CHAPTER 6

MONITORING BIOLOGICAL SOIL CRUSTS

Monitoring is the collection and analysis of repeated observations so that trends can be assessed. Typically, monitoring is used to evaluate landscape condition changes over time, often in relation to defined management goals. A monitoring program's objectives will determine the position in the landscape at 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 acceptable change is usually determined before monitoring commences.

Monitoring studies often differ from traditional research studies in that they are not designed to infer the cause of any observed changes. Monitoring studies usually lack replication and often have no controls. Plot sizes and measurement protocols may be similar in both monitoring and research studies, but the management objectives are often widely different. The following is a discussion of field-based monitoring strategies and procedures for biological crusts. Key attributes for each strategy are summarized in Table 6.1.

6.1 Monitoring Methods

During the past century, rangeland managers have grappled with methods to assess the health and trend of landscapes (Tueller 1988). Techniques have concentrated primarily on vascular plant attributes, such as cover, frequency, presence/absence, abundance, and biomass of various species, particularly perennial plants (Stoddart et al. 1975; Friedel and Bastin 1988; Friedel et al. 1988; Holechek et al. 1989; Milton et al. 1998). Recently, there has been more emphasis on soil surfaces, and monitoring techniques to assess soil surface condition have been developed (Tongway 1994; Pellant 1996; Whisenant and Tongway 1996; de Soyza et. al. 1997).

While many scientists acknowledge the close links between biological soil crusts and rangeland condition (Klopatek 1992), crusts and their component organisms have rarely been recorded during field-based assessment (West 1990). Early efforts to classify soil surfaces and include biological soil crusts were developed in the semi-arid woodlands of eastern Australia (Tongway and Smith 1989). This assessment showed differences in the stability, erosion, and nutrient status of soil surfaces, and provided a reliable estimate of potential productivity of the surface independent of vascular

Table 6.1 *Attributes of biological crust monitoring strategies. See the text for detailed discussion of each method.*

Recording Method: Individual Taxa vs. Morphological Groups	
Individual taxa	• Allows documentation of biodiversity. • More sensitive to change over time.
Morphological groups	• Quicker, easier identification. • Good evaluation of ecological function. • Less variability. • Less sampling time and intensity to get reliable estimates.
Sampling Methods	
Quadrats (using point or cover class estimates)	• Useful if clumps are <2 cm diameter or groups/taxa are highly interspersed. • Use if information on spatial relationships is not desired. • Provides cover estimate.
Line-point Intercept	• Useful if clumps are <2 cm diameter or groups/taxa are highly interspersed. • Provides information on spatial relationships. • Provides cover estimate.
Line Intercept	• Best if clumps are >2 cm diameter and groups/taxa are not highly interspersed. • Provides information on spatial relationships. • Provides actual measure of cover.

vegetation. The method used four classes for soil surfaces: Class 1 = stable, productive surfaces with high biological crust cover and species diversity; Class 2 = slightly unstable, moderately productive surfaces with broken biological crust cover and moderate species diversity; Class 3 = moderately unstable and unproductive surfaces with low biological crust cover and species diversity; and Class 4 = very unstable and unproductive surfaces where biological crusts are absent (Mucher et al. 1988).

This system was later refined and extended to other landscape types (Tongway and Hindley 1995) and other soil characteristics, such as the degree of cracking, surface coherence, microtopography, and biological crust cover. U.S. workers (Pellant 1996; USDI 1997) have also included biological crust cover as a component of federal land monitoring programs. In eastern Australia, the Department of Land and Water Conservation has been collecting data (including biological crust cover) on the condition and trend of rangelands since the mid-1980s (Green 1992). Monitoring staff in Canyonlands

National Park in southeastern Utah have been collecting cover estimates for biological crusts since 1987 (Belnap, unpublished data).

