32 Monitoring and Management of Biological Soil Crusts

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32.1 Introduction

Monitoring is the collection and analysis of repeated observations so that changes over time can be assessed. Typically, monitoring is used to evaluate changes in landscape condition in relation to defined management goals. The objectives of a monitoring program will determine the position in the landscape in which measurements will be made and the period over which data will be collected and assessed. Monitoring is often designed so that measurements can be made by more than one observer, and the level of change which is acceptable is usually determined before monitoring commences.

The principal aim of monitoring is to provide an objective basis for either changing or maintaining a current management practice. Thus, monitoring is intimately associated with management, with a feedback of information to the land manager and therefore the management process. In this chapter we discuss how soil crusts can be monitored, and the role of grazing, fire, and recreational use in the management of landscapes in which biological soil crusts are a major component. Monitoring using remotely sensed techniques are discussed in Chapter 31.

32.2 Crusts and Rangelands Monitoring

During the past century, rangeland managers grappled with methods to assess the health and trend of landscapes (see Tueller 1988). Techniques concentrated on the recording of vascular plant attributes such as cover, frequency, presence/absence, abundance, and biomass of various species, particularly perennial plants (Friedel and Bastin 1988; Friedel et al. 1988; Holechek et al. 1989; Milton et al. 1998).

While many scientists acknowledge the close links between biological soil crusts and rangeland condition assessment (see Klopatek 1992), soil crusts

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and their component organisms have rarely been recorded during field-based assessment (West 1990). Early efforts to classify the surface of soils and to include biological soil crusts in these assessments were developed in the semiarid woodlands of eastern Australia (Tongway and Smith 1989). This system was later refined and extended to other landscape types (Tongway and Hindley 1995). In eastern Australia, the Department of Land and Water Conservation has been collecting data (including crust cover) on the condition and trend of rangelands since the mid-1980s (Green 1992), and workers in the western US (Pellant 1996; USDI 1997) have recently included crust cover as a component of monitoring programs.

32.2.1 Long-Term Monitoring Efforts

Biological soil crusts are frequently monitored as part of a larger study rather than being monitored for their own sake, and the length of time between successive monitoring events will depend on the aims of the study and the purpose for which the data are intended. Two examples of long-term monitoring of crust cover illustrate how the data differ in their intensity of measurement as well as in their level of input.

In eastern Australia the Department of Land and Water Conservation has been monitoring rangelands condition since 1990 at more than 350 sites (Rangelands Assessment Program; Green 1992). These sites comprise seven rangeland types with distinct vegetation and soil communities. Vegetation and soil characteristics are monitored at each 300×300-m site within 52 0.5-m^2 quadrats placed regularly over the site. The cover of biological soil crusts is assessed within each quadrat, along with assessment of plant cover, erosion, and litter.

Long-term data from the Rangelands Assessment Program indicate some interesting trends. Biological crust cover on three rangeland types (ATVC, NFPL, SAND) was very low (<10%) and changed little over time (Fig. 32.1; see legends for interpretation of abbreviations). These landscapes are dominated by either clays or sands, and crust cover is intrinsically sparse. For the other four range types (GRAN, HRED, BLUE, ROBE) there was a general trend of increasing crust cover over time, with short-term increases and decreases in cover. Declining rainfall since 1990 resulted in reduced vascular plant biomass (Eldridge and Stafford 1999) so that biological soil crust was more apparent under conditions of sparse vegetation cover. In the absence of other data collected during the monitoring program, the results could easily have been interpreted as a real increase in crust cover brought about by some change in management or climate. The data also show that ground cover of vascular plants was higher than average in 1995 and lower than average in 1997 in the granite (GRAN)

