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Morphological groups: a framework for monitoring microphytic crusts in arid landscapes

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Microphytic crusts are important components of arid and semi-arid systems. They play important roles in ecosystem processes and are useful indicators of landscape health. Despite their importance, microphytic crusts and their component organisms are little understood, largely due to their small size and the difficulty in identifying them to species level. The influence of microphytic crust organisms on soils and landscapes, and their response to and recovery from perturbation is related largely by their morphology or external appearance. In this paper we examine the relationships between morphological groups of lichens and bryophytes associated with soil crusts, and their roles in ecosystem processes in rangelands. Using published and unpublished data we propose that the morphological group approach is a more efficient method of monitoring soil crust organisms than one based on the traditional species approach.

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Introduction

Arid and semi-arid grazing lands or rangelands cover large areas of North America, Eurasia, South Africa, South America, the Middle East and Australia. Rangelands are characterized by a low and generally unreliable rainfall, typically sparse native pastures and grazing by introduced or native ungulates. Plant and animal productivity is limited by climatic uncertainty and generally infertile soils, and the productivity of large areas of land is often reduced by erosion and other forms of land degradation.

One of the most inhospitable environments for organisms is on the soil surface in hot and cold deserts. Open spaces between vascular plants in arid and semi-arid rangelands provide a niche for microphytic crusts, also known as cryptogamic, microbiotic or biological crusts (Harper & Marble, 1988; West, 1990; Eldridge & Greene, 1994). These crusts result from an intimate relationship between the top few millimetres of the soil and an assortment of lichens, mosses, liverworts, cyanobacteria, algae, fungi and bacteria (Chartres, 1992). Because of their close association with the soil surface, crusts play a vital role in ecosystem processes in rangelands. They are most well developed, in terms of numbers of species and cover, on uncultivated, fine-textured soils with a sparse cover of rock or gravel, in areas where fire frequency is low (West, 1990). In areas where they are common, they play five major roles: (1) they stabilize the soil against both water and wind erosion (Eldridge & Greene, 1994; Williams *et al.*, 1995; Eldridge & Kinnell, 1997); (2) they regulate the flow of water into soils (Loope & Gifford, 1972; Blackburn, 1975; Danin, 1978; Brotherson & Rushforth, 1983; Eldridge *et al.*, 1997); (3) organisms in the crusts produce nitrogen and organic carbon (Skujins, 1984) which is used by vascular plant seedlings (Belnap *et al.*, 1994); (4) crusts provide favourable sites for the establishment and survival of vascular plant seedlings (Harper & St Clair, 1985; Belnap, 1994; Zaady *et al.*, 1997); and (5) crusts act as refugia for soil invertebrates which are important for decomposition and mineralization processes (Whitford, 1996).

Many soil crust organisms are either undescribed or poorly known, despite lichenological and bryological advances over recent years. Rangeland managers have been slow to embrace microphytic crusts as organisms deserving of study, despite increased knowledge over the past decade of their roles in ecosystem processes (Harper & Marble, 1988; West, 1990; Eldridge & Greene, 1994; Ladyman & Muldavin, 1996). This is due partly to perceived problems with identification, making monitoring a daunting task to all but the most experienced. The problem of identification is exacerbated by the small size of these organisms, which are often poorly developed and/or sterile due to the harsh environments in which they grow (Eldridge & Tozer, 1996 *a*).

Superficially, soil crust organisms can be lumped into two broad groups: those which are visible to the naked eye (thallophytic crusts; Box, 1981) and those which can only be viewed with a microscope (microscopic crusts; West, 1990). Crust organisms are diverse, ranging from unicellular algae and filamentous cyanobacteria, to lichens which are a complex symbiotic union between a fungus and an alga. Mosses may be erect or creeping, and the liverworts may be strap-like (thallose) or leafy.

Structure (or morphology) of many organisms is related to function. In areas where microphytic crusts predominate, there are often strong associations between morphology and function such that particular morphologies indicate the degree to which organisms or groups of organisms can resist or recover from stress. Lichens, in particular, exhibit a wide variety of morphologies, ranging from gelatinous (gel-like), single-layered structures, to the layered crustose (crusty), squamulose (scaly), foliose (leafy) and fruticose (shrubby) forms (Table 1).