NOTES

6.1.1 Sampling Design and Procedures

Biological crusts are typically measured using standard or slightly modified rangeland assessment techniques. These are generally based on measurement of plant and soil attributes within permanent sampling units (quadrats), stratified within relevant vegetation or soil zones (Ludwig and Tongway 1992). Stratification may be necessary where the landscape is composed of a number of homogeneous land units. On degraded sites, nearby reference areas should be measured in order to determine the site's potential for biological crust development. Biological crusts are likely to be most pronounced in areas protected from trampling, such as under shrubs or adjacent to obstacles such as fallen trees and rocks. Shallow, rocky soils often provide "refugia" for crustal organisms that have been destroyed by livestock on more productive soils. However, reference areas should be as identical as possible to their paired disturbed sites with regards to soil characteristics (texture, chemistry, depth), placement on the landscape, and vegetation production potential.

6.1.2 Using Morphological Groups for Monitoring

Biological crust organisms are rarely recorded during routine rangeland monitoring despite increased acceptance over the past decade of their importance in ecosystem processes (Harper and Marble 1988; West 1990; Eldridge and Greene 1994; Ladyman and Muldavin 1996). West (1990) contends that this is due to difficulties in identifying the organisms *in situ*, lack of a standardized sampling procedure with often undue emphasis on laboratory culturing, lack of conspicuousness of some organisms (particularly when the soils are dry), and their patchiness in time and space. As identification is problematic, monitoring can be a daunting task to all but the most experienced (Eldridge and Rosentreter 1999).

However, strong relationships exist between form (morphology) of biological crust organisms and their ecological functioning in relation to landscape processes and disturbance (Eldridge and Rosentreter 1999). Morphology determines how crust organisms function ecologically (relative to erosion and water retention) and their tolerance to, and recovery from, physical disturbance. Morphological groups have been proposed as surrogates for species in biological crust monitoring (see Table 1.1; Kaltenecker 1997; Ponzetti et al. 1998; Eldridge and Rosentreter 1999).

Morphological groups are biologically and ecologically efficient and convey to non-specialists a better image of the

NOTES

organismal form and its likely impact on soils and landscapes. These relationships hold true in different regions and continents and eliminate the need for complex, often confusing changes in nomenclature. Other advantages of morphological groups for rangeland monitoring include ease of identification, which is independent of sexual reproductive structures, and the ability to monitor sites more quickly with less specialized staff (Eldridge and Rosentreter 1999). Cover and abundance measures of morphological groups can be obtained more rapidly than measuring each individual species. This allows use of the same size plot for varied sites and assessment of more sites per unit time.

Although morphological groups are appropriate for broad-scale or regional monitoring, their use may not allow the detection of individual species, particularly rare or uncommon taxa. Specific goals of individual studies (i.e., determination of total diversity vs. functional diversity vs. site stability) need to be determined prior to initiation of monitoring. This will determine whether morphological groups can be used or whether monitoring needs to occur at the generic/species level. In all cases, crustal organisms are best detected or identified when moist. When sampling during dry weather, the soil surface to be measured can be moistened with water mist prior to reading to make the organisms more visible.

6.1.3 Quadrat Methods

In communities where biological crusts are patchy, lichen and moss cover is sparse, and/or large areas are being assessed, crust monitoring is often done using quadrats. These can be located either randomly or along a line transect. Quadrats can be used to estimate both biological crust and vascular plant cover (Anderson et al.1982a, b; Brotherson et al. 1983), using either point-intercept or cover classes (Fig. 6.1, 6.2). While cover of the various strata within the community (i.e., biological crusts, herbaceous plants, and shrubs) can be determined, horizontal spatial relationships between groups of organisms cannot be defined using quadrat methods. Where biological crust cover is relatively dense or where personnel turnover is high, microplot sampling effectively estimates cover (McCune and Lesica 1992). Reduced quadrat size is also useful if a goal of the study is to observe greater detail in biological crust composition in relation to environmental variation within the site. For example, Rogers and Lange (1971) used 15 x 20-cm quadrats to examine changes in crust floristics related to stock watering points in semi-arid and subtropical Australia. Other Australian studies have employed 0.5 m^2 subplots within larger plots to assess cover and frequency of crustal organisms (Eldridge and Bradstock 1994; Eldridge 1996; Eldridge and Tozer

1996; Eldridge 1999). U.S. workers have adapted a 20 x 50-cm quadrat and cover classes traditionally used for vascular vegetation monitoring (see Daubenmire 1959) for estimating biological crust cover (Rosentreter 1986; Ponzetti et al. 1998).