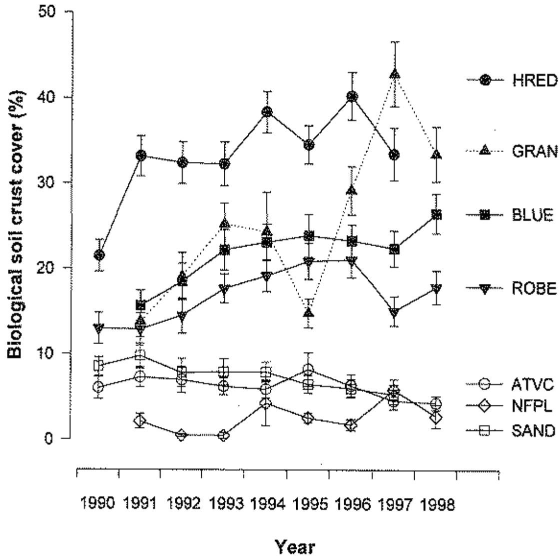

Fig. 32.1. Changes in mean (± standard error of the mean) cover (%) of biological soil crusts at 350 sites within seven rangeland plant communities in eastern Australia from 1990 to 1997. Plains sites: *BLUE Maireana* sp.; *GRAN* granitic soils, *Acacia aneura* and *Eucalyptus*; *HRED* hard red earth with *A. aneura*; *ROBE Alectryon oleifolius-Callitris glaucophylla*. *ATVC* plains and relict drainage lines with *Atriplex vesicaria*; *NFPL* relict floodplains with perennial grasses; *SAND* sandplains with dense woody shrubs

Table 32.1. Mean (± standard error of the mean) cover (%) for moss and *Collema tenax* in biological crusts of Virginia Park, Canyonlands National Park. Values are means of 60 0.1 m^2 frames, each containing 20 point hits, within three permanent 0.5-ha plots in two grassland communities. The 1967 values are from Kleiner and Harper (1977)

	Hilaria community		*Stipa/Sporobolus* community	
	Moss	*Collema*	Moss	*Collema*
1967	21.1	19.5	19.2	17.9
1996	18.5 ± 2.8	19.6 ± 2.0	17.6 ± 3.4	19.1 ± 3.0
1997	23.6 ± 2.4	15.1 ± 1.8	21.0 ± 2.4	9.1 ± 1.4
1998	27.8 ± 2.2	13.4 ± 1.4	24.1 ± 2.3	11.1 ± 1.1
1999	24.7 ± 2.2	14.0 ± 1.7	23.7 ± 2.2	7.0 ± 1.1

rangeland type, resulting in marked apparent fluctuations in cover of biological soil crusts.

In a study in southeastern Utah, biological soil crusts were sampled in two grassland types (dominated by *Hilaria jamesii* and *Stipa hymenoides/ Sporobolus* spp.) in 1964 (Kleiner and Harper 1977) and then annually from 1996 to 1999. Values for both moss and *Collema* lichens were similar in 1964 and 1996 (Table 32.1). However, between 1996 and 1999, both communities saw an increase in moss cover (>33 %) and a decrease in *Collema* cover (29 % in *Hilaria* and 42 % in *Stipa* community). The biggest change occurred between 1996 and 1997, and may have been partially a result of increased cool-season moisture in 1996, which would have favored mosses at the expense of *Collema*.

32.2.2 Monitoring Using Morphological Groups

Field identification of individual crust species can often be difficult, particularly for broad-scale monitoring programs. As strong relationships exist between the form (morphology) of biological soil-crust organisms and the way in which they function in relation to disturbance and ecological processes, morphological groups have been proposed as surrogates for species for monitoring of crusts in arid areas (Kaltenecker 1997; Ponzetti et al. 1998; Eldridge and Rosentreter 1999).

Morphological groups eliminate the need for exact determination of genera and species and avoid the problems associated with complex, often confusing changes in nomenclature. They allow easy identification that is independent of reproductive structures, and the ability to monitor more sites more quickly with less specialized staff. Measures of cover and abundances of morphological groups can be obtained more rapidly and simply than measuring individual species. Morphological groups may be too coarse to allow the detection of rare species but can provide substantial information about changes in biological soil-crust communities over time.

Kaltenecker (1997) used morphological groups to examine the recovery of biological soil crusts after fire in *Artemisia* shrublands in southern Idaho USA (Table 32.2). Unburned (control) sites were compared with burned sites where perennial grasses had been sown as part of a postfire revegetation treatment, or where the site was left untreated and had become dominated by annual exotic weeds. Crusts were dominated by short mosses such as *Bryum lisae, B. argenteum, Ceratodon purpureus*, and *Didymodon rigidulus* along with a variety of lichens. The results indicated substantial differences in cover of morphological groups between the three treatments (Table 32.2). Thus, although individual taxa were not measured, information was still gained regarding biological crust dynamics in conjunction with changes to vascular plant community structure following fire.

