Section III: Indicator calculation and interpretation

Section III explains how to calculate monitoring indicators, and how to interpret monitoring results. Section III includes two chapters.

Chapter 16 discusses three options for calculating indicators: by hand using a calculator, with Microsoft® Excel spreadsheets containing automated calculations, or with a Microsoft® Access database. Chapter 16 also introduces basic statistics, which can be used to detect changes in monitoring data over time.

Chapter 17 provides an overview of how to interpret monitoring indicators. This chapter links monitoring indicators to three ecological attributes: soil and site stability, hydrologic function and biotic integrity. Chapter 17 reviews each method, some of the indicators that can be calculated, and how the indicators relate to the three ecological attributes, as well as how they relate to important ecosystem processes. References and additional resources are provided for each method. Finally, this chapter introduces a variety of approaches for extrapolating monitoring data to the monitoring unit or landscape scale.

Chapter 16

Calculate indicators

This manual (Volume I: Quick Start and Volume II) includes instructions for the calculation of basic indicators for each measurement. All of the measurements can be used to generate many additional indicators. Some are listed in Table 4.2 and discussed in Chapter 17. Three options for basic indicator calculation are described below. See the “Extrapolation” section at the end of Chapter 17 for a discussion of different approaches for combining and extrapolating results from multiple plots.

Option 1: Hand or calculator calculation

The data forms were designed to facilitate rapid indicator calculation in the field. Instructions are provided in each chapter. While this is the least efficient method, it is useful where data are required to make an immediate field assessment (e.g., to improve the quality of qualitative assessments made using one of the systems described in Chapter 3) and a field computer is not available. It is also the most subject to error because calculations can only be checked by re-entering all of the data into a calculator or re-calculating by hand.

Option 2: Spreadsheets

Spreadsheet versions of each data form are available for download from http://usda-ars.nmsu.edu. To use these spreadsheets, you will need Microsoft® Excel 2000 or above, or a compatible program. Spreadsheets automatically calculate the basic indicators listed at the bottom of the data forms. This method has the advantage of allowing data to be re-checked after you enter the data. To calculate indicators from more than one plot, simply copy the blank data forms to new pages in the spreadsheet, or to new spreadsheets.

Caution. The formulas are written for specific line lengths, number of measurements and units (English vs. metric). Some of the variables can be modified; others cannot. Be sure to re-check the values in all yellow boxes at the top of the form before entering your data. It is also a good idea to check the calculated indicators against your best estimate.

Option 3: Database

A Microsoft® Access database will be available for downloading from http://usda-ars.nmsu.edu. The database is designed for field data entry using a tablet PC or laptop and can also be used on a desktop PC. The database calculates the basic indicators for selected methods. Future versions will include additional indicator options and supplementary methods. The database is user-friendly, so you do not need to be a database expert to use it. However, spending a few hours learning what databases are and how they work will help you take advantage of the many optional features, such as designing your own queries to extract different types of information.

Data entry is similar to the spreadsheets, except that there are a number of enhancements, such as choice lists, that can increase speed and accuracy. The biggest advantage of the database is that it automatically stores and organizes data from multiple plots, and from multiple visits to each plot. It also allows data to be combined and compared in many different ways.

Caution: Formulas in the database, like those in the spreadsheets, are based on specific line lengths and number of measurements. Where possible, we have included automatic checks in the database. However, the inherent flexibility within the database leaves it vulnerable to certain errors. For example, if your transect length is 25 m and you enter 50 m, your gap indicators will be off by a factor of two.

A recommendation: As with any software package, we strongly recommend that you check the formulas the first time you use them by comparing with hand calculated indicators and your own best estimates. If the values do not match, begin by checking the fixed variables (e.g., transect length and number of measurements), then the data, and finally the formulas.

How to report mean (average), median, range or standard deviation for each indicator of interest

Depending on the question you wish to answer, you can report indicator statistics by plot, ecological site, pasture, monitoring unit, management unit, etc. These statistics are calculated from data collected during the same year, not from data collected over multiple years. They are used to monitor changes through time.

The ***mean*** ($\overline{X}$) is the most commonly reported statistic. The mean or average is simply the sum ($\sum$) of all values (X) divided by the number (n) of values. It is useful as a general description but can be extremely misleading if the data are not normally distributed (bell curve) or thresholds exist. The formula for calculating the mean is:

$$\overline{X} = \frac{\Sigma X}{n}$$

The ***median*** is the middle value. An equal number of values are greater and less than the median. This is often more useful than the mean in characterizing a typical value for non-normally distributed data, particularly if there are extreme values. For example, if there are four plots with 10 percent bare ground and one plot with 85 percent bare ground, the mean is 25 percent and the median is 10 percent. The median is more representative of the area. However, both the median and the mean fail to reflect that while most of the area (four of five plots) has relatively high cover, at least some of the area (represented by one plot) has extremely low cover. It is often these areas that are of greatest interest from a management perspective. For this reason, it is useful to record the maximum and minimum values in order to report the ***range*** (e.g., 10 – 85 percent) of values.

In addition to the range, the ***standard deviation*** (s) is often used to help describe how variable the data are. The standard deviation is also used to determine whether or not there is a statistically significant difference between two values. The formula for calculating standard deviation is:

$$s = \sqrt{\frac{\Sigma(X - \overline{X})^2}{n-1}}$$

Detecting differences

Use a statistical computer program or the formulas listed in Appendix C, Option 3 to make statistical comparisons between years. It is best to consult someone with statistical training before applying these tests for the first time. Additional guidance is provided in a number of texts, including Bonham (1989) and Elzinga et al. (2001).

Monitoring Technical support

The monitoring web page (http://usda-ars.nmsu.edu) will include responses to Frequently Asked Questions (FAQs). We are committed to continuing to improve the quality of these tools, as resources permit. Unfortunately, we do not have funding available to provide direct technical support.

Chapter 17

Interpret results

If you have not already done so, calculate your indicators using the data form at the end of the relevant methods chapters, or automatically generate them using the applicable excel spreadsheet or the database (see Chapter 16). Then review the five parts of this chapter.

Combining indicators is discussed first. Options for interpreting your calculated indicators are described in the second part **(Interpretation options)**.

The third part of this chapter **(Attributes)** describes the three attributes (soil and site stability, hydrologic function and biotic integrity). It provides background information linking the indicators to each attribute, allowing the user to monitor the status of each attribute.

Each measurement and indicator are discussed individually in the fourth section of this chapter **(Measurements and indicators)**, which is organized by measurement. Scientific publications and technical references relevant to specific indicators calculated from each measurement are listed at the end of each method.

The fifth section (**Extrapolation**) describes how to interpret your data based on where the plot is located in the landscape. This section also explains how to extrapolate your results to larger areas, where relevant.

Combining indicators

We recommend that the indicators *not* be combined into an index unless you have extensive expert knowledge of the system, and the index is flexible enough to incorporate thresholds. National inventories represent a situation in which indices may be appropriate because they are often the only way to integrate large volumes of data. In this case, the risk of using an index is outweighed by the benefit of making these data interpretable.

The problem with using simple indices (e.g., averages) in complex ecosystems is that they tend to homogenize the data. Key indicators that a system is at risk of crossing a threshold (e.g., the presence of one individual of an exotic species) can be easily disregarded if other indicators convey stability. Instead, we recommend that the ***preponderance of evidence*** be used for each of the three attributes (soil and site stability, hydrologic function and biotic integrity). In this approach, all of the indicators for each attribute are considered individually and an evaluation is justified based on an understanding of how each indicator is related to the functioning *of that particular system*.

If a key early warning indicator suggests that the system is at risk of degradation, a change in management should be considered, even if other indicators do not reflect a change in the status of the system. On the other hand, some indicators, such as an unusually high density of annuals in an otherwise degraded area, may suggest opportunities to manage for recovery.

For more discussion on the "preponderance of evidence" approach, see Pellant et al. (2005).

Interpretation options

There are three options for interpreting your results. The option you choose depends on your objectives, and on how much information you have about your monitoring unit(s).

Option 1: Trend

Trend simply involves looking at the direction of change in each indicator: whether it is positive, negative or static.

Appropriate applications. Looking at trend is appropriate if the objective is simply to determine whether or not an area is changing. Trend can be used to identify areas for more careful management based on the rate and direction of change. Careful examination of the indicators that are changing can provide insight into the management changes that are most likely to be effective. Trend analysis provides little information that can be used to predict whether or not a change in management will be effective.

Information required. Most of the information necessary for trend interpretation is included in the "Attributes" and the "Measurements and indicators" sections. In many cases, additional knowledge of the ecosystem is necessary to determine whether a change in an indicator is large enough to represent a significant change in ecosystem function.

Option 2: Comparison to a standard
This involves comparing the indicator value to an optimum value. The similarity indices used by land management agencies represent an example of this approach. The species composition of a landscape unit is compared to that expected for a similar landscape unit at or near its ecological potential.

