Monitoring Manual

for Grassland, Shrubland and Savanna Ecosystems

Volume II: Design, supplementary methods and interpretation

by

Jeffrey E. Herrick, Justin W. Van Zee,
Kris M. Havstad, Laura M. Burkett and Walter G. Whitford

with contributions from

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Mike Pellant, David A. Pyke, Marta D. Remmenga, Patrick L. Shaver,
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Collecting Line-point intercept data
in a south-central New Mexico desert grassland.

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Introduction to Volume II

The Monitoring Manual for Grassland, Shrubland and Savanna Ecosystems is divided into two volumes: Quick Start (Vol. I) and Volume II. This two-volume document is intended to assist a wide range of users, including technicians (data collectors), field crew leaders, ranchers and landowners, land managers, rangeland professionals, and researchers.

Quick Start (Vol. I) includes basic methods and instructions for establishing photo points and completing four basic measurements. Volume II provides more detailed guidance on monitoring program design, data analysis and interpretation. It also includes a number of supplementary methods.

Section I describes how to design a monitoring program in six steps.

Section II includes eight supplementary monitoring methods and alternatives to the Line-point intercept method.

Section III describes how to organize, analyze and interpret monitoring data.

Section IV provides specific recommendations for designing monitoring programs to address the following issues:

- Riparian
- Livestock production
- Wildlife habitat
- Off-road vehicle use and other recreational land uses
- Fire
- Invasive species
- State and transition models
- Remote sensing
- Soil carbon

Section IV also explains how state and transition models can help you design monitoring programs that are more sensitive to significant changes, including thresholds. It also describes how to improve monitoring, using remote sensing. Finally, it discusses the relationship between soil carbon and monitoring.

Do I have to read the whole thing?

No. Begin by completing the checklist on the first page of Quick Start (Vol. I). This will help identify the chapters that are relevant to you. In many cases, you will not need to read Volume II at all. However, we do recommend that you familiarize yourself with Section I (to improve the quality of the monitoring program design) and Section III (to help with interpretation) of this volume.

Are these manuals all I need?

Possibly. Depending on your background, experience and monitoring objectives, Volumes I and II may provide enough guidance to design and implement a monitoring program. However, we strongly recommend consulting with other information sources and local experts to design a monitoring program that best suits your needs. A number of excellent references are included in the "References and Additional Resources" section at the end of this volume.

Electronic data forms

Additional information and electronic data forms can be downloaded from the following website: http://usda-ars.nmsu.edu. We are committed to continuously improving this document and will periodically provide online updates.

Monitoring for management

Monitoring is part of a broader process in which we use data to test and refine management decisions. Monitoring data allow the collective knowledge of scientists and land managers to be applied to improve resource management.

Monitoring is designed to support a diverse set of goals required by various societal interests (the upper triangle in Fig. Intro.1). The monitoring procedures described in this manual provide data on three key attributes of landscape and ecosystem sustainability: soil and site stability, hydrologic function and biotic integrity. These data provide the foundation for assessing and evaluating the degree to which societal goals and/or values are being met by current landscape management. They also provide the basis for management options that meet specific goals (Fig. Intro.1).

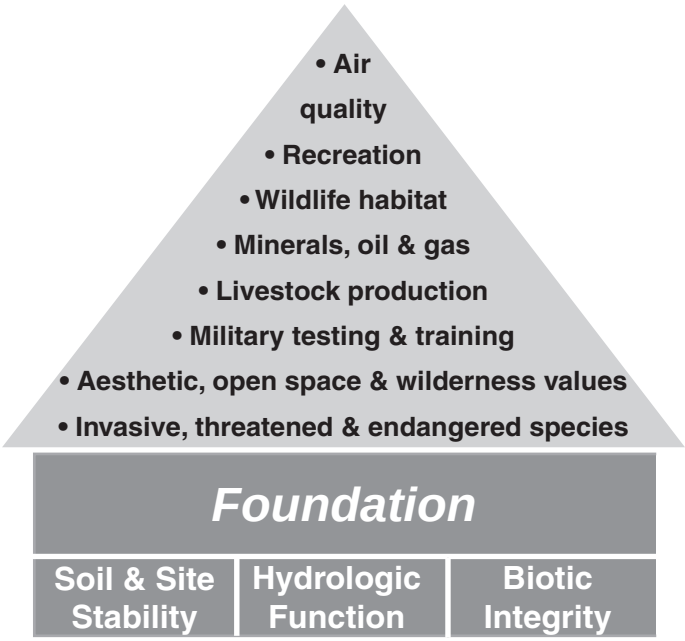


Figure Intro.1. Monitoring the three key attributes (primary monitoring objective) serves as the foundation for sustaining the potential to support diverse management objectives.

Adaptive management: management by hypothesis or prediction. Every time we change management or decide to continue with the same management, we are making a prediction. Sometimes these predictions are explicit. Predictions are more likely to be explicit when management requires a significant financial investment (e.g., fencing) or is believed to increase risk (e.g., fire). Frequently the predictions are implicit, because most management decisions are assumed to lead to improvements in the status of the land, the quantity and quality of goods and services provided by the land, or both.

