm.) Kremp. (on soil)

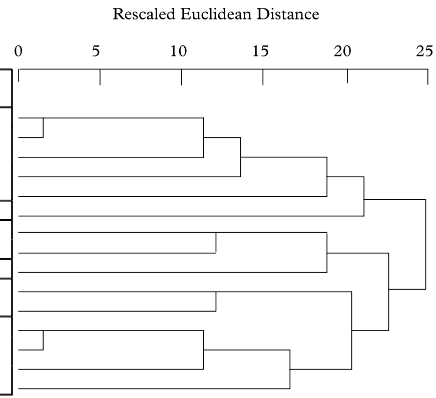

TABLE 2. *Relative frequency (%), and constancy of soil-associated lichens at nine sites in Patagonian rangelands, together with total number of species and mean number of species per station at each site in Patagonian rangelands. LB: Laguna Blanca, EG: Estancia Gallastegui, ER: Estancia. el Ranchito, ESL: Estancia San Luis, EA: Estancia el Amparo, EM: Estancia el Milagro. Ng: non-grazed, rg: regularly grazed, hg: heavily grazed.* n=*number of stations per site. Lichen groups as in Table 1. Species were ordered by decreasing relative frequency*

Lichen group	Species	LB ng *n*=29	EG ng *n*=27	ER ng *n*=24	ESL rg *n*=14	ER rg *n*=22	EA rg *n*=20	ER hg *n*=24	EM hg *n*=24	ESL hg *n*=20	Constancy
B	*Aspicilia contorta* on gravel	17·24	17·24	79·20	42·86	3·70	20·00	25	4·2	0	8
D	*Collema coccophorum*	93·20	92·59	100·00	85·71	90·90	100·00	33·30	41·70	0	8
E	*Catapyrenium squamulosum*	48·28	48·14	58·3	35·71	77·27	10·00	4·2	0	0	7
	Endocarpon pusillum	17·24	37·04	29·20	14·28	18·18	15·00	0	0	0	6
F	*Fulgensia subbracteata*	24·14	3·70	25·00	7·14	18·18	5·00	0	0	0	6
	Aspicilia contorta on soil	31·03	10·35	0	14·28	44·40	20·00	0	0	0	5
A	*Sarcogyne regularis*	6·90	40·74	58·30	64·29	0	0	8·30	0	0	5
	Acarospora heppii	6·9	3·70	29·20	28·57	4·54	0	0	0	0	5
	Rinodina mucronatula	10·34	33·33	25·00	14·28	4·54	0	0	0	0	5
	Catillaria lenticularis	3·45	3·70	12·50	7·14	0	0	0	0	0	4
	Caloplaca holocarpa	10·34	7·41	20·80	7·14	0	0	0	0	0	4
C	*Lecanora dispersa*	10·34	14·81	8·30	0	4·54	0	0	0	0	4
	Rinodina bischoffii	3·45	7·41	12·50	14·28	0	0	0	0	0	4
F	*Psora decipiens*	10·34	22·22	0	0	31·82	0	0	0	0	3
	Acarospora schleicheri	13·79	0	0	0	0	0	0	0	0	1
Total number of species			15	14	12	12	11	6	4	2	0
Number of species per crust			3·59	3·37	1·74	3·57	3·55	1·80	1·06	1·00	0

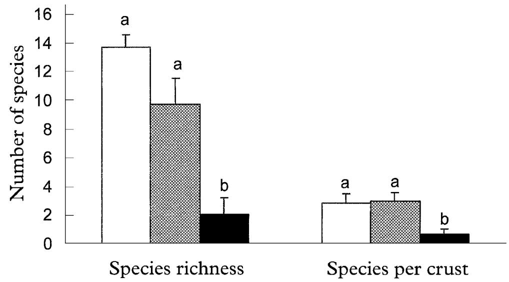

FIG. 1. Mean number of soil-associated lichen species (species richness, *n*=3?) and mean number of species per station (*n*=56–80?) at different grazing levels (±1 SE) in Patagonian rangelands. □ non-grazed; ▩ regularly grazed; ■ heavily grazed. Within each measurement type, columns with different letters are significantly different at $P \leq 0.05$ level.

and regularly grazed sites, whereas in groups A and C, the relative frequency was progressively reduced with increased grazing level.