Appropriate applications. Like Option 1, Option 2 is also appropriate if the objective is to determine trend. The quantitative departure from the standard can be used to prioritize areas for management intervention and to more precisely define relative improvement. Unlike Option 1, Option 2 can generate an assessment from measurements made at a single point in time. Like Option 1, however, it cannot be used to determine if a change in management is likely to be effective.

Information required. In addition to the information provided in the "Attributes" and "Measurements and indicators" sections, an optimum range of values must be identified for each indicator. Optimum values are different for each ecological site or monitoring unit.

Option 3: Comparison to a state and transition model
Indicator values or the range of indicator values associated with the reference state in a state and transition model (Ch. 24) are often used as a reference. Alternatively, comparison to indicator values associated with a threshold can be used.

Thresholds between ecological states are defined in terms of the status of a large number of interacting properties and processes. Consequently, *there is no unique threshold for a particular indicator*. Declines in one indicator can be compensated for by increases in another. For hydrologic function, for example, an increase in the amount of time it takes for water to soak into the soil can be compensated for by a reduction in the distance between plant bases. A decrease in the distance between plant bases increases the amount of time water is retained on the site, and therefore the amount of time water has to soak in.

Ideally, a range should be established for critical indicators of states or thresholds for each ecological site or equivalent functional unit. Where threshold ranges are used, they should be established with the understanding that additional information must be used to make evaluations when the indicator nears the threshold. For example, a typical threshold range for canopy gaps in arid grasslands susceptible to wind erosion is 50-75 cm. This assumes that the soil in the gaps has been recently disturbed. Where gravel or lichen crusts protect the surface, the threshold gap size may be much larger or may not even exist. This type of quantitative information is increasingly being incorporated into NRCS Ecological Site Descriptions (see Glossary) and associated IIRH Reference Sheets (see Ch. 4).

The NRCS, TNC (The Nature Conservancy), BLM and other organizations began developing and publishing state and transition models in 2001, and are continuing this process. These

Guidelines for Selecting and Using Reference Sites as Standards

- Use areas that are geographically close to monitoring sites, are located at a similar landscape position, and have similar soils. Landscape position is particularly important in areas with differences in runoff or solar exposure.
- Livestock and wildlife exclosures are essentially small "islands" and hence are not necessarily representative of processes that occur across larger areas. Be very cautious about using them as reference sites.
- Roadsides are generally associated with additional runoff and nutrients, and the soil is usually modified during road construction. They are not recommended as reference sites.
- Ideal reference sites are those in which anthropogenic disturbance is naturally limited by distance from roads and/or water.

models may be useful in helping to identify possible thresholds and suitable indicators.

Appropriate applications. Option 3 (comparison to a state and transition model) is the ideal approach for most ecosystems and objectives. It allows areas that are more likely to be at risk of serious degradation (e.g., crossing a threshold) to be identified. Where warranted, land managers can target areas at risk of serious degradation for intensive management intervention. Option 3 also helps land managers avoid wasting resources on areas that have crossed an ecological threshold and are therefore unlikely to respond to typical management inputs.

Information required. This approach requires that a threshold range be identified for each indicator and each ecological site or equivalent functional unit. It is also helpful to identify optimum and worst possible ranges for the indicator, as described under Option 2. For more information on state and transition models, please see Chapter 24.

How can qualitative indicators help?

In addition to assisting with site selection, qualitative indicators can be extremely helpful for interpreting quantitative indicators. They can also help identify additional quantitative indicators to calculate from the existing data. For example, if increased pedestalling or rills are observed, it may be worthwhile to look more closely at the Gap intercept data for both plant canopies and plant bases. Such an assessment may lead to the calculation of additional indicators (e.g., percent of the line covered by canopy gaps >75 cm).

Attributes

Three attributes (soil and site stability, hydrologic function and biotic integrity) define the foundation of most terrestrial ecosystems. Nearly all of the human values supported by grassland, shrubland and savanna ecosystems depend on minimizing soil erosion, controlling the flow of water through the system, and maintaining biotic recovery processes. This section includes a brief definition and a general description of each attribute, and a discussion of the types of factors that affect each attribute. In addition to the information below, please see *Interpreting Indicators of Rangeland Health* (Pellant et al. 2005) for a list of easily observed indicators of each attribute. Rangeland Soil Quality Information Sheets provide additional information about some indicators and the three attributes (see Appendix D or http://soils.usda.gov/sqi/management/gl_mgmt.html). Monitoring the Vegetation Resources in Riparian Areas (Winward 2000) includes quantitative indicators for a similar set of riparian system attributes.

1. Soil and site stability

Soil and site stability are defined as the capacity of the site to limit redistribution and loss of soil resources (including nutrients and organic matter) by wind and water. Grassland, shrubland and savanna ecosystems are affected by both wind and water erosion.

How can I tell if erosion is occurring? The best way to learn about the different types of erosion in your area is to make observations during an intense rainstorm and on a very windy day. Look especially for whether or not different types of surfaces (under and between vegetation, disturbed and undisturbed) erode.

Determining which type of erosion (wind or water) is most important on a site can be difficult. For example, wind erosion is clearly important in the conversion of grasslands to mesquite coppice dunelands in the southwestern United States and northern Mexico. Water erosion also plays an important role in soil loss and redistribution (Fig. 17.1), although its effects are often hidden by subsequent redistribution by wind.

Fortunately, it is not necessary to determine which type of erosion is most important in order to monitor changes in the ability of different sites to resist degradation. Most of the core indicators calculated from the four basic measurements reflect resistance to both wind and water erosion. Some indicators are related to wind and water erosion, while others are more relevant to only one type of erosion.

Figure 17.1. Runoff and erosion in a shrub-dominated community in the Chihuahuan Desert.

What factors affect erosion? The susceptibility of a site to wind and water erosion depends on static and dynamic factors. ***Static factors*** are generally independent of management. Slope and soil parent material are static factors. ***Dynamic factors*** change over relatively short periods of time and are generally more influenced by management. Plant cover and soil aggregate stability are dynamic factors.

The indicators focus on ***dynamic factors*** because management can affect them. It is important to understand how the relatively static erosion factors affect these indicators. These inherent factors ultimately determine the extent to which erosion can be controlled through management on a particular site.

***Water erosion: static factors*.** Factors influencing erosion that cannot be controlled by management include slope, aspect, soil depth, soil parent material and climate.

Slope: Water running off steep slopes has more energy to detach and carry soil particles to streams and lakes. Lower parts of longer slopes are more susceptible to rill and gully erosion because runoff concentrates downslope.

Aspect: South-facing slopes in arid and semi-arid areas in the northern hemisphere tend to have lower vegetative cover than north-facing slopes. This is due to greater evaporation and higher temperatures from the south-facing slopes, which are exposed to more of the sun's energy. The reverse applies in the southern hemisphere.

Soil depth: In higher rainfall areas, there is often greater erosion from shallower soils, particularly over bedrock, because these soils become saturated more quickly. Water that cannot soak into the soil evaporates or runs off, carrying exposed soil with it.

Soil parent material: Parent material and soil age affect soil erosion, primarily because of their effects on soil texture at different depths in the profile. Soil age is important because soils change over time: soil particles become smaller and vertical stratification of soil horizons increases. Infiltration is usually, but not always, faster in coarse-textured soils, such as sands. Texture also affects *soil erodibility*, or how easily particles detach from the soil surface. Poorly aggregated soils, such as those with a high amount of sand and low amount of organic matter, disperse readily from raindrop impact. Soil organic matter binds soil particles together, producing porous soils that soak up and hold water, and thus resist erosion.

Climate: Climate is another factor influencing erosion that cannot be controlled by management, although it is temporally variable. Three of the most important climatic factors are rainfall amount, intensity and erosivity. The *amount* of rainfall determines how much water is potentially available to cause erosion or to increase plant cover (limiting erosion).

Rainfall *intensity* is the rate at which rain reaches the ground. When the intensity exceeds the rate at which water can soak into the soil, runoff begins. Rainfall intensity is often expressed in units of inches or millimeters per *hour*, and is often reported for periods as short as 5 minutes. This is because runoff can be generated during very short, intense storms.

Rainfall *erosivity* is related to intensity because it is a measure of the energy of the rain. Clearly, the higher the intensity, the more energy there is. However, the size of the drops is also important, as larger drops are able to dislodge more soil than smaller drops.

The timing of precipitation events in relation to cover is also important. Intense storms occurring when cover is low are more likely to cause severe erosion than when cover is high.

Water erosion: dynamic factors. Factors affecting erosion that can be influenced by management include total cover, plant basal cover, spatial distribution of plant bases, soil structure and soil disturbance.