These predictions are identical to scientific hypotheses, and monitoring data allow us to explicitly test our prediction(s). While we may not be able to collect as much data as a researcher would, the data are likely to be more useful for adjusting management because they reflect the unique characteristics of the land we are managing. For example, we may decide to maintain a stocking strategy because we suspect that it does no harm to grass and soils. Our hypothesis, then, is that basal cover and soil stability will not deteriorate. We can test this hypothesis using monitoring data.

In order to accurately test our predictions, we need to carefully select both the types of indicators and the monitoring locations. To do so, we also must take into account the effects of other influences on rangelands, such as climate and soil variations. An informed selection of monitoring sites and sufficient replication are essential to producing useful data.

Additional tools

Three types of tools are extremely helpful in designing monitoring programs, interpreting the results and applying them to management. *Ecological sites* are used to stratify landscapes into similar units so that we can extrapolate our results. *State and transition models* are used to help evaluate the current status of an area relative to its potential, to identify areas that are at risk of crossing a relatively irreversible threshold, and to understand the factors that may contribute to the degradation or recovery of an area. *Qualitative indicators* are used together with state and transition models to evaluate current status and identify critical processes.

Landscapes and ecological sites. The landscapes that we manage are often highly variable. This is because managed areas encompass differences in geology, topography, soils and climate at several spatial scales. Site characteristics that define the potential of part of the landscape to support different types and amounts of vegetation, and therefore its potential response to management, are used to stratify the area to be monitored into monitoring units. Site characteristics in many parts of the United States are described in Ecological Site Descriptions (available from National Resource Conservation Service, NRCS) (Ch. 2). Ecological sites (landscape units) occur together as a mosaic in landscapes. The units can be further stratified, based on current status (Ch. 3) and management.

State and transition models. In many countries, conceptual models of how vegetation and soils change due to different kinds of drivers (such as drought or grazing) are being developed for each ecological site or similar landscape unit. These state and transition models describe changes in community composition that are easy to reverse, as well as those that are not (i.e., transitions to new states) (Ch. 24). State and transition models can help to indicate the potential risk of difficult-to-reverse transitions and the potential effectiveness of different management options.

Within a given ecological site, use vegetation and soil surface properties to identify the ecological state in the state and transition model. Identifying the ecological state helps define both future degradation risks and recovery options. Projections in each model are based on the collective observations of experienced managers, research data, monitoring data and simulation models.

Qualitative indicators. Qualitative indicators (Ch. 3) are important tools for matching patterns observed on the ground to those described in the state and transition models. Properties and processes that cannot be easily measured quantitatively can often be evaluated qualitatively. This is particularly true for patterns occurring at coarser scales, such as assessing the spatial extent of runoff and run-on areas, and the relationship of these areas to soils and current vegetation. Other examples of qualitative indicators include platy structure and horizontal root growth as indicators of compaction in soils that do not normally exhibit platy structure, and pedestalling of rocks and plants as soil erosion indicators.

It is important to recognize that snapshot observations do not provide absolute certainty about how rangelands may change in the future. By their nature, qualitative indicators can help direct your attention to several ecological processes across a broad area (with or without monitoring). They are thus well suited for snapshot inventories that indicate problems, potential causes and potential management remedies.

Making it work

In the long term, the data collected and interpreted on each type of monitoring unit or ecological site can help to refine ecological models and how rangelands are managed. But it is of limited value to learn only that a particular management strategy resulted in persistent loss of grass or soil. Both short-term and long-term monitoring data should be used, together with qualitative observations, to evaluate hypotheses frequently—especially as environmental conditions (such as rainfall) vary. If it begins to look like a management strategy does not conform to expectations, the strategy can be adjusted. Successful feedback between monitoring and management helps make land use more sustainable.

Section I: Monitoring program development in six easy steps

This section describes how to design and implement a long-term ecosystem-based monitoring program at the landscape level (an area > 400 ha or 1000 acres; Fig. 0.1). It is based on the assumption that one of the primary objectives of the monitoring program will be to detect long-term changes in the status of three basic attributes of grassland, shrubland and savanna ecosystems: soil and site stability, hydrologic function and biotic integrity (Fig. Intro.1).

The six steps

Each of the first six steps illustrated in the flow chart (Fig. 0.2) and listed in the Monitoring Program Design Checklist (found at the end of this Introduction to Section I) is described in its own chapter (Chs. 1-6). The steps are listed in the order they are normally completed. Because there is no "single" way to design a monitoring program, revisiting earlier steps is often helpful. For example, the assessments completed in Step 3 often reveal issues that lead to new management and monitoring objectives (Step 1). State and transition models can be helpful here by focusing attention on areas that are at risk, or have a high potential for recovery. It is also helpful to redefine management and monitoring objectives (Step 1) for specific monitoring units identified in Step 2.

Use the Monitoring Program Design Forms I (Ch. 1) and II (Ch. 4) to organize information about your monitoring program. Use the Monitoring Program Design Checklist to ensure that you have completed each step. The system allows maximum flexibility to address objectives and long-term changes, including monitoring for adaptive management, additional objectives, short-term monitoring, and monitoring threats and drivers.