Discussion

Classification of species into lichen groups

Based on ecological and morphological characters, soil-associated lichens of north-eastern Patagonia were clustered into two major groups, the saxicolous and the terricolous species, which were subsequently subdivided into two and four groups, respectively (Table 1). In the study area, as in most arid regions in Australia (Eldridge 2001), crustose lichens were dominant among the soil-associated species. In our study, 13 of the 14 lichen species found were crustose. As mentioned above (see Introduction), when clustering species some problems were encountered in fitting some of them precisely into morphological categories. Most species could be clearly assigned to the saxicolous or terricolous groups, except *Aspicilia contorta* which was found colonizing both siliceous gravels and soil. Furthermore, the terricolous species *Psora decipiens* was included in the group of 'pale, areolate lichens' but it may also present a squamose thallus. Specimens referred here to as *Collema coccophorum*, the only foliose lichen in the study area, exhibited considerable variation in thallus type ranging from distinctly foliose to granular or coralloid.

Abundance of species and lichen groups in non-grazed and grazed sites

In the study area, as in other arid ecosystems (Eldridge & Koen 1998), disturbance by grazing reduced lichen abundance. The relative frequency and the number of species were significantly higher in non-grazed and regularly grazed sites than in heavily grazed sites. Heavy grazing affected a large number of species but the saxicolous lichens colonizing calcareous gravels (group A) were one of the most sensitive groups. This negative effect of grazing is probably the result of trampling, since calcareous gravels dominate the soil surface in inter-patch areas where trampling effects are stronger than beneath the canopy of spiny-shrub patches. Furthermore, calcareous gravels have a much less resistant structure than siliceous gravels and trampling can cause their fragmentation. Similarly, some lichens of group F with large areoles such as *Psora decipiens* could be more sensitive to trampling than foliose, or squamose lichens. The decrease in abundance of *P. decipiens,* may be comparable to the response of *Psora crenata* and *P. decipiens* to grazing in Australia, where these species were regarded as indicators of disturbance (Eldridge & Ferris 1999; Belnap & Eldridge 2003). Other factors may also reduce the frequency of species. For example, the low constancy and relative frequency of *A. schleicheri* in the study area may be related to the high calcium carbonate content of the soils of the area. This species has been identified as an indicator of low calcium carbonate in the Great Basin (Rosentreter & Belnap 2003).

Two species, *A. contorta* on gravels (group B) and *C. coccophorum* (group D), might be the most resistant to grazing since they exhibited the highest constancy in the study area. The relative frequency of *A. contorta* (on gravels) was not significantly affected by grazing levels and could be related to the