Destructive sampling might be necessary if detailed documentation of biological crust species composition is desired. Eldridge and Semple (unpublished data) removed small cores (4 cm^2) from an area of high biological crust cover and diversity and used a dissecting microscope to record cover and abundance of crustal organisms. Use of a short-focus telescope is a similar, non-destructive method (Pickard and Seppelt 1984), but is less accurate.

Within a quadrat, cover and frequency are relatively quick to assess, can be recorded by taxa or morphological groups, and are often good indicators of the ecological and hydrological status of the landscape (Eldridge and Koen 1998). Frequency is determined as the number of times that an organism or group is recorded within a given number of sampling units (expressed as a percentage). This measure describes the abundance and distribution of species and is useful to detect changes in community composition over time. It is one of the easiest and fastest methods available for monitoring changes in vegetation (USDI 1996). Frequency methods are used extensively by federal land management agencies for monitoring changes in landscape condition or trend in relation to vascular plants, and can easily incorporate biological soil crusts.

6.1.4 Line-intercept Methods

Line-intercept has been used in the northern Great Basin in studies that characterized both the crust and vascular plant

Figure 6.1 *Quadrat frame used for point-cover estimation. This frame is 25 x 25 cm in size. Hits are determined by dropping a pin vertically from each intercept within the frame.*

NOTES

Figure 6.2 *Data form for point-intercept using a quadrat method (left) and example of data collection (right).*

Date:			**Personnel:**							**total = 20/stake**
Plot	**Stake**	**Cyano**	**Collema**	**Moss**	**Litter**	**Bare**	**Placidium**	**Psora**		

Date: 5-4-01 **Personnel:** JHK, RR **total = 20/stake**

Plot	Stake	Cyano	Collema	Moss	Litter	Bare	Placidium	Psora		
1	1	III	~~IIII~~	I	II	~~IIII~~	II	II		
1	2	~~IIII~~ I	III	II	~~IIII~~	IIII				

NOTES

communities (Kaltenecker 1997; Kaltenecker et al. 1999a, b; Kaltenecker, unpublished data). Using line-intercept (see Canfield 1944 for a description of the original methodology developed for vascular plant communities), taxa or morphological groups (Eldridge and Rosentreter 1999) are recorded every centimeter along a number of 10-m or 20-m line transects (Fig. 6.3, 6.4), with cover and floristics of the biological crust and vascular plant communities calculated as a percentage of the total line transect length (Rogers 1994). Each line forms a single, independent sampling unit.

Line-intercept is a rapid and efficient method of sampling when the vegetation community is strongly patterned and is therefore useful in many arid and semi-arid ecosystems. Line-intercept is easiest

Figure 6.3 *Use of line-intercept for measuring biological crust cover along with other community attributes (vascular plant cover, litter, bare mineral soil, rock). Note the placement of the transect line close to the soil surface. Cover of each entity is measured along the top edge of the tape. A misting of water makes crustal organisms more visible and therefore easier to measure.*

when organisms have a definitive boundary, and can be difficult to apply in sites with dense or intermingling vegetation. An advantage of line-intercept over quadrat methods is the ability to derive linear spatial relationships between organisms from the data.

Lines should be long enough to include most of the variability in both the vascular vegetation and biological crust. Optimum line length should be determined from pilot sampling. It is imperative that the line is placed in exactly the same location each time to prevent sampling error associated with repeated measure. Permanent markers, such as steel stakes or nails, may be located along the line to ensure correct placement. If vascular vegetation is measured at the same time, a longer transect might be required with intensive sampling of the biological crust along a shorter portion of the line (USDI 1997).