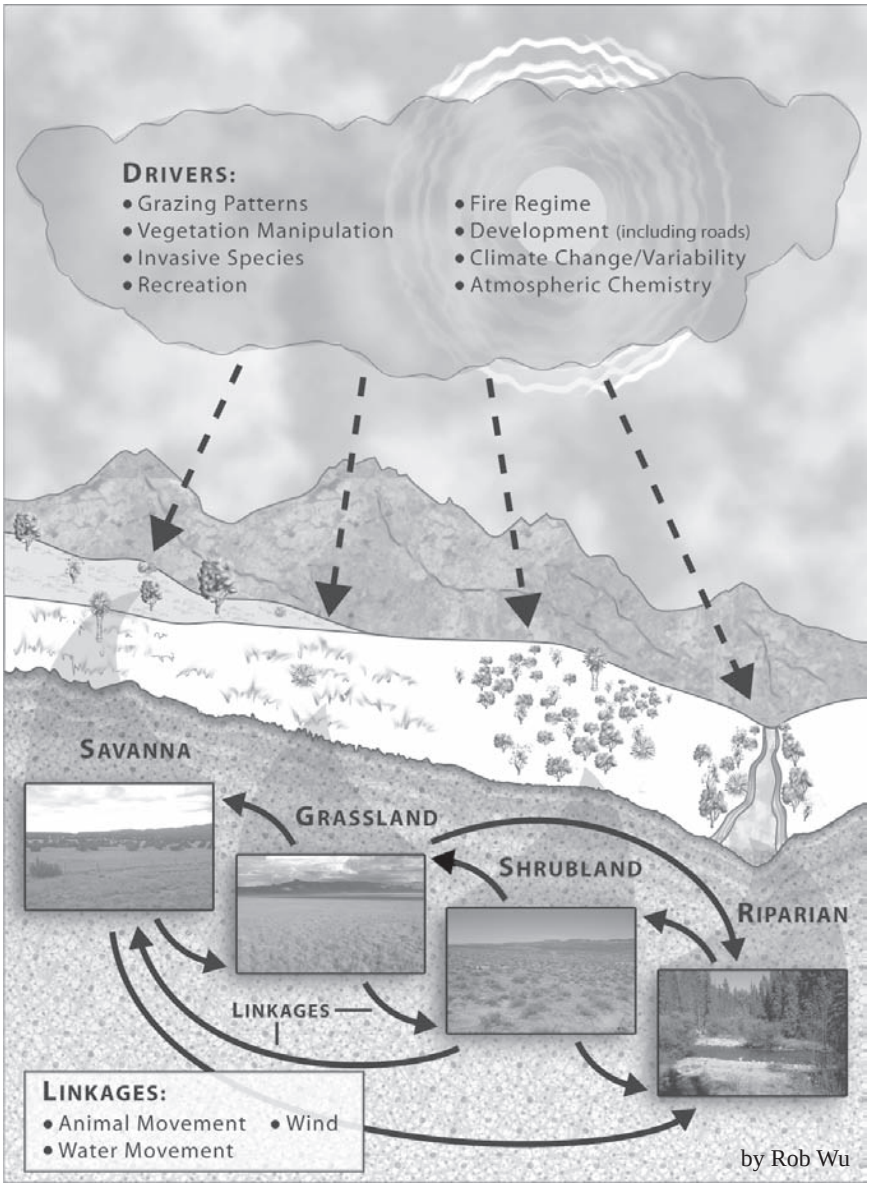


Figure 0.1. Landscape-scale monitoring programs should be responsive to the most important drivers, and sensitive to interactions among landscape units.