In this paper we propose that morphological groups are more efficient indicators of ecological function than individual taxa (species) or groups of species. We discuss the concept of morphological groups as they apply to microphytic crust organisms, drawing on published and unpublished data from arid and semi-arid landscapes worldwide, demonstrating that morphological groups are both cost and time efficient as well as ecologically sound. We discuss the relationships between morphological groups and vital ecosystem processes such as water retention and erosion, and present generalized models exploring the links between morphological groups and their resistance to, and recovery from environmental stress. Finally, we discuss how soil crusts can be monitored using morphological groups rather than individual species.

Table 1. Description of morphological groups of cyanobacteria, lichens and bryophytes (adapted from McCune & Goward, 1995 and Eldridge & Tozer, 1997)

Morphological group	Description	Representative genera
Cyanobacteria		
Cyanobacteria	Blue–green, dark red or blackish single-celled, colonial or thread-like strands in the soil	Microcoleus, Nostoc, Oscillatoria, Scytonema
Lichens		
Gel-like lichens	Lichens with an unlayered thallus becoming jelly-like when wetted. They tend to be blackish in colour and turn blue–green when wet. They have an algal partner which is a cyanobacterium which allows them to fix atmospheric nitrogen	Collema, Leptogium
Crusty lichens	Lichens forming a crust-like growth that is tightly attached to the substrate	Aspicilia, Caloplaca, Diploschistes, Lecidea
Scaly lichens	Lichens with thalli occurring as discrete scales, warts or flakes that can be ear-shaped, convex or concave	Acarospora, Buellia, Catapyrenium, Peltula, Psora
Leafy/Shrubby lichens	Three-dimensional lichens. Leafy (foliose) lichens tend to be flattened, with a definite upper and lower surface. Shrubby (fruticose) lichens tend to be ropy or shrub-like, and are sometimes branched	Cladia, Cladina, Heterodea, Parmelia, Physconia and some Xanthoparmelia
Bryophytes		
Mosses	Plants green and erect; leaves (with mid-vein) arranged around the stem	Bryum, Crossidium, Didymodon, Pottia
Liverworts	Prostrate, green, leafy plants without a mid-vein (leafy liverwort), or Y-shaped and prostrate on the soil surface with roughly a triangular cross-section (strap-like liverwort)	Riccia, Cleva

The concept of morphological groups

Morphological groups, structure and function

Non-lichenized microphytes form natural morphological groups (Table 1) which include the cyanobacteria that are almost invisible to the naked eye, and algae and bacteria which are difficult to distinguish without microscopy and are not treated at field-based evaluations. Although algae and bacteria are present in most systems, they are not included in this classification as is it almost impossible to determine their presence in a field setting. The other group, the bryophytes, comprises two distinct morphological groups, mosses and liverworts, which can further be subdivided where necessary.

Lichens can be divided on the basis of their major growth forms (Jahns, 1973), and morphological groups such as gel-like (gelatinous), crusty (crustose), scaly (squamulose), leafy (foliose) and shrubby (fruticose; Table 1) are frequently the starting point for artificial identification keys for lichens. Each combination of a fungus and alga produces a separate lichen, the external appearance of which depends on the arrangement of the algal cells within the composite structure. Some primitive lichens consist of loose fungal mycelia enclosing scattered groups of algae, or gelatinous colonies of algae penetrated by fungal hyphae. These unlayered lichens are typical of genera such as *Leptogium* and *Collema*. More complex and typical lichens consist of defined layers; an upper fungal cortex, algal layer, medulla and lower cortex, resulting in a layered lichen thallus or body. The external appearance or habit of a lichen results from a complex interaction of its anatomy and growth form. Lichen shape depends on the anatomy of the cortex, the outer layer which is comparable to the epidermis of a plant leaf. These outer cells of the cortex can differentiate to form thin fine hairs, or a powdery layer, or even a series of small perforations. The interaction between the alga and fungus in a lichen determines the final anatomy and morphology of the fungal component of the lichen, and therefore the shape and biology of each lichen species formed (James & Henssen, 1976). The external morphology and the internal structure are directly related (Jahns, 1973), and morphology is therefore a good indication of the lichen's ability to function physiologically (Lange & Green, 1996) and ecologically.