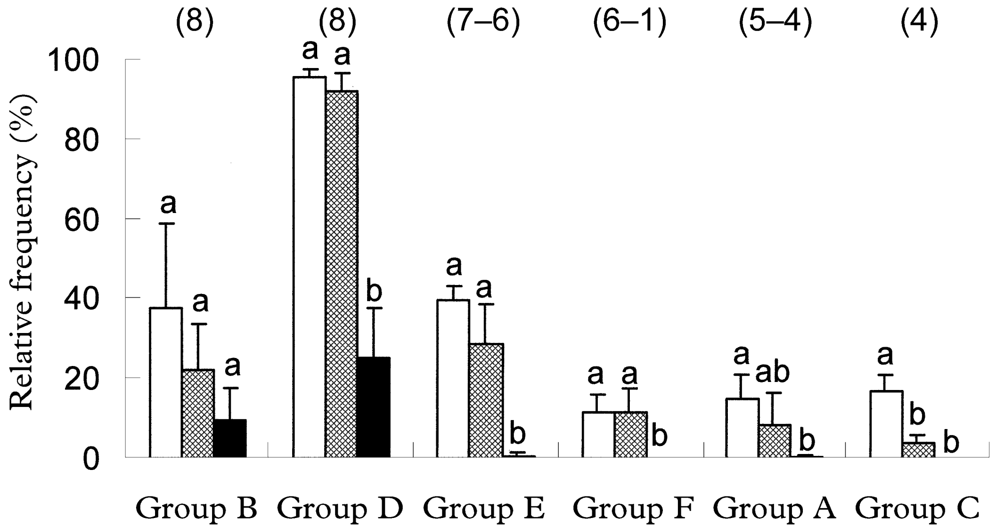

FIG. 2. Effect of grazing level on mean relative frequency of soil-associated lichen groups A, B, C, D, E, and F as defined in Table 1 (n=3, ± 1 SE). The range of constancy values for species within each lichen group is given in parentheses. □ non-grazed; ▩ regularly grazed; ■ heavily grazed. Within each lichen group, columns with different letters are significantly different at the $P \leq 0.05$ level.

resistance of siliceous gravels to trampling. The relative frequency of *C. coccophorum*, although reduced in heavily grazed sites, nevertheless still remained very high. These results are consistent with those reported by Belnap and Eldridge (2003) for grazed and non-grazed sites in Australia indicating that *C. coccophorum* is one of the lichen species least affected by trampling around watering points.

Lichens containing cyanobacteria that fix atmospheric nitrogen, mostly in the genera *Collema*, *Peltula* and *Heppia*, have been recorded as resistant to grazing and are pioneers in overgrazed areas (Eldridge & Tozer 1997). Further, Eldridge (1998) considered *Endocarpon pusillum* as a pioneer species in Australia since it occurred in degraded sites. In the present study, this species and the other component of group E (*C. squamulosum*) were highly constant in the study area. *Endocarpon pusillum*, however, was not found in heavily grazed sites and *Catapyrenium squamulosum*, although present in one heavily grazed site, was relatively infrequent.

Conclusions

Six well-defined groups of soil-associated predominantly crustose lichens (two saxicolous and four terricolous) have been established based on ecological and morphological characters. These lichen groups were differentially distributed amongst three sites subjected to different levels of grazing. Species of three lichen groups (group A: *Rinodina bischoffii*, *Caloplaca holocarpa*, *Catillaria lenticularis*, *Acarospora heppii*; group C: *Lecanora dispersa*, *Rinodina mucronatula* and group F: *Psora decipiens*, *Fulgensia subbracteata*, *Aspicilia contorta* on soil) were identified as very sensitive to grazing, and are suggested as potential bioindicators of grazing disturbance. In contrast, it is suggested that the saxicolous form of *Aspicilia contorta* (group B), and *Collema coccophorum* (group D) are comparatively resistant to grazing disturbance.

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References

Belnap, J., Kaltenecker, J. H., Rosentreter, R., Williams, J., Leonard, S. & Eldridge, D. (2001) *Biological soil crusts: Ecology and Management.* Technical Reference 1730–2. Denver: U.S. Department of the Interior, Bureau of Land Management, U.S. Geological Survey, Printed Materials Distribution Center.

Belnap, J. & Eldridge, D. (2003) Disturbance and recovery of biological crusts. In *Biological Soil Crusts: Structure, Function, and Management. Ecological Studies* **150** (J. Belnap & O. L. Lange, eds): 363–383. Berlin: Springer-Verlag.

Bertiller, M. B. (1998) Spatial patterns of the germinable soil seed bank in northern Patagonia. *Seed Science Research* **8:** 39–45.

Bertiller, M. B., Carrera, A. L., Bisigato, A. J. & Sain, C. L. (2001) Degradation of Patagonian ecosystems of Argentina by grazing. A regional approach. *Simposio Internacional: Medio ambiente y uso sustentable de recursos naturales en América Latina. Desafíos para la cooperación interdisciplinaria.* Lima, Perú. 15–19 November.