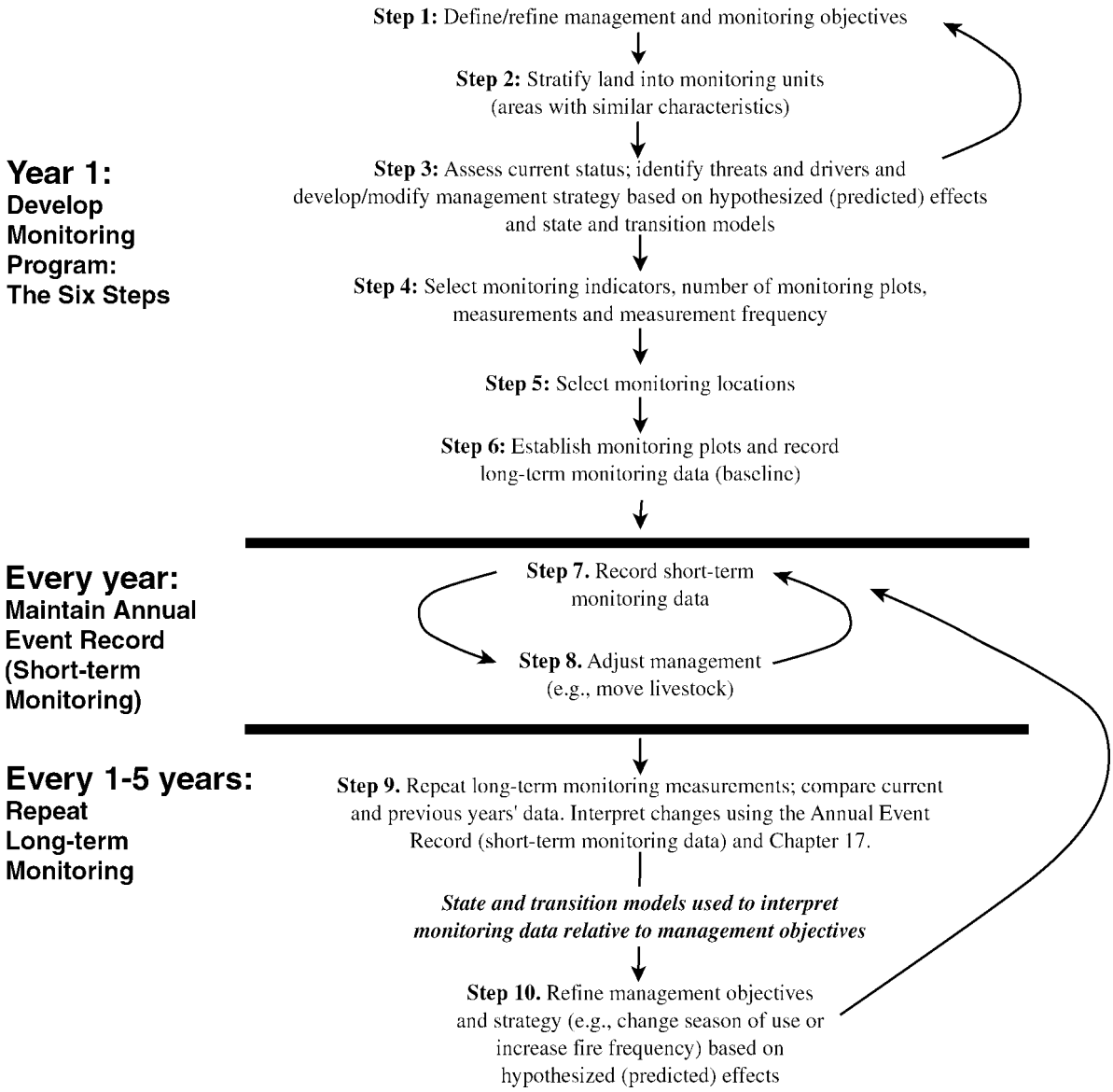


Figure 0.2. Monitoring program design and implementation (Steps 1-6) and integration with management (Steps 7-10).

Monitoring for adaptive management and management by hypothesis

In addition to long-term monitoring data, adaptive management requires three types of information: short-term monitoring data, knowledge of potential threats or drivers, and clearly defined hypotheses (predictions) of management effects (Steps 1, 3 and 7 of the checklist). State and transition models (Ch. 24) can be used to integrate assessment and monitoring data with current knowledge about potential management effects (based on management experience, scientific studies and simulation models) to generate these predictions.

Monitoring for additional objectives

Monitoring for the three basic attributes can serve as the foundation for use-specific monitoring, as illustrated in Figure Intro.1.

The basic measurements (described in Quick Start) were selected in part because they also can be used to generate indicators related to specific uses. For example, the Line-point intercept generates vegetation cover and composition indicators that are related to the quantity and quality of forage production. These indicators, together with spatial structure indicators from the Gap intercept method, can be used to assess and

monitor wildlife habitat quality, as well as plant community changes in response to fire.

The value of the basic measurements can often be increased at a relatively low cost through slight modifications (see Section IV). For example, vertical vegetation structure can be measured by adding plant height measurements to the Line-point intercept protocol (Ch. 15), or by adding the Vegetation structure method (Ch. 11). In some cases, such as riparian monitoring, supplementary measurements (Section II) may be required. Section IV also provides recommendations for addressing specific monitoring objectives.

Short-term monitoring (Annual Use Records)

Short-term monitoring data (listed at the end of Quick Start) are used to make short-term management changes (Steps 7 and 8). For example, information on residual cover or biomass is often used to decide when to move livestock to a new pasture. This information is also used to interpret long-term monitoring data.

Monitoring threats and drivers

Information on potential threats and drivers, such as development of new roads or a change in fire frequency, is used to help identify areas where a change in management and/or monitoring will be required. Threats and drivers are identified in Step 3.

What if I don't have enough time?

Nearly any monitoring is better than no monitoring. Using management and monitoring objectives to guide monitoring program design can reduce monitoring costs. A few days of careful planning often can reduce monitoring costs by 50 percent or more and result in much more useful data.

- Use photo points where few changes are expected (see description of state and transition models in Ch. 24) or where you require only a qualitative record.
- Select measurements that are sensitive to changes defined in the management and monitoring objectives.
- Select measurements that generate indicators that are relevant to multiple objectives. The measurements included in Quick Start were selected in part because they are sensitive to changes in the three key attributes, while generating numerous indicators that are relevant to many other objectives.
- Match monitoring frequency to expected rates of change based on minimum detectable change. If the smallest change in basal cover you can detect is five percent (Ch. 4) and it takes at least five years for this change to occur, it's a waste of time to repeat measurements more frequently.