Morphological groups and landscape monitoring

Morphological groups, guilds or life-forms have been used to evaluate microphytic (cryptogamic) communities in forested ecosystems (Cornelisson & ter Stegge, 1989; Carleton, 1990; McCune, 1993, 1994; Rosentreter, 1996). In some forest systems, groups of lichens have been used to provide an early warning sign of forest dieback (Scott & Hutchinson, 1990). Apart from exploratory research correlating morphological groups with landscape health and stability in eastern Australia (Eldridge & Koen, 1998), and some preliminary use in bunchgrass deserts in Montana (Ponzetti *et al.,* 1998), we are unaware of extensive use of morphological groups of soil lichens and bryophytes in routine evaluation of rangelands.

Traditional rangeland assessment techniques are based on measurement of plant and soil attributes within sampling units (quadrats), or along transects (e.g. point-based methods) stratified within relevant vegetation communities or landscape elements (Ludwig & Tongway, 1993). Vascular plant attributes such as foliage cover and frequency are recorded, along with measurements of soil and landscape attributes which are likely to reflect changes in landscape health (Tongway, 1994; Pellant, 1996; Whisenant & Tongway, 1996). Whilst many scientists acknowledge the close links between microphytic crusts and changing land condition (Klopatek, 1990), biologists have rarely recorded these organisms in routine vegetation inventories (West, 1990).

Any mention of microphytic crust organisms is usually confined to broad classes of organisms (e.g. mosses or lichens), or used only in passing reference. The recording of data within broad classes is often misleading or uninformative, as different morphological groups (e.g. gel-like *vs.* leafy lichens) respond differently to physical disturbance and provide different ecological functions (Kaltenecker, 1997). This is probably due to difficulties in identifying the organisms *in situ*, lack of a standardized sampling procedure with often undue emphasis on laboratory culturing, the variability in conspicuousness of these organisms (particularly when the soils are dry) and their patchiness in time and space (West, 1990). West (1990) further advocates more rapid, non-destructive, morphologically- or functionally-based approaches to *in situ* field identification to draw more attention to microphytic crusts. We believe that morphological groups within broad classes of microphytes address the concerns of West (1990).

Ecological efficiency of morphological groups

Morphology largely determines the ecological functioning of microphytic crust organisms in relation to landscape processes and disturbance. Morphological groups also convey to non-taxonomists a better image of what the organism resembles and therefore its likely impact on soils and landscapes (Table 2). Morphologies are not locally or even continent-specific, and although many different species may occur

Table 2. *Advantages and disadvantages of using morphological groups compared with traditional methods based on identification to species level. No level of importance is attached to their order*

Advantages	Disadvantages
Biological considerations	
• Communicates an image • Communicates a function • Eliminates confusion caused by taxonomic changes • Is independent of continent, region or area	• Some organisms are difficult to characterize even to a morphological group • Different workers may place species in different morphological groups • Differences in colour may be affected by the abiotic environment
Efficiency considerations	
• Requires less training • Easier to measure with less indecision and greater repeatability • More rapid and statistically powerful data analyses • No dangerous chemicals required in field • Allows more rapid field measurements • Cheaper to monitor	• A change in species composition occurring within a morphological group may go undetected

throughout the world, all fit into a limited set of morphological groups. Arid lands in particular tend to be covered by microphytic crust lichens and mosses which rarely or only episodically reproduce sexually (Rosentreter, 1986; Eldridge & Tozer, 1996 a; Kaltenecker et al., 1996), making identification to species level difficult or even impossible.

Morphological groups also eliminate the need for complex and often confusing changes in nomenclature through time and between regions (Table 2). Whilst some groups are proportionally well known, often causing chaos in the literature (Friedmann & Galun, 1974), others are taxonomically poorly known (West, 1990). Some authorities split taxa whilst others lump them, creating enormous difficulties when comparing ecological or taxonomic studies between regions. A knowledge of the genera comprising morphological groups allows non-specialists to equate unfamiliar lichens or bryophytes in the literature with morphologically similar genera in their geographic area. Taxonomic changes over time are obvious to specialists, but new students, generalist ecologists and land managers cannot properly interpret older studies.