Total cover is the single most important factor affecting water erosion. Soil that is covered by plants, litter, gravel, lichens or mosses is protected from raindrop impact. In order to be effective, though, the materials must be relatively close to the soil surface. Water that drips from tree canopies onto an exposed soil surface can dislodge soil as effectively as rain directly striking the soil.

Plant basal cover, as well as the number and type of other obstructions to water flow, impacts water erosion. Water that remains on a site longer has more time to soak in. Anything that increases the length of time water must travel to get to the bottom of the slope (i.e., path length) will increase water retention time. Plant basal obstructions also reduce the energy of the water by slowing it down. In addition, the rate of infiltration into the soil is often higher around plant bases, due to root channels and the activity of soil organisms (increased micro- and macropores).

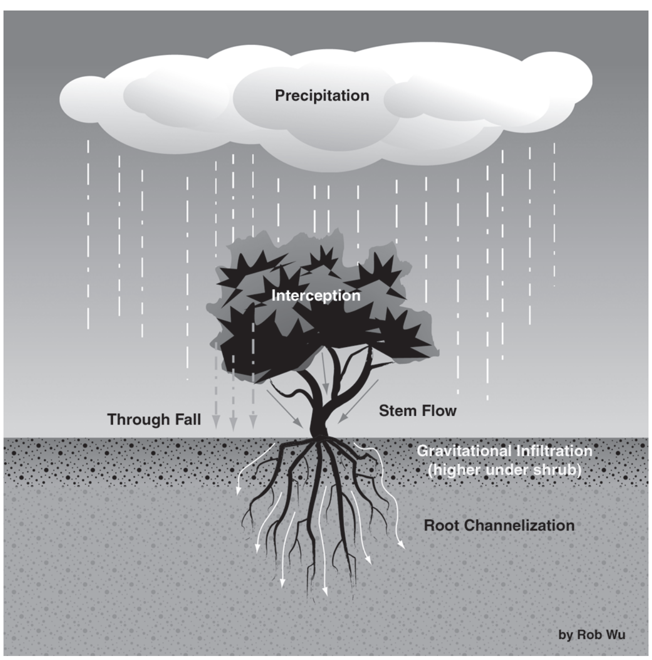

Figure 17.2. Effect of vegetation structure on infiltration (figure modified from Martinez-Meza and Whitford 1996).

Spatial distribution of plant bases and other obstructions is also important. Obstructions that are uniformly or randomly distributed across the surface generally have a more positive effect on reducing water erosion than clumped obstructions (Fig. 17.3 versus Fig. 17.4). One exception occurs in arid environments when plant cover is so low that the only way to slow water, and to accumulate enough water for plant production, is by concentrating the vegetation in bands along the contour. These bands are a common feature in large areas of Australia, as well as parts of North America and Africa (Fig. 17.5).

Soil structure affects soil susceptibility to erosion. Soil erodibility is reduced by soil organic matter, which helps glue soil particles together. The glue can include byproducts of litter and root decomposition and the decomposer microorganisms themselves (Fig. 17.6). In arid ecosystems, soil

Figure 17.3. Relatively uniform vegetation.

Figure 17.4. Clumped vegetation.

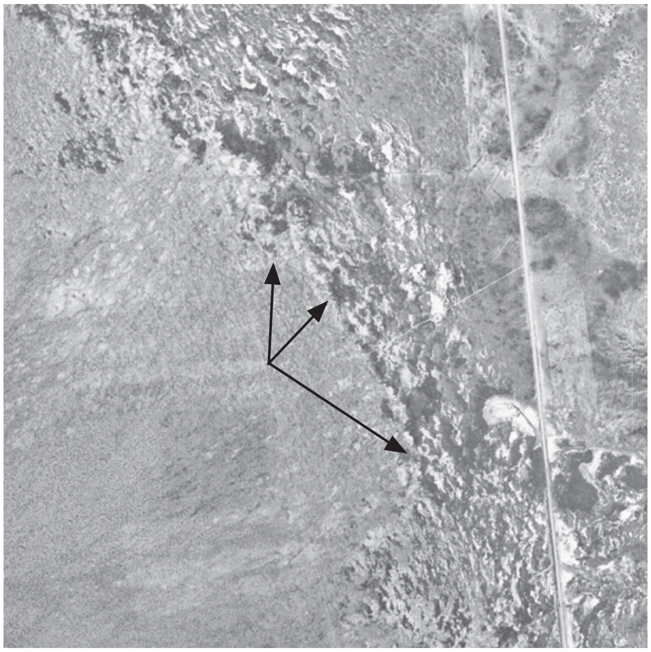

Figure 17.5. Banded vegetation on the Jornada Experimental Range, New Mexico.

lichens and photosynthetic cyanobacteria that live in the top few millimeters of soil play an important role in stabilizing soil. Where they are sufficiently dense to be visible, they can form a biological soil crust.

For a good overview of the role of other soil microbiota in creating soil structure, cycling nutrients and increasing infiltration, see Tugel et al. (2000). Additional information on soil microbiotic crusts, including mosses, lichens and cyanobacteria, is available at www.soilcrust.org.

Soil structure is also important because it affects the rate at which water soaks into the soil. Well-structured soils have a more stable soil surface, which limits soil dispersion, sealing and physical crusting. In addition, well-structured soils tend to have more continuous pores for conducting water into the soil, thereby limiting runoff.

Soil disturbance is the other factor that significantly affects soil and site stability. Disturbance of the soil surface breaks the bonds that hold soil particles together, and exposes the more erodible soil below. Nearly every study has demonstrated that disturbance of the soil surface potentially increases soil erosion for some length of time, particularly where plant canopy or litter does not protect the soil surface.

Wind erosion: static factors. The amount of soil lost or redistributed by wind is a function of soil erodibility and the velocity of the wind at the soil surface (Fig. 17.7). Soil erodibility for wind is different than that for water. For water, it is a function of how tightly soil particles are glued together and their ability to resist detachment by water. The ease with which soil particles are carried by wind depends on their size, shape and density.

Soil erodibility: In general, soils with a high proportion of fine sand are the most susceptible to wind erosion. This is because the particles are light

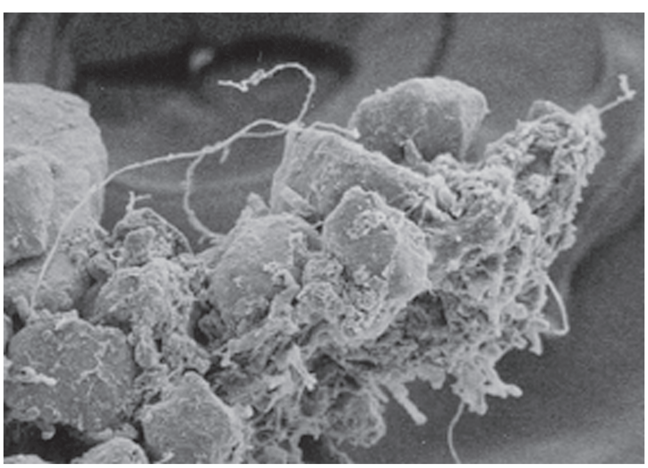

Figure 17.6. Fungal hyphae entanglement of soil particles.

Figure 17.7. Plants buried by wind-deposited soil.

enough to become carried by the wind, but large enough to prevent becoming tightly bound into larger particles, as occurs with clay soils. Soils that are very gravelly or stony tend to be more resistant to wind erosion, particularly after some erosion has occurred (wind erodes the lighter particles, concentrating these heavier materials at the surface).

Wind velocity at the soil surface tends to be lower in landscapes with a lot of uneven surfaces (e.g., boulders and narrow ravines). However, topographic complexity can lead to locally increased wind erosion associated with concentrated airflow over ridges and around isolated obstructions.

Wind erosion: dynamic factors. Factors affecting wind erosion that can be influenced by management include plant cover, plant density, soil structure and soil disturbance.

Plant cover: Like water erosion, the most important factor for wind erosion is cover. Unlike water erosion, tall vegetation usually provides better protection than short vegetation, provided that both are arranged in approximately the same spatial distribution. Vegetation directly protects the soil surface beneath it. It also protects nearby soil by reducing wind velocity at the soil surface.

Plant density: Where vegetation is widely spaced, as in areas with planted windbreaks, the density of the vegetation is also important. A band of vegetation that is too dense can actually increase wind erosion on the lee side due to increased turbulence.

Soil structure affects wind erosion both by increasing surface roughness and by reducing erodibility. Soils with better structure tend to be rougher. An exception is physical crusts. Degradation of fine-textured soils can lead to the development of dense, physical crusts that are relatively resistant to wind erosion (Fig. 17.8). The resistance of physically crusted soils to wind erosion is primarily due to the strong physical bonds that form when the soil dries. Although these bonds are destroyed when the soil is re-wetted (making these same soils highly susceptible to water erosion), they effectively limit removal of particles from the surface while dry and undisturbed.