Figure 6.4 *Line intercept data form (this page) and example of data collection (next page).*

Site Name:				**Date:**			
Treatment:		**Transect #:**		**Reader:**		**Recorder:**	
Cover Type	**From (cm mark)**	**To (cm mark)**	**Under (Cover Type)**	**Cover Type**	**From (cm mark)**	**To (cm mark)**	**Under (Cover Type)**

Site Name: Kuna Butte				Date: 4-18-01			
Treatment: unburned		Transect #: 1		Reader: JHK		Recorder: EM	
Cover Type	From (cm mark)	To (cm mark)	Under (Cover Type)	Cover Type	From (cm mark)	To (cm mark)	Under (Cover Type)
Artrw	0	40					
tall moss	0	36	Artrw				
short moss	36	40	Artrw				
short moss	40	52					
crustose	52	55					
squamulose	55	62					
short moss	62	70					
Agsp	70	85					
short moss	70	74	Agsp				
short moss	83	85	Agsp				

6.1.5 Line-point Intercept Methods

The line-point intercept method is similar to line-intercept, but uses random or predefined points along a line rather than intercepts, and records only the entity or entities (if recording over- and understory) associated precisely with that point. Cover and floristics of the biological crust and vascular plant communities are then calculated as a percentage of the total number of points. Line-point intercept is useful for estimating cover in communities where the crust and vascular vegetation are not strongly patterned. As with line-intercept, linear spatial relationships can be assessed using this method.

6.1.6 The Issues of Scale

Size and shape of the sampling unit depends upon the vegetation type and spatial distribution. Ultimately, the size and number of quadrats will depend on a compromise between statistical considerations (see Section 6.1.8) and what is logistically possible. Generally, in sparsely vegetated landscapes, larger linear quadrats are useful in decreasing variability because of cover heterogeneity. Circular quadrats are often preferred to square because they reduce edge effects. The nature of the impact being investigated will also influence the monitoring method(s) used. For example, studies focusing on species composition will require microplot sampling, while compressional impacts (off-road vehicles, grazing) on biological soil crusts may be best examined by using repeated photo-points, remote sensing, or aerial photography interpretation on large plots of up to several hectares in area.

6.1.7 Voucher Specimens

Representative specimens of each crustal organism should be collected as vouchers for each site. Voucher specimens should include all the variation within a morphological group. A site's biodiversity can later be assessed by identification of voucher specimens by an expert and application of diversity indices.

Voucher specimens require specialized preparation to preserve them for long-term storage (Rosentreter et al. 1988). This often includes removal of excess soil, stabilization of the underlying substrate, and fixation of the specimen onto a stiff card to protect it from breakage. A collection of local or regionally occurring crustal organisms stored in a herbarium is useful for future identification of taxa and for describing a study area's floristics. This enables other researchers and land managers to evaluate differences in biological crust composition between regions.

NOTES

6.1.8 Statistical Considerations

Statistical considerations are important when designing any sampling procedure. It is important that the size and number of sampling units, their placement in relation to landscape heterogeneity, and their replication (if significance testing is required) do not compromise any future data analyses. The most efficient design is usually the one that yields the highest statistical precision (smallest standard error and narrowest confidence interval around the mean) for a given amount of effort or money. It is therefore crucial that a biometrician or a statistician with an ecological background be consulted prior to establishment of a monitoring program.

While the value of statistical analysis regarding changes in biological soil crust cover or floristics cannot be undervalued, rigorous statistical examination might not always be necessary or even desirable for a monitoring program (Eldridge and Rosentreter 1999). The danger, however, is that subsequent personnel may wish to look for statistically significant results using a monitoring protocol that was not established to allow rigorous examination. Monitoring sites are frequently unreplicated or pseudo-replicated, and analyses may therefore result in erroneous conclusions (Hurlbert 1984).