Using State and Transition Models for Monitoring Design

State and transition (S&T) models (Chapter 24) are conceptual models that describe the soil and vegetation dynamics for a particular type of land with similar soils and climate. Applying S&T models to monitoring program design helps a) define ecological potential, benchmarks, or reference conditions and b) specify predictions about the possible future change of different land units in a landscape. This approach allows monitoring site selection to be based on objectives and the ecological processes involved in land change. Designing a monitoring program within a state and transition model framework helps specify the ecosystem attributes to be monitored and other details that may vary among states and ecological sites.

Applying S&T conceptual models to monitoring site selection minimizes monitoring expenditures in highly degraded states where all available evidence suggests they will not change; and focuses monitoring efforts in 'at risk' states and plant communities where management has the potential to limit degradation or promote recovery. With this logic in place, monitoring can be treated as a series of tests matched to specific parts of a landscape. Key components of this test are the steps used to apply S&T models to a monitoring program design.

Steps for S&T Monitoring Design

First, stratify the landscape (Chapter 2) into ecological sites or potential-based land classes. This is done using soil surveys, landform maps, digital elevation models and knowledge of key soil gradients. Next, stratify each ecological site into states based on S&T models using aerial photography, remote sensing and/or field surveys. Finally, select monitoring methods that detect changes in focal patterns and processes within each specific ecological site and state.

Monitoring Program Design Checklist

Step*	Task	Completed?
	Develop monitoring program	
1	**Define management and monitoring objectives**	
	Define management objectives	_____
	Define monitoring objectives	_____
2	**Stratify land into monitoring units (areas with similar characteristics)**	
	Assemble background information (maps, photos, management history)	_____
	Define stratification criteria (e.g., soils, vegetation, management units)	_____
	Complete stratification and list monitoring units on Monitoring Program Design Forms I and II (Chs. 1 & 4).	_____
3	**For each monitoring unit, assess current status; identify threats and drivers; refine long-term management and monitoring objectives; and develop/modify management strategy**	
	Select assessment system (e.g., Pellant et al. 2005)	_____
	Verify that personnel have relevant qualifications	_____
	Complete assessments	_____
	Identify and record threats, drivers and opportunities	_____
	Refine long-term management and monitoring objectives	_____
	Develop/modify management strategy	_____
4	**Select monitoring indicators, number of monitoring plots, number of measurements, and measurement frequency based on objectives and resource availability**	
	Select monitoring indicators	_____
	Define number of monitoring plots	_____
	Define measurement frequency	_____
	Estimate time requirements	_____
5	**Select monitoring plot locations**	
	Choose and apply site selection approach	_____
	Select “rejection criteria” and use to eliminate unsuitable locations	_____
6	**Establish and describe monitoring plots, and record long-term monitoring data (baseline)**	
	Establish and permanently mark monitoring plots	_____
	Describe monitoring plots and record GPS locations, including coordinate system, datum and zone	_____
	Record long-term data	_____
	Error-check and copy data and keep copies in different locations	_____
	Short-term monitoring (all years)	
7	**Record short-term monitoring data (at least 1x/year) (Quick Start)**	_____
8	**Adjust management, if necessary (Quick Start)**	_____
	Repeat long-term monitoring (every 1-5 years)	
9	**Repeat long-term monitoring measurements (Ch. 6), compare data with Year 1 and interpret changes (Ch. 17)**	
	Repeat long-term monitoring measurements	_____
	Copy data and keep copies in different buildings	_____
	Calculate indicators	_____
	Compare with Year 1 (or previous years)	_____
	Interpret changes using short-term monitoring data and Section III	_____
10	**Refine management strategy, if necessary**	_____

*Steps 1-6 correspond to Chapters 1-6, except where noted.

Chapter 1

Step 1: Define management and monitoring objectives

Checklist

1.1. Define management objectives ..... _____
1.2. Define monitoring objectives ..... _____

Why monitor?

Monitoring data are used to:

- evaluate the effects of past management;
- confirm effective management practices;
- identify trends that can be used to predict future changes so management can be adapted accordingly;
- learn more about how different factors (drought, fire, management) affect the land.

The most useful monitoring programs help managers achieve long-term management objectives by generating relevant data. Consequently, it is essential to clearly define both management and monitoring objectives before designing a monitoring program.

Use the Monitoring Program Design Form I (end of Ch. 1) to record your objectives as you develop them. You may find it easier to complete the stratification process (Ch. 2) before defining specific short- and long-term objectives.

Step 1.1. Define management objectives

(a) List the *general long-term management objective(s) for the area to be monitored* on the first line in Monitoring Program Design Form I. What do you want the land to look like? What goods and services do you want it to be able to provide now and 100 years from now?

(b) List *specific long-term management objectives* for each monitoring unit or type of land in the fifth column of the Monitoring Program Design Form I (see Ch. 2 for a discussion of monitoring units). The long-term monitoring program will be designed to measure progress towards meeting these objectives. For example, the specific objectives may include maintaining or increasing the production of particular products (e.g., forage for livestock) or services (e.g., filtering water before it reaches streams). State and transition models (Ch. 24) can be used to help define what types of changes are possible in different areas.