Photo by Arlene Tugel

Figure 17.8. Dry lakebed (playa) with saline physical crusts in the Great Salt Lake, Utah. ***Inset*:** Non-saline physical crust on a playa in southern New Mexico.

Unfortunately, soils with physical crusts also reduce water infiltration relative to soils without physical crusts. Reduced water infiltration leads to lower plant production. Lower plant production (and lower plant cover) reduces surface roughness and increases wind velocity at the soil surface. The beneficial effects of physical crusts on soil erodibility are negated by increased water erosivity at the soil surface. Consequently, in the long run, physical crusts can increase both wind and water erosion.

Soil disturbance is an extremely important factor for wind erosion. This is especially true in areas with low vegetative cover, or where there are relatively large non-vegetated patches (Fig. 17.9).

Figure 17.9. Wind erosion in the Mojave Desert.

Disturbances occurring during seasons with high winds cause greater wind erosion than disturbances occurring at other times of the year, particularly where vegetative cover is low.

Studies completed throughout the western United States have consistently shown that erosion is inevitable on disturbed, bare surfaces. Wind erosion is significantly reduced where the soil is protected by a physical crust (fine-textured soils) or biological crust (all soils), *provided that there is no source of loose soil upwind*. The latter point is extremely important and often ignored when interpretations are made for an individual plot. Loose sand grains that become airborne can easily slice through even the most resistant physical crust, and can cover (and thereby kill) biological crusts.

2. Hydrologic function

Hydrologic function is defined as the capacity of the site to capture, store and safely release water from rainfall, run-on and snowmelt. This definition can be scaled up or down to any spatial level, from an individual plant to the Missouri River watershed. A properly functioning system captures and controls the release of as much water as possible from a site through infiltration, evapotranspiration, and slow movement of water (across the surface or laterally through the soil). Deep percolation to replenish the water table also occurs in most properly functioning systems. Rapid runoff creates flashy, intermittent streams and generates large amounts of sediment. Too much sediment can reduce stream water quality and rapidly fill lakes and reservoirs with sediment.

Factors affecting hydrologic function. The ability of the system to *capture* water depends on (1) how much water arrives at the soil surface (as rainfall, snowmelt and runoff from higher landscape positions); (2) how fast it arrives; (3) when it arrives; and (4) how quickly it can soak into the soil. The ability to *store* water depends on soil depth and other soil properties. The ability to *release* water that does not enter the soil depends on vegetation and soil surface characteristics. The ability to release water once it is in the soil depends on the properties of the soil and underlying materials (if the water is released to groundwater or streams via subsurface flow). The ability to release water once it is in the soil also depends on complex interactions between plant roots, soil organisms and the physical and chemical characteristics of the soil (if the water is released through evaporation or transpiration).

Factors affecting the ability of the system to capture water and to release water that does not soak into the soil are discussed within this chapter under "soil and site stability." The remainder of this section focuses on the storage and release of water that has already soaked into the soil.

Relatively static factors. The amount of water that can be stored by the soil depends on *soil texture, structure and depth*. Soil texture and depth are both inherent soil properties, although both can be affected by erosion. Soil structure is strongly affected by soil texture. Sandier soils generally hold the least water because the pores between the sand grains are large, and because they tend to have minimal structure. Rock, stones and gravel in the soil profile also reduce storage capacity.

These factors, together with the slope and structure of the material underlying the soil, also affect transmission of surface water vertically to groundwater or laterally to springs and streams. Water moves vertically through the soil until it encounters an impervious layer (such as unfractured bedrock). Then it moves laterally, following the slope, eventually reappearing in a seep, spring or stream. This is the invisible source of water that keeps ephemeral streams running for weeks after a rainstorm, even in relatively arid environments. In areas without an impervious layer, any water that cannot be stored continues to move down through the soil, eventually ending up in the groundwater. The groundwater may also move laterally, eventually reappearing as surface water downslope.

Relatively dynamic factors. Both *soil structure* and *vegetation* have large effects on infiltration (see soil and site stability within this chapter). The ability of the soil to store and release water also depends on soil structure and vegetation.

Soil structure: While larger pores (0.003 to 5 mm) transmit water, smaller pores store water. Water in the smallest pores (<0.005 mm) is not accessible to most plants (Brady and Weil 2002). The volume accounted for by the smallest pores depends primarily on the amount of clay in the soil and is affected little by management.

The volume of pores that hold water accessible to plants depends in part on soil structure. Vegetation and soil biota, along with wetting, drying, freezing and thawing cycles, rearrange soil particles and glue them together, forming the water-holding pores. Consequently, the type and distribution (horizontal and vertical) of both plant roots and soil biota can affect soil structural development over time.

Vegetation has a more direct effect on the amount of water that is released to surface and groundwater after water has soaked into the soil. Plants, and the litter they produce, shade the soil, limiting evaporation. Green plants also serve as pipelines, carrying water from deep in the soil into the atmosphere. The effect of a plant on total evaporation from a site depends on the depths from which its roots are drawing water, how much of the year it is green and photosynthesizing, and how easily water is lost from its leaves. All three of these vary widely among plant species, within the same plant species growing in different environments, and even within the same plant species in different microenvironments in the same watershed. Generally, in arid environments, more deeply rooted species with greater leaf area, such as trees and shrubs, will conduct more water into the atmosphere on an annual basis than shallow-rooted grasses and forbs.

Spatial pattern: This manual focuses on factors that affect the capture and retention of water at the landscape scale. The hydrologic function of a watershed depends on these site-based factors, and how the ecological sites are distributed across the watershed. If surface water quality and quantity are significant issues, the spatial distribution of landscape units within a watershed and the status of each need to be considered. The effects of a degraded watershed on stream water quality can often be partially limited by careful management of the riparian zone and of the area immediately surrounding this zone. Long-term sustainability of the watershed, however, depends on careful management of riparian and upland areas.

3. Biotic integrity

Biotic integrity "reflects the capacity of a site to support characteristic functional and structural communities in the context of normal variability; to resist loss of this function and structure due to a disturbance; and to recover following disturbance(s)" (Pellant et al. 2005). The emphasis of the third attribute is on the long-term sustainability of the system, in contrast to the first two, which focus more specifically on current function.

The relative importance of resistance and resilience varies among ecosystems, and depends

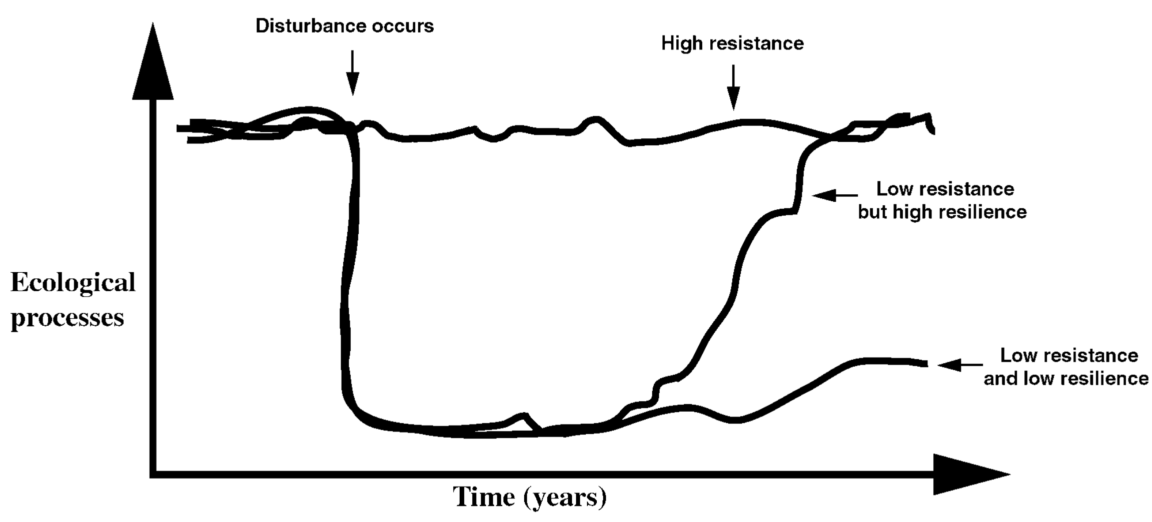

Figure 17.10. Resistance is the ability of a system to resist a disturbance over time. Resilience is the ability of a system to rebound after a disturbance (adapted from Seybold et al. 1999).

on the type of stress or disturbance (Fig. 17.10). For example, blue grama grasslands are very resistant to overgrazing by cattle. With heavy grazing, much of their biomass and growing points become concentrated close to the ground where they are protected to a great degree. However, they are not as resilient as many annual grasslands. Both resistance and resilience are relative terms: there is a threshold beyond which no system can resist or recover from degradation. In general, ecosystems will be more resistant and resilient in response to disturbances that are most similar to those with which they have evolved.