Efficiency-based in situ morphological groups are much easier and faster to identify by the observer. Observers can be trained rapidly to identify morphological groups, allowing more sites to be monitored per unit time with fewer specialists. When using a large number of categories (i.e. species) to characterize sites, numerous zeros are likely to be recorded due to the absence of particular species, making detailed comparisons between sites difficult. Pooling a large number of functionally similar species into a reduced number of morphological groups will tend to decrease the size and number of zeros in the data set, allowing more rapid and less cumbersome field recording and making the data more amenable to familiar methods of statistical analysis.

Assigning species to morphological groups

Different levels of precision may be required for different levels of monitoring. These levels can be achieved by using a hierarchical system of classification which can be adapted according to the situation. This also enables comparisons to be made between different studies. Proposed criteria for separating organisms into morphological groups are listed in Table 3.

Morphological groups as indicators of landscape function

Morphological groups of crust organisms, particularly lichens, can be ranked according to their effectiveness at maintaining vital ecosystem functions. Conceptual models are presented which enable rangeland managers to predict how changes in management influence landscape processes by altering the composition of microphytic crust communities.

Morphology and water erosion control

Morphological types which provide a continuous ground cover are likely to reduce raindrop impact, whilst those which enhance soil roughness and surface detention are likely to influence overland flow processes. Moss-dominated surfaces are most effective, lichen-dominated surfaces of intermediate effectiveness and cyanobacterial-dominated surfaces least effective at protecting the soil against raindrop impact (Johnson & Rosentreter, 1988; Tchoupopnou, 1989). Mosses with twisting leaves such as Grimmia and Didymodon spp. reduce raindrop impact and trap sediments mobilized by overland flow (Danin et al., 1989; Danin & Gaynor, 1991; Eldridge, 1998 a).

Table 3. *Characteristics used to assign microphytic crust taxa into morphological groups*

Morphological group	Features		
	Primary	Secondary	Tertiary
Cyanobacteria*	Filament type: filamentous or non-filamentous		
Lichens			
Gel-like			
Crusty	Colony size: small (< 10 mm) or large (> 10 mm)	Thallus continuity: continuous or discontinuous	Thallus colour: white, brown green, black etc.
Scaly	Hair-like attachments (rhizines): present or absent	Thallus continuity	Thallus colour
Leafy	Thallus type: attached or unattached	Thallus colour	
Shrubby	Thallus height: short (< 10 mm) or tall (> 10 mm)	Thallus colour	
Bryophytes			
Mosses	Growth form: erect or postrate	Canopy density: dense or open	Plant height
Liverwort	Thallus type: flattened or leafy		

*Algae and bacteria are not included in this classification.

Scaly lichens are moderately effective at controlling water erosion because they enhance surface roughness and the sinuosity of flow, and therefore reduce the transportability of rainwater (West, 1990). Those species with thread-like attachments (rhizines) enhance soil stability by binding erodible micro-aggregates into non-erodible aggregates (> 0·25 mm; Eldridge & Greene, 1994). Many have convex surfaces (e.g. *Endocarpon* and *Psora* spp.) which trap water and soil particles. Some strap-like liverworts respond to rainfall by increasing their surface area up to five-fold (Rogers, 1994), providing effective barriers to raindrop action. The generally short-lived and structurally less complex cyanobacteria and gel-like lichens such as *Collema coccophorum* are least effective at protecting the surface against water erosion (Eldridge, 1996).

Morphology and wind erosion control

Microphytic crusts are known to increase threshold wind velocities and reduce soil flux compared with crust-free surfaces (Williams *et al.*, 1995; Leys & Eldridge, 1998). Tall mosses such as *Tortula ruralis* and *Barbula calycina* and shrubby lichens provide effective barriers to soil particles (> 100 μm) which are transported along the surface by saltation and creep. These mosses also provide sites for entrapment of coarse particles (Eldridge, 1998 *a*). Scott (1985) showed in laboratory experiments that the

flexing movements of *B. calycina* leaves prevented them from being inundated by sand grains, allowing moss stems to 'swim through' successive layers of sand. Other arid area mosses such as *Grimmia messapotamia* are effective traps of airborne silts and clays (Danin *et al.*, 1989; Danin & Gaynor, 1991). They trap dust between their stems and leaves and after small rainfall events are able to grow up through layers of accreting soil, effectively fixing aeolian soils *in situ*. Morphological types such as scaly, leafy and shrubby lichens, which tend to increase surface roughness, reduce wind erosion by absorbing energy from saltating sand grains and/or reducing surface drag and therefore the erosive power of the wind.