(c) List *short-term management objectives* that are necessary to achieve each of the long-term objectives for each type of monitoring unit in the same (fifth) column of the Monitoring Program Design Form I. Use of short-term monitoring indicators helps ensure the short-term objectives are being met, and helps interpret long-term monitoring data.

Examples of management objectives are listed in Table 1.1.

Step 1.2. Define monitoring objectives

Monitoring objectives follow directly from the management objectives. Additional monitoring objectives may result from plot assessments (Ch. 3). Where possible, the monitoring objectives should be quantitative. Use Appendix C to help decide if monitoring objectives are realistic.

(a) List the *general long-term monitoring objectives for the area to be monitored* in the second row of the Monitoring Program Design Form I. These should be based on the general long-term management objectives. There are three general types of monitoring objectives: (i) change in average status, (ii) change in the status of areas with a *high degradation risk*, and (iii) change in the status of areas that have a *high recovery potential*. Monitoring programs

Table 1.1. Examples of management and monitoring objectives for a mid-elevation ranch in an area dominated by sagebrush and perennial bunchgrasses. Similar objectives can be generated for areas in which recreation, mining and/or biodiversity conservation are the primary land uses.

General

Management: Maintain or increase land productivity and the number of land use options. Minimize land degradation risk.
Monitoring: Focus monitoring on areas with a high degradation risk and/or recovery potential in order to provide as much management-relevant information as possible.

Type of monitoring unit	Long-term objectives	Short-term objectives
Steep, highly erodible south-facing slopes	***Management:*** (1) Minimize soil erosion. (2) Increase habitat diversity for wildlife. ***Monitoring:*** Detect changes in ground cover, especially grass basal and shrub foliar cover. Detect the presence of invasive species, including cheatgrass.	***Management:*** (1) Control grazing to maintain sufficient ground cover and minimize erosion. (2) Time grazing to promote perennial grass reproduction and establishment while maintaining sufficient sagebrush cover for wildlife habitat. ***Monitoring:*** Detect changes in ground cover during and at the end of the grazing period. Record the beginning and end date of each grazing period.
Riparian	***Management:*** (1) Increase tree cover. (2) Increase bank stability. ***Monitoring:*** Detect changes of >10% in tree cover along the stream and throughout the riparian area. Detect changes of >5% in the cover of bank-stabilizing species along the stream.	***Management:*** (1) Limit growing-season use of trees until they are taller than browse line. (2) Limit livestock and recreational access and crossings to erosion/compaction resistant substrates, like gravel. (3) Time grazing to promote growth of bank-stabilizing species. ***Monitoring:*** Document completion date and effectiveness of new animal distribution control structures (e.g., fencing, hardened crossings). Where possible, directly document livestock distribution (e.g., with dung pat counts). Record the beginning and end of each grazing period.

designed to primarily address the first objective are usually the least cost-effective because a lot of effort is devoted to monitoring areas with a low probability of change. Selecting one or both of objective types (ii) and (iii) allows resources to be focused on areas where management is most likely to have an effect. See Chapter 5 for more information on site selection.

(b) List the *specific long-term monitoring objectives* for each type of monitoring unit in the sixth column of the Monitoring Program Design Form I. The potential for degradation and recovery varies both within and among monitoring units. State and transition models (Ch. 24) can be used to help select appropriate monitoring objectives for each type of monitoring unit.

(c) List the *short-term monitoring objectives* necessary to ensure the management plan is being followed and to document management changes. Record objectives in the same sixth column of Monitoring Program Design Form I.

Examples of monitoring objectives are listed in Table 1.1. Figures 1.1 and 1.2 show two additional examples, where arrows indicate desirable changes.