Bertiller, M. B., Ares, J. O. & Bisigato, A. J. (2002) Multiscale indicators of land degradation in the Patagonian Monte, Argentina. *Environmental Management* **30:** 704–715.

Bisigato, A. J. & Bertiller, M. B. (1997) Grazing effects on patchy dryland vegetation in northern Patagonia. *Journal of Arid Environments* **36:** 639–653.

Büdel, B. (2001) Biological crusts of South America. In *Biological Soil Crusts: Structure, Function, and Management. Ecological Studies* **150** (J. Belnap & O. L. Lange, eds): 51–55. Berlin: Springer-Verlag.

Cabrera, A. L. (1976) *Regiones Fitogeográficas Argentinas.* Enciclopedia de Agricultura y Jardinería Tomo II, 2nd ed. Buenos Aires: ACME

Degelius, G. (1954) The lichen genus *Collema* in Europe. *Symbolae Botanicae Upsaliensis* **13:** 1–499.

del Valle, H. F. (1998) Patagonian soils: a regional synthesis. *Ecología Austral* **8:** 103–123.

Eldridge, D. J. (1998) Soil crust lichens and mosses on calcrete-dominant soils at Maralinga in arid south Australia. *Journal of Adelaide Botanic Garden* **18:** 9–24.

Eldridge, D. J. (2001) Biological soil crusts of Australia. In *Biological Soil Crusts: Structure, Function, and Management. Ecological Studies* **150** (J. Belnap & O. L. Lange, eds): 119–131. Berlin: Springer-Verlag.

Eldridge, D. J. & Ferris, J. M. (1999) Recovery of populations of the soil lichen *Psora crenata* after disturbance in arid south Australia. *Rangelands Journal* **21:** 194–198.

Eldridge, D. J. & Greene, R. S. B. (1994) Microbiotic soil crusts: a review of their roles in soil and ecological processes in the rangelands of Australia. *Australian Journal of Soil Research* **32:** 389–415.

Eldridge, D. J. & Koen, T. B. (1998) Cover and floristics of microphytic soil crusts in relation to indices of landscape health. *Plant Ecology* **137:** 101–114.

Eldridge, D. J., Rosentreter, R. (1999) Morphological groups: a framework for monitoring microphytic crusts in arid landscapes. *Journal of Arid Environments* **41**: 11–25.

Eldridge, D. J. & Tozer, M. E. (1997) *A Practical Guide to Soil Lichens and Bryophytes of Australia's Dry Country.* Sydney: Department of Land and Water Conservation.

Graetz, R. D. & Tongway, D. J. (1986) Influence of grazing management on vegetation, soil structure and nutrient distribution and the infiltration of applied rainfall in a semi-arid chenopod shrubland. *Australian Journal of Ecology* **11:** 347–360.

Körner, C. (1994) Scaling from species to vegetation: the usefulness of functional groups. In *Biodiversity and Ecosystem Function* (E. D. Schulze & H. A. Mooney, eds): 117–140. Heidelberg: Springer Verlag.

Memmott, K. L., Anderson, V. J. & Monsen, S. B. (1998) Seasonal grazing impact on cryptogamic crusts in a cold desert ecosystem. *Journal of Range Management* **51:** 547–550.

Mueller-Dombois, D. & Ellenberg, H. (1974) *Aims and Methods of Vegetation Ecology*. New York: Wiley and Sons.

Norusis, M. J. (1997) *SPSS Advanced statistics 7.5. SPSS*, Chicago.

Rosentreter, R & Belnap, J. (2003) Biological soil crusts of North America. In *Biological Soil Crusts: Structure, Function, and Management. Ecological Studies* **150** (J. Belnap & O. L. Lange, eds): 31–55. Berlin: Springer-Verlag.

Scutari, N. C., Diez, B. D. & Lumbsch, H. T. (2002) New records of soil-associated lichens from northeastern Patagonia (Chubut, Argentina). *Mycotaxon* **83:** 369–383.

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