A pilot study may be necessary to determine optimal quadrat size, the shape or number to be used, or the transect length that will enable the operator to reduce Type I error (erroneously rejecting a true null hypothesis). For any site-by-time combination, a species-area curve (McCune 1992) can be calculated to give the optimal sampling intensity needed to estimate parameters for a given proportion of the population. For example, in semi-arid eastern Australia, Eldridge and Tozer (1995) found that between six and eight 0.5-m^2 quadrats were needed to adequately describe the biological crust in a woodland community, while only three quadrats were required to describe the crust in a grassland.

Species-area curves are likely to vary in relation to landscape heterogeneity, and the observers must ensure that all site measurements are made from a homogeneous sample. For example, in the patterned semi-arid woodlands in eastern Australia, where groves of trees located on the contour are separated by treeless inter-groves, the biological crust cover varies markedly between the two zones (Eldridge 1999; Tozer and Eldridge, unpublished data). Monitoring should occur within, rather than across, geomorphic zones; otherwise, species-area curves are meaningless and will fail to reveal the optimal number of units necessary to detect differences.

Despite the importance of statistical considerations, the sampling intensity may depend entirely on sampling efficiency. This is particularly important in studies where cores or samples are

collected for laboratory identification and analysis. As a broad generality, one day of collecting and recording crustal organisms in the field can generate up to 10 days of processing and identification in the laboratory. Sampling intensity, therefore, is often a compromise between what is statistically necessary and what is logistically feasible.

6.2 Other Monitoring Methods

As discussed in Chapter 4, changes in biological crust biomass and function often cannot be assessed by visible cover change (Belnap 1993). Obviously, monitoring of cover changes is the easiest and most practical method. However, if resources are available, additional methods should be used to more accurately track biological crust responses to disturbance or management change. The methods described below are examples of monitoring that provides information about biological crusts from a functional perspective.

Determination of cholorophyll *a* using spectrophotometric or high pressure liquid chromatography (HPLC) analysis is an efficient and reliable measure for monitoring changes in photosynthetic biomass, even when visible cover is difficult to detect (Belnap 1993). In areas dominated by cyanobacteria and cyanolichens, monitoring nitrogenase activity is an effective way to determine functional changes in the biological crust (Belnap et al. 1994; Belnap 1996). Both methods require destructive sampling, but can provide valuable information regarding stages in biological crust development.

The slake test is a simple method of determining soil surface stability under wet conditions. Small soil surface fragments (6 to 8 mm diameter) are immersed in rain-quality water, observed over a period of several minutes, and rated according to cohesion of fragments after soaking (Table 6.2). Biological crusts will maintain cohesion when soaked, while physical or chemical crusts will tend to slake or disperse (see Tongway and Hindley 1995 for detailed methods regarding this test). More complicated methods of determining stability include the use of wind tunnels and simulated rainfall.

6.3 Impacts of Monitoring

Care should be taken to establish rigorous protocols when sampling within quadrats and along lines. Because crustal organisms are susceptible to damage by humans, inadvertent trampling within the sampling units may create biased results. Studies on biological soil crusts require that voucher specimens be collected to provide a

Table 6.2 *Classification of results from the slake test. Adapted from Tongway (1995).*

Class	Stability Rating	Observed Behavior of Soil Fragment
1	Very unstable	Fragment collapses completely in <5 seconds into a shapeless mass. A myriad of air bubbles is often present.
2	Unstable	Fragment substantially collapses over about 5-10 seconds with only a thin surface crust remaining; >50% of the sub-crust material slumps to an amorphous mass.
3	Moderately stable	Surface crust remains intact; slumping of sub-crust material is <50%.
4	Stable	Entire fragment remains intact after 5 minutes. This level of stability can remain for many hours.

permanent record of the species found in an area. Removal of voucher specimens or destructive sampling modifies the community and should occur away from permanent plots.