Mechanisms of resistance and resilience are extremely complex and vary in response to different combinations of disturbances. This explains why it is so difficult to identify universal indicators of biotic integrity.

In addition to resistance and resilience, biotic integrity reflects the capacity "to support characteristic functional and structural communities in the context of normal variability" (Pellant et al. 2005). The obvious indicator is the presence of plant functional groups on the plot. However, the absence of these groups does not necessarily mean that the site is currently incapable of supporting them. In some cases they have been removed from the site chemically (herbicides), mechanically or due to overgrazing, but the site is still able to support them. Conversely, some perennial species can persist long after a site has degraded to the point where establishment of new individuals is impossible without extensive intervention. In this case, the presence of a functional group on a site can be a false indicator of biotic integrity. In state and transition model terminology, the site has crossed a threshold into a new state (Ch. 24).

Our objective in the development of this monitoring system has been to select measurements that generate data that can be applied to a wide variety of indicators. We have selected a few indicators that appear to be useful for many ecosystems and types of disturbance regimes. We discuss other general types of indicators that could be calculated and applied to specific situations. In all cases, it is important to carefully interpret the indicators in the context of as much local information as possible.

Measurements and indicators

This section includes a discussion of the basic indicators. It also includes selected additional indicators that can be calculated from the data.

The indicators were selected because they provide information on the status of the three basic ecosystem attributes: soil and site stability, hydrologic function and biotic integrity. We encourage the users of this manual to be creative in their development of additional indicators and to consult ongoing projects designed to generate sets of nationally and internationally recognized indicators (e.g., the Sustainable Rangelands Roundtable in the United States).

Photo points

Photographs are extremely useful for providing visual documentation of where change has occurred, and for providing an independent check on changes indicated by the quantitative data. They usually cannot be used as a substitute for quantitative data. It is extremely difficult to generate reliable quantitative data from photos, except under very controlled conditions.

References

Coulloudon et al. 1999a
Hall 2002a
Hall 2002b
Howery and Sundt 1998

Line-point intercept

The Line-point intercept method measures the proportion of the soil surface that is covered by different species of vascular plants, as well as rocks, litter, mosses and lichens.

Total cover is the proportion of the soil surface that is covered by vascular plant parts, litter, rocks larger than 5 mm in diameter, mosses and lichens. Total cover is positively correlated with soil and site stability and hydrologic function. It protects the soil surface from raindrop impact, thereby limiting detachment of soil particles and physical crusting of the soil surface. Additionally, higher cover generally means there are more obstructions to water flow.

Basal and foliar cover are more sensitive indicators of biotic integrity. They are more closely related to production, energy flow and nutrient cycling because, unlike total cover, they don't include rock cover. *Basal cover* is simply the area covered by plant bases. It is generally a more reliable long-term indicator than foliar cover because it is less affected by growing season, drought, grazing or other short-term disturbances.

Changes in total *basal cover* should be interpreted in the context of changes in species composition. In areas with the potential to support perennial grassland, an increase in basal cover due to a change in species composition usually (but not always) indicates an improvement in biotic integrity. This is because perennial grasses tend to have higher basal cover than shrubs.

Sometimes an increase in basal cover can improve soil and site stability, while reducing biotic integrity. An example is the replacement of a cool season (C3) bunchgrass-blue grama community by a predominantly blue grama community (decreased species richness and a change in dominant functional/structural group). Blue grama develops high basal cover, and therefore enhances soil and site stability. It is also very resistant to some types of disturbances, such as grazing, which can maintain or improve biotic integrity. Cool season bunchgrasses, on the other hand, increase resistance and resilience through their diversity of reproductive strategies (they reproduce more easily from seed). They also increase resistance and resilience by extending the range of climatic conditions to which the community is adapted (they are more efficient at lower temperatures).

Foliar cover is often used as an indicator of changes in plant community composition. Due to its variability, however, data should be compared across several years with consideration for yearly climatic variability. In order to make these comparisons, it is critical that the same method be used. As used here, it is limited to the area physically covered by plant parts (leaf, stem, flower, etc.).

There are an almost infinite number of additional indicators that can be calculated from the Line-point intercept data. *Minimum estimate of species richness*, or the total number of species detected on a plot, is perhaps one of the most useful. However, it needs to be applied very carefully. Line-point intercept generally yields the lowest estimate for species richness of any method. Line-point intercept usually detects only those species that represent a relatively high proportion of the total cover. Species with <5% cover on a site are often not detected with Line-point intercept, or are underestimated. For more accurate estimates of species richness, nested plot methods should be used, such as the modified Whittaker method described in Chapter 10.

The area covered by *species resistant to catastrophic disturbances* is also a potentially useful indicator of both soil and site stability and biotic integrity. It provides some estimate of how the system will respond to potential degradation. This indicator can be sensitive to changes (i.e., resilience), particularly if it is based on basal cover. Specifying the types of disturbance that are expected for the site is therefore important.

Dead and decadent vegetation contribute positively to foliar cover protection of the soil surface. However, excessive increases in standing dead cover can be a sign of higher than normal mortality rates or reduced decomposition. It can also reflect reduced fire frequency, or grazing frequency or intensity. Therefore, it is related to biotic integrity. *Proportion of dead plant intercepts* is an indicator of the amount of dead and decadent vegetation for a given species.

Invasive plant cover is an extremely important indicator of change in many ecosystems and is consistently associated with a decline in biotic integrity. Exotic species invasions often lead to declines in soil and site stability and hydrologic function. These effects are documented with other indicators, such as *woody plant cover*. Woody plant cover generally increases as invasive species increase.

References

Anderson 1974
Benkobi et al. 1993
Blackburn 1975
Blackburn and Pierson 1994
Cerda 1999
Gutierrez and Hernandez 1996
Huenneke 1995a,b
Johnson and Gordon 1988
Morgan 1986

Pierson et al. 1994
Smith and Wischmeier 1962
Thurow et al. 1988a,b
Warren 2001
Weltz et al. 1998
Whitford 1988

Gap intercept
The spatial pattern of vegetation is correlated with soil and site stability, hydrologic function and biotic integrity. The Canopy Gap intercept method does not measure spatial pattern directly, but does provide an indication of the extent to which plant cover is aggregated (forming a few large gaps) or dispersed (forming many small gaps). A reduction in total plant foliar cover will usually, but not always, increase the area encompassed by larger gaps. The distance between plant bases (basal gaps) increases when plants become more aggregated and when basal cover declines (e.g., when shrubs replace grasses).

The *proportion of line covered by canopy gaps exceeding a designated length (e.g., 50 cm)* is a useful indicator. Canopy gaps affect soil erosion, hydrologic function and biotic integrity. The area covered by large gaps can vary tremendously. This indicator can vary even across sites with the same total foliar cover (as measured by the Line-point intercept method), depending on how the vegetation is arranged (see Figs. 17.11 and 17.12).

The susceptibility of disturbed soil to wind erosion depends on the wind velocity at the soil surface. Wind velocity is higher in large gaps than it is in small gaps, because vegetation reduces wind speed. Research has shown that for typical desert grasslands, soil redistribution by wind from a disturbed surface occurs when gap diameter (the diameter of the spaces between the vegetation) exceeds approximately 50 cm (20 in). On average, this is equivalent to a gap intercept of approximately 39 cm (15 in).

The minimum gap diameter for wind erosion to occur varies, depending on other factors. The minimum gap diameter is larger where the vegetation is taller, or the height of the vegetation is more variable. Greater variability in vegetation height creates greater surface roughness, which reduces wind velocity near the surface.

Figure 17.11. Large canopy gaps.

Figure 17.12. Small canopy gaps.

Larger gaps generally indicate greater spatial variability in soil organic matter inputs (organic matter decreases as you get further from vegetation). This means that soil structure is typically poorer in large gaps than in small gaps. Consequently, soil in the gaps is more erodible by both wind and water. Water erosion is further increased in areas with large gaps because these gaps tend to be more highly connected (less vegetative obstructions to water flow). This means that once a soil particle is detached, there is little to prevent it from continuing to move downslope.

Hydrologic function is similarly affected by large gaps: water moves more quickly offsite and therefore has less time to soak in. However, there are at least two exceptions to this statement. Infiltration at the ecological site level can actually increase on some sites with greater vegetation patchiness. This generally occurs in areas with extremely low precipitation relative to plant water requirements. Water from a relatively large area must be concentrated in order to provide enough moisture for these species to grow. The plants, in turn, increase infiltration capacity in the patches where they do become established by increasing soil organic matter. This soil organic matter protects the soil surface from raindrop impact and supports an active soil biotic community. In some areas, these patches eventually form bands of vegetation across the slope (Fig. 17.13). This pattern effectively increases the amount of water that is intercepted, increasing infiltration.