Table 32.2. Cover (%) of lichens and mosses, arranged by morphological group, in unburned *Artemisia tridentata* communities (control) and two postfire treatments (seeded and unseeded). Cover was assessed using 20-m line intercept transects. (Kaltenecker 1997)

	Control	Seeded	Unseeded
Lichens			
Gelatinous	8.1	0.8	0
Crustose	3.8	0.4	0
Squamulose	2.4	0.2	0
Fruticose/foliose	0.6	0	0
Mosses			
All	58.5	45.1	35.0
Short	23.2	43.1	34.0

32.2.3 Field Techniques for Monitoring

32.2.3.1 When and Where to Monitor

The length of time between successive monitoring events will depend on the aims of the study, the purpose to which the data are intended, climate of the study area, and the composition of the biological crusts in question. Some biological soil-crust components, e.g., phycolichens, grow very slowly, and differences are difficult to detect over short periods of time (<5 years). Others, such as bryophytes, cyanobacteria, and several cyanolichens, can respond more rapidly, particularly in moist, cool weather. Most monitoring efforts occur during the peak growing season to measure the full biological potential of the site. As some crust groups are difficult to detect when the soil surface is dry, soils can be sampled during naturally moist periods or by artificially moistening the surface prior to measurement (Rosentreter 1986; Kaltenecker 1997; Kaltenecker et al. 1999b).

Monitoring can be used to assess impacts of a specific land use, to measure recovery, or to ascertain normal background variation in crust populations, and location of sampling sites will vary depending on intent of the effort. In areas of active disturbance, soil crusts are likely to be best developed in areas protected from trampling such as under shrubs, or adjacent to obstacles such as fallen trees and rocks. Shallow rocky areas often provide refugia for crust organisms which have been destroyed by trampling. However, these refugia may not reflect the exact potential of the area in question. For instance, species composition and percent cover under shrub canopies and on shallow soils can be quite different than those found in interspaces or deeper soils.

Repeated sampling of relatively undisturbed reference sites is often critical in order to measure recovery rates and natural variation in crusts in the absence of disturbance.

32.2.3.2 How to Monitor

Biological soil crusts are typically measured using standard or slightly modified rangeland assessment techniques. The size of the sampling unit should be appropriate to the size, density and spatial distribution of the organisms being studied, their habitats and the nature of the impact being investigated. For example, the impacts of off-highway vehicles on crust communities may be best examined by using repeated photo-points, remote sensing, or aerial photography interpretation on large plots of up to several hectares in size. Where finer-scale assessments are needed, line-intercept or quadrat methods, stratified within relevant vegetation or soil zones, are more appropriate. The size and number of samples will depend on a compromise between statistical considerations and what is feasible.

Line-Intercept and Line-Point Methods. Line-intercept methods, where the proportion of the line comprising various species or groups is measured, are generally best for communities where the vegetation (including the biological soil crust) is strongly patterned and soil-crust organisms have distinct boundaries. Line-intercept is difficult in densely crusted and species-rich areas, or where individual crust species are intermingled (Kaltenecker 1997). As soil-crust organisms are very small, the line must be placed near the soil surface in exactly the same location at each measurement time. This can be achieved by placing permanent markers such as steel stakes along the route of the line. Line-point methods differ in that entities are recorded at predetermined or random points along a line. These methods are easier to use than line-intercept where vegetation is not strongly patterned, but a large number of points may be required for statistical efficiency. A variant of the line-intercept method is the short-focus telescope (Pickard and Seppelt 1984).