Whilst the cyanobacteria and even gel-like lichens are acknowledged as effective barriers to detachment (Dulieu *et al.*, 1977; Tsoar & Tyge Moller, 1986) largely through their roles in soil aggregation (Belnap, 1994), they are the least effective at entrapment of detached particles. In some environments, however, these organisms increase in size and surface roughness with age, and this roughness may act as a physical trap.

Morphology and soil water relations

Although little is known about moisture retention in arid area mosses, it is thought to be considerable (Pocs, 1982). Along with liverworts and shrubby lichens, mosses absorbs relatively large amounts of water during wet periods and, depending on their anatomy and physiology, retain water on the soil surface. Unlayered gel-like lichens can absorb up to 13 times their weight in water compared with layered crusty, scaly and leafy lichens which absorb only up to three times their weight (Blum, 1973; Galun *et al.*, 1982). Cyanobacteria too are capable of absorbing up to eight times their weight in water almost instantaneously (Belnap & Gardner, 1993), increasing the water-holding capacity of coarse textured soils (Campbell *et al.*, 1989). Cyanobacteria such as *Microcoleus vaginatus* use this moisture to produce sheath material. Gel-like lichens are generally dark coloured, absorbing more solar radiation and reaching higher temperatures than lightly-coloured crusts (West, 1990). Evaporation rates are likely to be greater, however, on darker surfaces. The extent to which the greater water-holding capacity of gelatinous lichens and cyanobacteria is offset by increased evaporation is unknown.

Scaly and leafy lichens can probably retain only small amounts of moisture, though no empirical data are available. Crusty lichens are least effective at moisture retention, and field trials suggest that infiltration through these lichens is almost negligible despite the presence of a lower surface which is in intimate contact with the soil surface. Their flat surfaces tend to restrict the accumulation of water on the soil surface, resulting in low hydraulic gradients.

Morphological groups, landscape stability and recovery from disturbance

Morphological groups and ecosystem resilience

Given their marked influence on ecosystem processes (Harper & Marble, 1988; West, 1990; Eldridge & Greene, 1994), it is reasonable to expect that microphytic crusts would be key indicators of ecosystem health (Eldridge & Koen, 1998). Microphytic crust organisms are suitable response indicators (Hunsaker & Carpenter, 1990), i.e. they indicate the biological condition of the resource at scales ranging from the ecosystem and community levels, to that of the individual organism. As long-term

landscape stability is intimately linked with the ability of organisms to resist or recover from disturbance, it follows that groups which are relatively intolerant of disturbance should be suitable indicators of landscape health. A generalized model relating susceptibility of morphological groups to disturbance is given in Fig. 1.
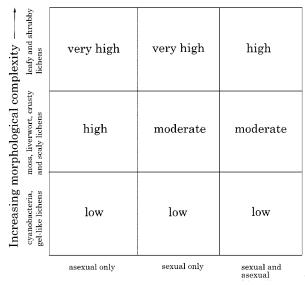
In arid South Australia, Rogers & Lange (1971) demonstrated that the gel-like lichen *Collema coccophorum* and the scaly lichen *Heppia lutosa* (= *H. despreauxii*) were least affected by sheep tramping. The scaly *Psora decipiens* and *Catapyrenium lachneum* (= *Dermatocarpon lachneum*) were only found at distances greater than about 150 m from the water point. Crusty growth forms (e.g. *Diploschistes thunbergianus* and *Toninia sedifolia*) were similarly affected by disturbance, being found at intermediate distances (100–200 m) from the watering point.

The susceptibility of shrubby and some leafy lichens to disturbance is high to very high, depending on their relative reproductive plasticities. Species reproducing both sexually and asexually have higher relative tolerances to disturbance, whereas those which reproduce either sexually or asexually are quite intolerant (Fig. 1). Several studies (Rogers & Lange, 1971; Eldridge & Tozer, 1996 *b*; Eldridge, 1998 *b*; Eldridge & Koen, 1998) provide strong evidence that foliose lichens, particularly those unattached to the soil, are the most susceptible to physical disturbances.