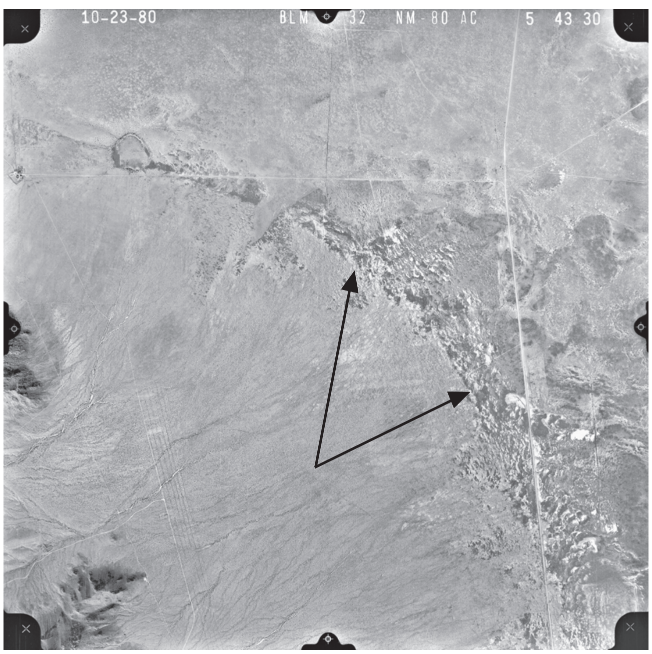

Figure 17.13. Large gaps between banded vegetation patches shown in an aerial photo.

The second exception occurs when grasses with dense near-surface roots, such as blue grama, replace bunchgrasses without any change in gap sizes. Infiltration through these root mats can be quite slow, especially at the beginning of storms, because the mats repel water. Conceivably, if gap sizes increased in this situation you could see an increase in infiltration rate at the landscape level (infiltration is slower through blue grama root mats than in the interspaces).

Patchiness is also highly correlated with biotic integrity. As gaps open in the existing vegetation, susceptibility to invasion by exotic species generally increases. Also, the ability of existing species to become re-established in the larger plant interspaces following disturbance often declines due to changes in both the soil and microclimate.

The *proportion of line covered by basal gaps exceeding a designated length (e.g., proportion of line covered by gaps exceeding 50 cm)*. The relationship between basal gaps and the three ecosystem attributes is similar to that for canopy gaps. The primary difference is that basal gaps vary less in response to short-term disturbances (see discussion of basal cover under Line-point intercept). Another difference is the relative strength of the relationship to the attributes. Wind erosion is more sensitive to changes in canopy gap size, while water erosion and hydrologic function are strongly linked to changes in basal gap dimensions. There is little research comparing the effects of basal versus canopy gap dimensions on exotic plant invasions, or on basal versus canopy gap recovery following disturbance. The few existing studies have focused on canopy gaps.

Standard gap dimensions are 25-50 cm, 51-100 cm, 101-200 cm and >200 cm. The proportion of the line covered by gaps of other sizes can also be calculated. In addition, it may be of interest to know what species are associated with the large gaps. For example, do all large gaps occur at the perimeter of invading shrubs? The Gap intercept data can be combined with the Line-point intercept data to generate relevant indicators.

Relevance to pastures and other high foliar cover systems. Canopy and basal gap indicators are clearly less sensitive to changes in high cover plant communities, such as wet meadows, where gaps rarely occur. However, it is worth including the measurement because it takes very little time (less than 5 minutes) and may detect changes missed by casual observation. In these situations, you may want to reduce the minimum gap intercept from 20 or 30 cm (8 to 12 in) to 10 cm (4 in), particularly if invasive species are linked to increases in gap sizes.

References

Kuehl et al. 2001
Schlesinger et al. 1990
Tongway and Ludwig 1997
Tongway 1994
Whitford et al. 1998

Soil stability test

The Soil stability test is a relatively simple test that is sensitive to complex changes in physical, chemical and biological processes. These are the processes that glue soil particles together.

Two core indicators are calculated from this test: the *average surface stability value* and the *average sub-surface stability value*. The *percentage of the surface samples tested that are equal to 6 (very stable)* is another useful indicator that is easy to calculate. Both are correlated with all three ecosystem attributes. Higher stability has been directly correlated with reductions in erosion. It is more difficult for individual soil particles to become detached as the soil stability value increases.

More stable soils are less likely to form physical crusts, which soak up water more slowly. Thus, hydrologic function tends to be better on soils with high stability values. However, there are some cases in which soil surfaces stabilized by microbiotic crusts (high stability values) actually have lower infiltration rates than similar soils without crusts. Infiltration rates are also decreased when soils become hydrophobic or “afraid of water.” This can occur in at least two situations. One is immediately following a very hot fire, such as in forested areas. The other is in areas with high densities of fungi. In both cases, the soil is relatively stable because water cannot penetrate into the soil (and therefore cannot dislodge soil particles) but as slope increases, runoff concentrates and rills and gullies can form.

Soil stability values generally are positively correlated with biotic integrity, because biotic activity is required to bind the soil particles together. The smallest soil particles are bound together by physical and chemical forces, and by soil organic matter that formed long ago. These microaggregates are then glued to each other and to larger sand-sized particles, and become aggregates that are too large to fall through the screen in the soil stability test kit. The glue that binds these larger aggregates is primarily recently produced live and dead soil organic matter. This organic matter includes fungi, bacteria that feed on decomposing roots and plant litter, root exudates (material that is produced by roots), and the feces of soil organisms that feed on the fungi, bacteria and root exudates. These compounds degrade fairly rapidly in the soil, so high stability values are an indication that biotic recovery mechanisms are functioning.

Soil stability at different depths and under different types of vegetation can be used to reflect changes in organic matter cycling.

Changing the rating system. The rating system is arbitrary and can be adjusted to increase its sensitivity in different ecosystems. For example, in areas with very high aggregate stability, classes 5 and 6 can be split into several classes, based on the amount of material that remains on the sieve. Where possible, however, the original rating system should be followed to facilitate comparisons among different datasets.

References

Blackburn and Pierson 1994
Herrick 1999
Herrick et al. 2001
Seybold and Herrick 2001
Warren 2001
Whitford 1996

Belt transect (woody and invasive plants)

The *density* (number of plants per hectare) *of woody and invasive plant*s is a very sensitive indicator of biotic integrity in many areas. This is particularly true for systems that are at risk of changing from a native grass-dominated system to one that is dominated by shrubs, trees, exotic grasses or forbs. In some cases, the size of the woody/invasive is also important, especially where fire can kill small individuals. In these cases, individual indicators should be calculated for each size class (*plant density by size class*).

The probability that woody/invasive plants will be encountered is higher with larger plots. If invasive species are a threat, and few or none have been detected in the area, much larger areas should be systematically searched.

References

Bonham 1989
Sheley et al. 1999

Compaction test (impact penetrometer)

The impact penetrometer is used to detect changes in soil compaction. When soils become denser, or compacted, the number of hammer strikes needed to push a rod down through the soil profile increases. This measurement is normally only used when a compaction problem already exists, or a change in management or vegetative cover is likely to result in a change in soil density.

Compaction is a natural phenomenon that occurs in all ecosystems. Compaction becomes a problem when recovery processes, including freeze-thaw, root expansion and soil movement by soil biota and animals, fail to balance the compacting effects of vehicles, livestock, wildlife and other factors.

Compaction affects hydrologic function because it reduces pore sizes, causing water to move more slowly through compacted layers than through non-compacted layers. Compaction can reduce the amount of water that soaks into the soil and increase runoff. Consequently, it can indirectly reduce soil and site stability. Compaction makes it more difficult for roots to access water, both because water already in the soil moves more slowly to refill depleted zones around roots, and because it is more difficult for the roots to penetrate the compacted soil. Compaction can restrict the movement of soil organisms, consequently limiting the release of plant nutrients.

Compaction also affects the amount of water that can be stored by the soil. It reduces soil water storage capacity in most soils, but can increase storage capacity in extremely coarse-textured soils.

The *number of penetrometer strikes* required to reach a particular depth can be a very sensitive and precise indicator of soil compaction. It is much easier to consistently generate this indicator than to directly measure the density of the soil. The results must be carefully interpreted because other factors can cause changes in the resistance of the soil to penetration. The most important factor is soil moisture content. It takes less energy (fewer strikes) to penetrate moist or wet soil than dry soil. Consequently, the penetrometer is best used to make repeated comparisons on dry soils, rather than to compare different soils, or soils at different moisture contents. At a minimum, the moisture content of the soil should always be described or, if possible, measured for each of the depths evaluated.

A second important factor is soil texture. It is generally more difficult to penetrate soils with high clay content.