Quadrat-Based Methods. Quadrats are generally effective where soils are sparsely crusted, or where crusts occur in distinct patches. As in vascular plant studies, quadrats may be nested. Cover is relatively quick and easy to assess, and can be recorded by individual species or by morphological group. In Australia, frequency and cover of the soil crust is commonly assessed in 0.5-m^2 quadrats (Eldridge and Bradstock 1994; Eldridge 1996, 1999; Eldridge and Tozer 1996). Quadrat size may be reduced where crust cover is dense or greater detail is required. For example, Rogers and Lange (1971) used a quadrat size of 15 × 15 cm to examine changes in soil-crust floristics in relation to stock watering points in semiarid and subtropical Australia. Very small cores of soil crust (circular quadrats) can be extracted and assessed in the laboratory under a microscope (Eldridge et al. 2000). Rectangular plots of 20 × 50 cm are frequently used to monitor shrub-steppe vegetation, including crusts (Daubenmire 1959; Ponzetti et al. 1998) in the western United States.

Cover in quadrats can be estimated using either cover classes or point-quadrat methods, and whilst both methods are comparable (Ponzetti et al. 1998), there are tradeoffs in efficiency and effort. Trained recorders can quickly and consistently read many plots using ocular cover classes in a relatively short period of time. Point-quadrat methods can be less subjective, but uncommon species are often missed and species diversity may be underestimated.

32.3 Biological Soil Crusts and Rangeland Management

There are many factors to consider in the management of landscapes where biological soil-crust communities are a major component. Total protection from disturbance is often the easiest way to maintain or improve biological soil crusts, but it is not often feasible or desirable. Biological soil crusts can often be maintained by manipulating the type, intensity, timing, frequency, duration, or extent of disturbance. The impact of various management strategies on biological soil crusts can be assessed by comparing areas with protected relic sites or rangeland reference sites (National Research Council 1994) which provide an indication of the ecological potential of a site.

32.3.1 Grazing

Management of biological soil crusts should aim to reduce the impact of grazing when crusts are brittle or susceptible to compression. In high altitude or cool-season rangelands, crusts on all soil types are least vulnerable to disturbance when the soils are frozen or snow-covered (Chap. 27). On sandy or sandy loam soils, crusts are less susceptible to disturbance when moist or wet and on clay or clay loam soils when crusts are dry (Marble and Harper 1989; Memmott et al. 1998). In general, early to mid-wet season grazing and light to moderate stocking rates are recommended.

In the United States, implementation of rest-rotation strategies that minimize the frequency of surface disturbance during dry seasons, and maximize the period between disturbances, will reduce impacts to biological soil crusts.

Winter grazing is beneficial to vascular plant communities, and can substantially reduce the costs of supplementary feeding. Winter grazing also most closely imitates the grazing behaviour of native herbivores (Burkhardt 1996). Livestock should be removed before the end of the wet season to allow recovery of soil-crust organisms before the oncoming dry periods. Wet, muddy conditions should also be avoided in order to prevent crusts becoming buried (Kaltenecker and Wicklow-Howard 1994; Kaltenecker et al. 1999b). In Australia, practices such as "low risk" or conservative stocking are recommended to ensure that biological soil crusts are not destroyed by trampling. Conservative stocking involves the use of small groups of animals in a larger number of paddocks, at stocking rates which are generally below the district average (see Chap. 29).

In general, strategies which disperse livestock throughout the rangeland rather than concentrating them in one location will reduce damage to crusts (Eldridge and Greene 1994). Livestock can be dispersed by (1) locating water (or other supplements) on sites with low potential for biological soil-crust development such as on rocky areas, (2) providing more than one watering point per paddock, (3) using brush barriers or fencing to discourage livestock from moving across sensitive areas. Where stock are concentrated for feeding, such as during droughts, feeding should be confined to the one small area to minimize the damage to other areas. Livestock should be excluded from reference sites, and sites with highly erodible soils or sparse plant cover. In general, decisions on stocking levels and season of use should be made annually, jointly by managers and users, with optimal coverage of both vascular plants and biological soil crusts as the management objective (Kaltenecker and Wicklow-Howard 1994; Kaltenecker et al. 1999b).

32.3.2 Fire

Prescribed fire can be a useful tool for manipulating the cover, composition or vigor of vegetation communities. For example, burning may be useful on more productive sites with low potential for exotic plant invasion to reduce high woody vegetation densities resulting from overgrazing. However, biological soil-crust organisms are generally killed by hot ground fires, resulting in loss of cover and species diversity (see Chaps. 28, 29).