Detailed studies on calcareous soils at Maralinga, an area of Australia where nuclear test were carried out in the 1950s, reveal that recovery to full crust cover (approx. 40% cover) occurs after about 40 years (Eldridge, 1998 *b*). The major floristic difference between undisturbed sites and those with 40 years recovery was the presence of the attached leafy lichens *Xanthoparmelia pumila*, *X. alternata* and *X. constipata*, and the unattached leafy lichens *Chondropsis semiviridis* and *X. convoluta*. A similar conclusion was reached by McCracken *et al.* (1983) for *Xanthoparmelia chlorochroa* spp. *sens. lat.* The reasons why leafy lichens are intolerant to disturbance relates to their reproductive strategies and dispersal mechanisms. Fertile leafy lichens growing on soil are rarely encountered in arid Australia and are thought to produce sexual reproductive structures at intervals of less than 1 in 20 years (J. Elix, pers. comm., 1995). Recolonization during normal years is probably through dispersal of detached fragments, possibly via low levels of natural disturbance by animals and/or wind and water erosion (Bailey, 1976; Eldridge, 1996). Although low rates of trampling may assist this dispersal, excessive trampling leads to complete destruction of the lichens and destabilization of the soil surface (Eldridge & Tozer, 1996 *b*). Most leafy lichens have growth rates of less than 1–5 mm year^{-1} (Hale, 1983). Slow growth exacerbates their susceptibility to physical damage when trampled. In North America, low tolerance to trampling has also been reported for unattached lichens (Rosentreter, 1994). Although the species vary between North American and Australian rangelands, none of the unattached lichens commonly produce specialized sexual or asexual structures (Rosentreter, 1994; Eldridge & Tozer, 1996 *b*).

Reproductive strategy as an indicator of recolonization rate

Rates of recolonization of morphological groups are likely to be a function of the morphology and the ability of organisms to exploit a range of sexual or asexual reproductive strategies (Fig. 2). Whilst long-range spore transport is frequently invoked to explain the dispersal of lichens and bryophytes, particularly those with extensive circum-polar distributions (Hirst & Hurst, 1967; Rogers & Lange, 1972), there is little direct evidence to support this. Given the low probability of a fungal spore and compatible alga reaching a suitable substrate simultaneously, it is more probable that local recolonization is independent of spore dispersal. Most dispersal is probably by asexual structures such as isidia and soredia which contain the full complement of both the fungal and algal components (Hale, 1983).
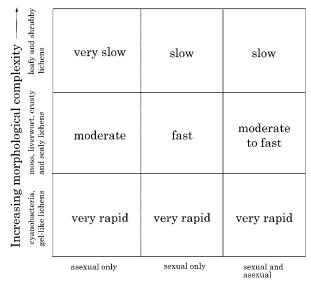
Figure 1. Susceptibility of morphological groups to disturbance as a function of morphological complexity of the organisms and the diversity of their reproductive strategies.

Studies by Johansen *et al.* (1984) demonstrated the rapid recovery, within 2 years of a wildfire, of the gel-like lichen *Collema tenax* and the moss *Pterygeneurum ovatum*. They attributed this recovery to abundant spore production by *Pterygeneurum*, and the asexual wind- and water-dispersed fragments of *Collema*. The results suggest that gel-like lichens such as *Collema*, and weedy ephemeral mosses such as *Bryum*, *Funaria* and *Pterygeneurum* spp. which are able to exploit sexual and asexual strategies, are more tolerant of disturbance than those relying on sexual reproduction alone (During, 1979; Hale, 1983; Longton, 1988; Rosentreter, 1994).

Field-based procedures for monitoring rangelands using morphological groups

Similar sized plots or transects used for general rangeland studies can be used for measuring cover and abundance of morphological groups of microphytic crusts, though smaller quadrat sizes may be appropriate in some areas. At many rangeland sites where the vegetation is strongly patterned, such as in bunchgrass communities, the line intercept method is often used to record vegetative cover. In many rangeland studies where crust cover is extensive, cover classes within smaller nested quadrats, e.g. 20 cm × 50 cm plots, may be easier to use to measure vegetative cover. In higher rainfall rangelands in eastern Australia where grass cover is extensive, cover and abundance of morphological groups as well as all species has been assessed using small cores (approx. 4 cm^2) of soil surface placed under a dissecting microscope (D.J. Eldridge, unpublished data). In the rangelands of Idaho, U.S.A., the line intercept has been used extensively by the Bureau of Land Management to measure both vascular vegetation and microphytes (Kaltenecker *et al.*, 1996; Kaltenecker, 1997). The dominant morphological group within each centimetre is recorded along a number of 10 or 20 m line transects, and the coverage for each morphological group is converted to a percentage of the total line transect distance. Some morphological groups such as small