Ratios can be used to help determine if a compaction layer exists and to monitor changes in compaction. In order to make these comparisons, the soil must have uniform texture and moisture content throughout the measurement depth for the area of interest. In most cases, this means the soil must be dry because soil moisture varies with both depth and plant cover.

The *ratio of strikes in the interspaces vs. under plant canopies* can also be helpful. As for all comparisons, however, the fact that the soil in the interspace is more resistant to the penetrometer does not necessarily mean that compaction is having a negative effect on root growth or infiltration. Qualitative indicators can often be used to assess the effects of compaction on root growth. The infiltrometer (Chapter 8 and the next section) can be used to evaluate the effects of compaction on infiltration.

References

Blake and Hartge 1986
Bradford 1986
Campbell and Hunter 1986
Herrick and Jones 2002
Larson and Pierce 1993
Thurow et al. 1995
Warren et al. 1986
Webb and Wilshire 1983
Willatt and Pullar 1983

Single-ring infiltrometer (water infiltration)
Water infiltration rate in a cylinder is an indicator of how quickly water soaks into the soil during rainstorms. It is important to remember that *infiltration rate* calculated from the Single-ring infiltrometer is simply a relative *indicator* and does not measure actual infiltration rates during rainstorms or snowmelt. Single-ring infiltration rates are significantly higher (sometimes as much as 10x) than natural infiltration rates. This is primarily because during the test, water can move horizontally as well as vertically after it enters the soil. Consequently, while the test is fairly sensitive to changes in the soil surface, it is not very sensitive to subsurface compaction unless the cylinder is inserted deep into the compacted layer. Note that if the cylinder is inserted more deeply, more time and water are required for the infiltration to equilibrate because the soil must become fully saturated to a depth below the bottom of the cylinder.

There are two other important differences between the Single-ring infiltrometer and infiltration during natural precipitation events. The first is that the test does not include the effects of raindrop impact. Raindrops can rearrange bare soil particles and contribute to the formation of a physical crust, thereby reducing infiltration rates. The second difference is that with the Single-ring infiltrometer there is no opportunity for water redistribution to occur from areas with low infiltration rates, such as plant interspaces, to areas with higher infiltration rates, such as under plant canopies.

Single-ring infiltration data for areas with deep layers of embedded litter or duff should be carefully interpreted. This material is usually removed to a standard depth prior to beginning the measurements, or the ring is inserted deeply enough so that the bottom extends into mineral soil. Both duff and embedded litter are often hydrophobic. By repelling water, they initially reduce infiltration rates. However, they also have high porosity and can significantly reduce runoff after they have been wetted. Infiltration rings often artificially reduce hydrophobicity of intact layers of embedded litter or duff, resulting in an even greater overestimate of infiltration rates. If the litter or duff is removed prior to measurement, infiltration rates can be underestimated.

Despite these limitations, the rate of infiltration recorded with the Single-ring infiltrometer can be a valuable indicator of change in the hydrologic characteristics of the soil surface.

References
Abu-Awaad 1997
Bouwer 1986
Morin and Van Winkel 1996
Pierson et al. 1994
Thurow et al. 1988a,b
Thurow et al. 1995
Warren et al. 1986
Webb and Wilshire 1983

Plant production
Total plant production is one of the most important indicators of biotic integrity because plants reflect changes in resource availability, including water and nutrients, and because they respond rapidly to changes in the disturbance regime. It also reflects the amount of energy potentially available to herbivores. The annual production of specific species or specific groups of species (e.g., functional groups) is often used to estimate carrying capacity for both livestock and wildlife. The number of species recorded in all production subplots can be used as a minimum estimate of species richness.

The value of plant production data is often limited by various factors. Both the precision and accuracy of the data can be quite low, variable and difficult to define. Individuals vary widely in their abilities to estimate biomass. One way to alleviate this limitation is by double sampling (comparing estimated weights to clipped weights). Data from clipped plots help standardize data for herbaceous species, but are less useful for woody species. Another source of error is in estimating the correction factors for plant material that has been removed or has not yet been produced. Individuals vary widely in their ability to select correction factors. Accurately estimating correction factors depends on correctly predicting future weather and plant growth responses to weather and other conditions.

Production data are often used to calculate a *similarity index*. This requires a standard, such as one or more of the plant communities found in the reference state. Most of the indicators discussed for the Line-point intercept method can also be calculated using production instead of cover.

Reference
USDA-NRCS 1997

Plant species richness (modified Whittaker approach)
Species richness is simply the number of species that occur in an area. It is one of many biodiversity indicators. No method will detect all species. A minimum estimate of species richness can be calculated by counting the number of species recorded on the Line-point intercept data form. The modified Whittaker nested plot approach described in Chapter 10 has been shown to be more effective than other methods in measuring species richness. Plant species richness allows the maximum number of species on the plot to be predicted. This is done by plotting the number of species found in each subplot against the area searched. Data points are then connected with a line. The line is then extrapolated to predict the maximum number of species (horizontal axis; Fig. 17.14).

For more information on the modified Whittaker approach, please see recent publications by Tom Stohlgren and others listed here in the References.

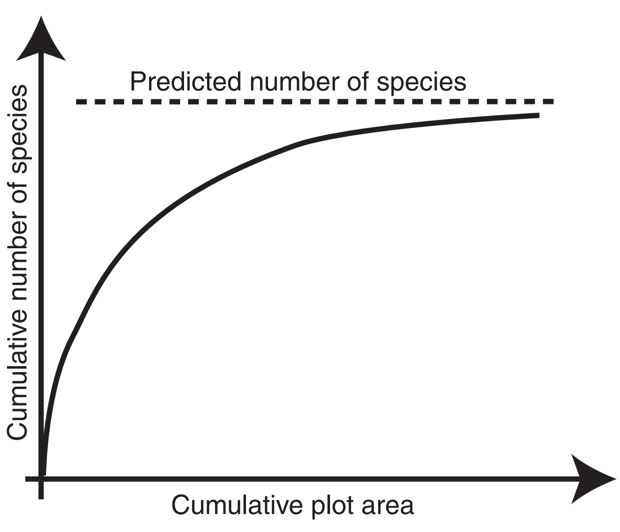

Figure 17.14. Species area curve.

References
Huenneke et al. 2002
Stohlgren et al. 1995
Stohlgren et al. 1997

Vegetation structure
The cover pole is used to quantify changes in vegetation structure. Higher vertical structure indicator values are caused by the presence of vegetation at many different heights (i.e., non-uniform vegetation height). Vertical structure is related to wildlife habitat quality and reducing wind speeds near the soil surface. It also affects the aesthetic value of the land. Vertical structure often determines where recreational activities are most likely to occur on a landscape.

Vegetation structure indicators are most often correlated with vegetation biomass and wildlife habitat quality. The two indicators included here, *visual obstruction* (Robel 1966) and *Foliage Height Diversity* (FHD; MacArthur and MacArthur 1961), have both been related to habitat quality for various wildlife species.

As yet unpublished studies in New Mexico have shown that cover pole indicators are correlated with foliar cover and height, and with Gap intercept indicators.

References
Benkobi et al. 2000
MacArthur and MacArthur 1961
Mills et al. 1991
Nudds 1975
Robel 1966
Robel et al. 1970

Tree density
Tree density is a useful indicator of biotic integrity in savanna and woodland plant communities. Changes in tree density are also often associated with changes in soil erosion. This is because they affect wind velocity at the soil surface, and the distribution of herbaceous plants and litter. As with the belt transect, the precision of tree density estimates is very sensitive to plot size. If this is an important indicator, and density is low, larger plots should be used.

In addition to total density, the data collected with this method can be used to calculate *density* *by species and by size class*. Size classes can be based on tree height and/or diameter. The amount of wood that could be potentially harvested can also be estimated using species-specific conversion tables (Wenger 1984).

References
USDA Forest Service 2003
Bonham 1989
Wenger 1984

Riparian-specific measurements
The Riparian channel vegetation survey and Riparian channel and gully profile are basic supplementary methods that should be added when monitoring plots fall in riparian areas. For more intensive riparian monitoring (e.g., following intensive restoration work), or where the characteristics of the stream itself are of interest, additional measurements should be included. Sources for other measurements are included at the end of this section.

Interpretation of riparian data is extremely complex because the potential of riparian areas depends on many factors that are not readily observable, including geology of the watershed and of the channel itself. Participation in one or more riparian assessment course is strongly encouraged before attempting to interpret the indicators described here. The information below simply serves as a basic introduction to some of the indicators that can be calculated with the measurements described in this manual.

Riparian channel vegetation survey
The Riparian channel vegetation survey is designed to provide the same type of information generated by the Line-point intercept method. The same basic indicators can be calculated. Please see the Line-point intercept discussion within this chapter.