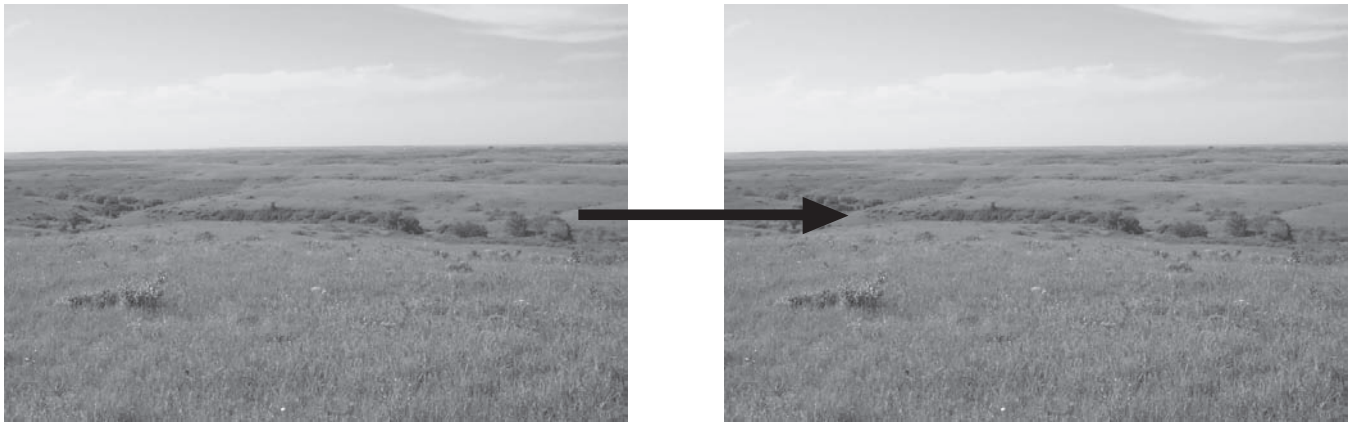


Figure 1.1. Tallgrass prairie functioning at its highest potential, Kansas, USA. Arrow reflects lack of significant change over time. *Long-term management objective(s):* Maintain biodiversity and productivity. *Long-term monitoring objective(s)*: Detect changes in plant cover and production by plant functional group; detect changes in plant species richness.

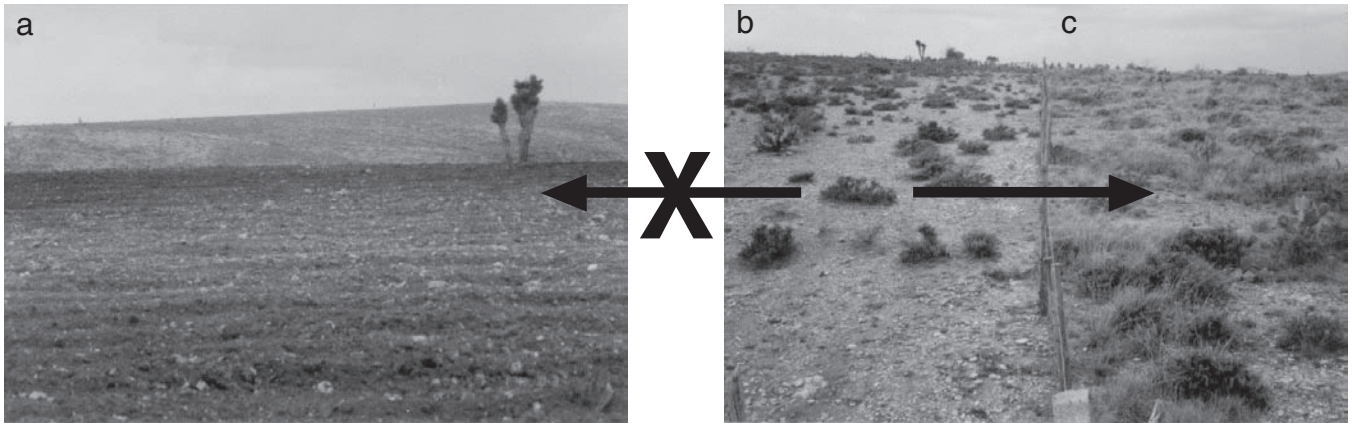


Figure 1.2. Overgrazed rangeland on left side of fence (b), and appropriately grazed rangeland on right side of fence (c), and conversion to rain fed agriculture (a), Zacatecas, Mexico. Arrows reflect desirable and undesirable changes from a long-term ecological sustainability perspective. *Long-term management objectives:* (1) Increase grass cover for livestock forage production. (2) Avoid cultivation, which leads to a relatively irreversible threshold due to increased soil degradation and erosion. *Long-term monitoring objectives*: (1) Detect changes in plant cover and production by plant functional group and vegetation spatial distribution. (2) Collect sufficient data to detect 5% change in bare ground.

Monitoring Program Design Form I. List different types of monitoring units and management and monitoring objectives for each type of unit. Record notes on the back of this form.

General management objective(s):

General monitoring objective(s):

Monitoring Unit Name* (Ch. 2)	Soil/ landscape position** (Ch. 2)	Dominant vegetation (Ch. 2)	Current status (Ch. 3)	Management objectives (Ch. 1) – Long-term – Short-term	Monitoring objectives (Ch. 1) – Long-term – Short-term	Total area (all units of this name)	Monitoring level (Ch. 4)

*Copy these to the first column of Monitoring Program Design Form II (Ch.4)
**Or ecological site or equivalent, if known.

Chapter 2

Step 2: Stratify land into monitoring units

Checklist

2.1. Assemble background information (maps, photos, management history) _____
2.2. Define stratification criteria (e.g., soils, vegetation, management units) .. _____
2.3. Complete Stratification ..... _____
2.4. Complete Monitoring Program Design Forms I (Ch. 1) and II (Ch. 4) ..... _____

This chapter describes how to stratify the area into monitoring units and decide which units to monitor. Data from individual monitoring plots can be more reliably extrapolated to represent larger areas if the area of interest is stratified.

Because rangelands are among the most diverse ecosystems in the world, it is impossible to design a monitoring system that perfectly reflects changes in all landscape units. However, the accuracy and precision of any monitoring system can be improved by carefully dividing the area into relatively uniform monitoring units.