Figure 2. Capacity of morphological groups to recolonize after disturbance as a function of morphological complexity of the organisms and the diversity of their reproductive strategies. Recolonization rates: very rapid = < 6 months; fast = 6–12 months; moderate = 1–5 years; slow = 5–10 years; very slow = > 10 years.

mosses are difficult to see in the field when dry. A useful technique is to spray a fine stream of water along the transect prior to measuring. This allows a clearer definition of some groups such as liverworts which, when dry, are superficially similar to scaly lichens.

At each site, representative specimens of each species should be retained as voucher specimens. Voucher specimens need to include all of the variation within a morphological group. For example, some species within the scaly lichen group will have fine hair-like attachments (rhizines) whilst others will not. Similarly, there may be slight differences in colour or shape. This rapid assessment saves time and energy, and an expert can identify the individual species within a group at a later stage if he or she is interested in biodiversity. Specimens should be properly curated, databased and stored in appropriate herbaria. Taxa growing on soil may need special pretreatment to prevent them from disintegrating over time.

A note of caution

The use of morphological groups is highly dependent upon the objectives of the particular study, and therefore morphological groups may not always be appropriate. Whilst morphological groups are appropriate for broad scale or regional monitoring, they will probably be too coarse to allow the detection of rare or uncommon species in a study where the aim is to document total species diversity. When working in a new area or with unfamiliar species, it is recommended that initial measurements be made at the species level. Analyses can be undertaken at a species level, and the data later collapsed and re-analysed at the morphological group level to compare the results (Ponzetti *et al.*, 1998). Whilst this may initially be more time consuming, it allows future monitoring to be undertaken using morphological groups.

Ponzetti *et al.* (1998) offer the following cautions when using the morphological group approach with soil crust organisms. First, recorders must have appropriate training, the degree of which will increase with the complexity of the ecosystem. Second, the decision to use morphological groups must be related to the objectives of the study. As stated above, if a total species inventory is required, then clearly morphological groups are inappropriate. Third, despite the strong correlations between morphological group and organism function for many species, some species will fail to fit neatly within clearly defined groups. For example, not all black lichens are gel-like and thus will not all fix nitrogen. Therefore, to avoid misinterpretation it is imperative that appropriate training be undertaken, in conjunction with the design and testing of morphological groups at a local level (Ponzetti *et al.*, 1998).

Conclusions

Microphytic crusts are integral components of rangeland systems and their presence is often indicative of the condition and trend of these systems. Consequently, measurements of their status at a site are fundamental to rangeland monitoring programmes. Crust organisms are difficult to identify due to their small size, lack of reproductive structures and their often poor development resulting from the harsh environments in which they occur. This makes them poor subjects for monitoring at the species level.

The external appearance or morphology of lichens, and to a lesser extent bryophytes, is often indicative of their function in arid systems. Morphology is a useful surrogate of the ability of these organisms to influence water relations and erosion, and their tolerance of and recovery from physical disturbance. We maintain that for general monitoring in arid and semi-arid landscapes it is more efficient to use morphological groups than individual species. However, the decision to use morphological groups will depend on the purpose of the study and assumes an *a priori* knowledge of species in the study area, as well as an appropriate level of training by field operators.

Data collection using morphological groups is faster, easier and more efficient and, therefore, more cost effective. Aside from these advantages, morphological group descriptions are often more meaningful to non-specialists, and are more independent of geographical location. Furthermore, the use of morphological groups decreases the confusion caused by changes in nomenclature.

For routine monitoring, data on morphological groups of species can be collected rapidly using appropriate point-based or quadrat-based methodologies. Combined with judicious collection of key representative samples, these data can form the basis for comprehensive assessment of soil crusts and their associated organisms through time.

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