Additional indicators can be used to determine the relative effectiveness of the plant community in protecting the streambank from erosion. Indicators can be added to monitor changes in woody species cover. Woody species can be important for creating favorable conditions for both terrestrial and aquatic animal species. This survey can also be used to characterize plant community structure using the height measurements.

Stabilizing species cover is often the most important indicator for both hydrologic function and biotic integrity. Stabilizing species generally have an extensive, deep, fibrous root system that helps hold the soil together, resisting the erosive action of the stream and promoting sinuosity. In riparian areas dominated by herbaceous species, the same indicator can be calculated using basal cover.

The *stabilizing species as a percent of total species cover* is related to the relative dominance of bank stabilizing species. It is particularly useful where multiple species are intercepted at each point. Higher values are associated with areas where a higher proportion of the species intercepted are stabilizing species.

Production or biomass measurements can be used to generate a more accurate estimate of relative dominance. Recording multiple intercepts of the same species at each point can also be used to generate a more accurate indicator of relative dominance.

An additional indicator is *woody cover*. The presence of woody species, particularly trees, is an indicator of a healthy riparian system in many regions. In order to effectively interpret this indicator with respect to hydrologic function, it is important to know something about the species that are contributing to woody cover. The age distribution is important to biotic integrity. Younger trees are an indication that regeneration is occurring. However, the negative effects on hydrologic function and biotic integrity of some invasive trees (such as tamarisk) can outweigh their positive stabilizing effects.

References
Briggs 1996
Prichard et al. 1998a
Prichard et al. 1998b
Winward 2000

Riparian channel and gully profile
The Riparian channel and gully profile is used to describe changes in the shape of the channel. It can also be used to monitor recovering (or

deepening) gullies. A number of indicators can be calculated. Two of the most common are described below. *Please note that the interpretation of these indicators is context-dependent. A trained riparian specialist who is familiar with local soils, hydrology and vegetation should be consulted regarding interpretations.*

Bank angle or *slope gradient* is the slope of the bank. In riparian systems, the optimal bank angle for a functional stream depends on geomorphology and soil. For gullies, a reduction in the angle is nearly always indicative of a recovering system.

Changes in the *width-depth ratio* indicate changes in the stability of the stream. The ideal width-depth ratio depends on a number of site characteristics. Healthier streams generally have lower width-depth ratios, except where incision and/or a reduction in sinuosity have occurred. If significant changes in this indicator occur, consult a riparian expert with knowledge of the hydrology of the streams in your area. Note that the width-depth ratio calculated from the channel profile method will not necessarily be the same as one based on bank-full. Bank-full is defined based on the water level during typical high flow events. Width-depth ratios based on bank-full are potentially most closely related to the functioning of riparian systems. The two types of width-depth ratios are correlated.

A reduction in width-depth ratio in gullies is generally a sign that active cutting is occurring, while an increase can be an indicator of recovery through deposition or stabilization of the gully edges. However, changes in gully morphology also can be due to changes in upslope processes (sediment sources) and subsurface properties (e.g., a very gravelly or highly erodible layer of soil).

References

Briggs 1996
Prichard et al. 1998a
Prichard et al. 1998b
Winward 2000

Extrapolation

Careful extrapolation of the results from individual measurements is important for most monitoring programs. Extrapolation allows the results to be interpreted throughout much larger areas than the monitoring plots themselves.

There are three general approaches for extrapolation: (1) non-spatial; (2) spatially implicit; and (3) spatially explicit (Peters et al. 2004). Non-spatial extrapolation is used where plots are randomly selected. Spatially implicit and explicit extrapolations require stratified random plot selection. These two approaches can be applied to randomly selected plots if the plots are subsequently stratified. The third approach, spatially explicit extrapolation, requires knowledge about where the plot is relative to other types of monitoring units.

Information from non-randomly selected plots (e.g., key areas and other subjective systems) cannot be quantitatively extrapolated. However, expert knowledge can often be used to make qualitative inferences about other larger areas based on data from subjectively selected plots on key areas.

Non-spatial extrapolation

Non-spatial extrapolation is the simplest approach. Here you simply average the values from all plots and use this value to represent the entire area sampled. This is generally only appropriate where the land is so homogeneous that there is only one type of monitoring unit. In other words, the soil, climate, topography, vegetation and management are functionally similar throughout the area being monitored and interactions with adjacent areas are insignificant (or do not vary).

Spatially implicit extrapolation

In this approach the average of all plots within a single type of monitoring unit is used to reflect typical conditions throughout the unit. This approach is also quite simple and the level of certainty associated with the estimate of each indicator can be easily calculated using standard statistical methods (see Appendix C).

Spatially explicit extrapolation

In spatially explicit extrapolation, interpretations for each plot are modified based on attributes of adjacent plots. In the case of wind erosion, an area that is classified as highly susceptible to wind erosion based on canopy gap data might be reclassified as only moderately susceptible because it is surrounded by dense woodland that reduces wind speed. Alternatively, it could be reclassified as very highly susceptible if it is downwind of a large sand source, such as an area recently cleared of vegetation. This is because mobile sand can erode through protective crusts even in the absence of disturbance by vehicles or animals.

Spatially explicit extrapolation generally requires some kind of model, or at least a set of clearly defined rules.

Spatial context

While the spatial context is used only in the spatially explicit extrapolation approach, it should be considered in the interpretation of all monitoring data, even if no spatial extrapolation is planned. Information about where a plot is located in the landscape can be used to improve the quality and value of data interpretation at both plot and landscape scales.

The spatial context must be considered in order to determine (1) whether data from the plot truly reflect the status of the area that it was selected (randomly or subjectively) to represent, and (2) whether the indicators measured at the plot scale are adequate to reflect the status of the area.

Anomalous plots. Both subtle differences in the relatively static properties of a plot (e.g., slope and soil texture) and the location of the plot in the landscape can confound extrapolation.

Soil texture significantly affects plant production potential and soil erodibility. Climate also varies significantly across the landscape. For example, south-facing slopes are subjected to higher evaporation rates and generally have shallower soils than north-facing slopes. Both higher evaporation rates and shallower soil depth result in lower soil moisture availability on south-facing slopes, increasing bare ground and the potential for rill formation even on sites that are at or near their potential.

Ecological sites that are located lower on the landscape (downslope) may receive runoff water during intense storms or snowmelt. The effect of increased runoff can be positive if additional water is retained on site and becomes available for plant growth (concave microsite). Increased runoff can be negative if it results in greater erosion (convex microsite). Microsites that capture wind-driven snow generally have a higher production potential than sites that are free of snow most of the time, except where the snow persists long enough that it significantly limits the length of the growing season. Sometimes these microsite differences are reflected in different ecological sites, but most ecological sites include a broad range of microsites with variable potential.

We recommend avoiding locating plots in anomalous sites. Using a random or stratified random plot selection approach can significantly minimize the effects of these plots on the interpretation. If you cannot avoid anomalous sites, increase the level of replication beyond the minimum recommended. The effects of these anomalous plots on average values decline as the number of plots included increases. Please see Chapter 5 for a discussion of how to deal with potentially anomalous plots during the plot selection process.

Adequacy of plot-scale indicators. Determining whether the indicators measured at the plot scale are adequate to reflect the current status of the area can be extremely difficult. Both larger scale patterns and processes, and the status of adjacent areas that may affect the area represented by the monitoring plot(s), must be considered.

The importance of larger scale patterns and processes is reflected in attempts to monitor the urban-wildland interface using small plots. High vegetation structural diversity measured at the plot scale is an indicator of good habitat quality for many species. However, its value as an indicator declines if the plot is located in the middle of a sprawling subdivision of 1-5 acre lots (i.e., habitat structural diversity is suitable, but habitat size is too small to be used).

The status of adjacent areas is particularly important when considering monitoring site susceptibility to runoff and erosion. High ground cover and soil surface stability are generally good indicators of soil erosion resistance. However, high ground cover and soil stability are insufficient to resist gully formation by concentrated runoff from roads located on adjacent land. Even if landscape-level indicators are unavailable, qualitative information about the surrounding area can be used in both cases to improve indicator interpretation.

Temporal context

The temporal context is also important, particularly when using the data to make management decisions. In arid and semi-arid environments, time since grazing, as well as timing, amount and intensity of precipitation, affects many of the indicators. Foliar cover and production are particularly variable, but all of the indicators are sensitive to these factors.

A long historical record can be extremely helpful. Information on historical use and management can help when interpreting the rate and direction of trends.

Pulling it all together: the big picture

Perhaps the most useful tools for interpreting monitoring data are the state and transition models described in Chapter 24. These are used to help define the status of each monitoring plot relative to potential thresholds, and to identify potential future drivers of change.

Additional reading

For more information on the three types of spatial extrapolations described here, see Peters et al. (2004). Ludwig et al. (1997) discuss many of the issues that are important for defining landscape context. The use of aerial photographs in identifying historical manipulations is described in Rango et al. (2002).