Historically, wildfires in semiarid and arid landscapes produced a patchwork mosaic of burnt and unburnt patches. These were probably small occurring at a scale ranging from individual plants to landscapes. This has also resulted in a mosaic of successional stages of plants and crusts, with propagules readily available to replenish burned sites. Unlike many controlled (manipulated) burns, wildfires were also relatively infrequent, allowing crust organisms to recolonize burned sites before another burn. In the semiarid

Eucalyptus woodlands in eastern Australia, researchers are using fire to alter the vegetation community to make it more suitable for the reintroduction of the mallee fowl, a large ground-dwelling bird. Whilst controlled burning has benefited the native vegetation, if the fires are too frequent (> once every 16 years), the biological soil crust is converted into one dominated by cyanobacteria at the expense of lichens and mosses (Eldridge and Bradstock 1994).

There is now much evidence to show the strong links between the lack of biological soil crusts and fire. In the western United States, overgrazing and disturbance of crusts in *Artemisia* shrublands results in removal of soil crusts and often invasion by annual grasses such as *Bromus tectorum* (West 1994). Large, unnaturally frequent fires have become commonplace in these annual grasslands. These fires often spread to adjacent intact shrub communities, further destroying remnant patches of crust, and converting the shrublands into grasslands (Whisenant 1990). Management of intact shrub communities aims to maintain healthy soil crusts to prevent invasion by annual grasses. This is being accomplished by grazing regimes to minimize disturbance of the crust and reduce competition from exotic species, selective use of fire to prevent fuel buildup, and restrictions on off-road vehicle use.

Management of burned areas aims to prevent reestablishment of exotic plants whilst maximizing the recolonization of soil-crust species. Burned sites are assessed to determine whether they will regenerate naturally or if they require rehabilitation. Many burned sites require revegetation to stop exotic plant invasion, and most techniques require some soil-surface disturbance. This may appear inconsistent with recovery of biological crusts, but failure to treat sites can result in irreversible dominance by annual species, which prevents the return of well-developed biological soil crusts (Kaltenecker 1997; Kaltenecker et al. 1999a). Similarly, it has been suggested that grazing can reduce the vigor and cover of annual weeds such as *Bromus tectorum*. However, the effective use of livestock in controlling exotic annual plants has not been demonstrated, and grazing late in the growing season may be detrimental to biological soil crusts as well as to native vegetation.

Once revegetated, protection from grazing and recreational use is often necessary for recovery of the biological soil crust and the vascular plant community. Restoration can be enhanced by sowing local ecotypes of native plants using seeding methods which minimize disturbance to the soil surface.

32.3.3 Recreational Use Management

Many recreational activities have similar impact as livestock, and therefore the same management principles apply. However, there are also major differences. People are often more difficult to control, their access is often unlimited, and they tend to go where they want, despite the use of barriers.

People also have a greater affinity for open vegetation, as it is easier to walk or drive through. Consequently, people are often harder to control than livestock.

Concentration of recreational use is generally desirable, and the use of designated campsites reduces the impact of haphazard placement of sites by individuals. Trails minimize the amount of biological soil crust that is disrupted by trampling, and in some high-value areas, walkways may be built over the tracks to prevent soil damage. Campers and hikers can be educated on where to place campsites, how to travel through country where there are no tracks or trails, and how to use the environment without causing damage.

There are a number of general management practices which reduce the impact on soils and soil crusts. These include: (1) restrict road locations to less sensitive areas; (2) design roads and drainage to minimize erosion and sedimentation; (3) promote extensive, low-density uses such as hiking and backpacking during late fall and winter periods; (4) restrict access during sensitive dry seasons; (5) restrict high-density, high-impact uses such as tree cutting and firewood collection to short periods during late fall and winter, and rotate these areas, ensuring long recovery periods of 5–10 years minimum before they are reused; (6) exclude sensitive sites; (7) provide designated trails, and restrict their use in high density recreational areas; (8) provide interpretive guides and information on the value of biological soil crusts at significant access points; (9) require analyses of the environmental impacts to biological soil crusts of all developments such as right-of-ways, oil, gas and exploration permits, and permits to drill.

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