Monitoring units are areas located in a particular part of the landscape (e.g., flood basin or hill summit), within which vegetation, soil type, management and current status are relatively similar. All sections within a given monitoring unit are expected to respond similarly to changes in management and to catastrophic disturbances, such as a combination of drought and fire. Monitoring units may range in size from less than an acre to several square miles or more.

Multiple monitoring units of the same type (e.g., hill backslope in Fig. 2.1) often repeat across the landscape, geographically separated from one another by other monitoring units. Figure 2.1 shows how a landscape unit (floodplain) was divided into two types of monitoring units based on management (grazed vs. ungrazed).

Not all monitoring units will necessarily be monitored (Fig. 2.1). For example, highly stable types of monitoring units (such as bedrock) might not be included in a monitoring program if the primary objective is to monitor for degradation risk or recovery (see Ch. 1). Use Monitoring Program Design Forms I (Ch. 1) and II (Ch. 4) to keep track of potential monitoring units.

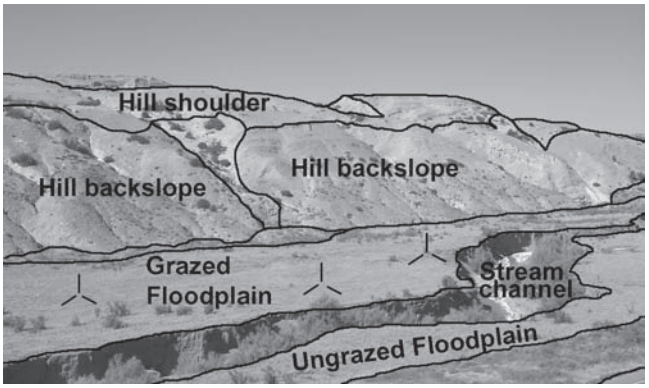


Figure 2.1. Example of how monitoring units are defined using landscape, soil, vegetation and management criteria. In this example, three monitoring plots, shown here as three sets of three transects (spokes), were located in the summer-grazed floodplain monitoring unit, which has a high potential for both degradation and recovery. No monitoring plots were located on monitoring units on the adjacent slopes because they did not meet the selection criteria, which included livestock use.

Stratification: How to do it

Landscape stratification is a three-step process:

2.1 Collect background information, maps and photographs.
2.2 Define stratification criteria.
2.3 Divide the area into monitoring units:
  (a) divide the area into soil-landscape units;
  (b) subdivide the soil-landscape units into soil-landscape-vegetation units (if necessary);
  (c) subdivide the soil-landscape-vegetation units into monitoring units based on type of management.

Record each type of monitoring unit from 2.3 in Monitoring Program Design Forms I and II.

Step 2.1. Collect background information

The following resources are helpful in stratifying the landscape into monitoring units and selecting the units to monitor. See Table 2.1 for sources of background information (regularly check http://usda-ars.nmsu.edu for the most up-to-date list). In some instances, there is a fee for these resources, but many of them can be downloaded free from the Internet. New sources are constantly becoming available.

Aerial photographs. One of the easiest ways to organize information is on a map or recent aerial photograph of the area, or through a Geographic Information System (GIS). Ideally, use one or more aerial photographs with fences and roads marked on them.

If you want to be able to locate yourself on the aerial photo using GIS and a GPS (Global Positioning System) unit, you will need a digital image that has been modified so that the distances on the photo correspond directly to distances on the ground (orthorectified). The most widely available photographs of this type are the USGS Digitial Orthophoto Quarter Quadrangles, or DOQQs. Each of these images covers one quarter of a 7.5 minute USGS topographic map.

Satellite imagery. High resolution satellite imagery can be used for stratification. See Chapter 25 for more information on the use of remote sensing in monitoring.

Written and oral histories. Information on historic changes can help predict which parts of the landscape are most likely to change in the future. Sources of information on historic changes include old monitoring records (often stored in the local Bureau of Land Management [BLM] or United States Forest Service [USFS] offices), old aerial photographs and survey records. Interviews with current and previous land managers are among the most valuable sources of information.

Property maps. Conservation plan maps (available from NRCS offices) locating current and historic homesteads, fence lines, corrals, roads, watering holes, supplemental feeding locations, and areas seeded, herbicided or where vegetation was removed are valuable when stratifying the landscape into monitoring units. All of these have the potential to affect the way land will respond to future management.

Species lists. Lists of plant species commonly found in the area are helpful. Vegetation measurements are usually recorded to the species level. At a minimum, lists of potential invasives and exotics should be acquired for all monitoring programs.

Ecological Sites and Site Descriptions (ESDs). Each ecological site includes several similar soils. Each ESD includes partial species lists and basic soils information and state and transition models that can be used to help plan and interpret monitoring (see end of Introduction).

Soil maps. Soil maps are commonly available in the form of county soil surveys. Soil maps are often drawn on aerial photos. In addition to maps, soil surveys have a wealth of information on soil properties and the suitability of soils for different uses. GIS layers of soil surveys can be obtained for most counties from the local NRCS office.

Soil maps of pastures and rangelands rarely include map units named with a single soil series due to the complexity of most rangeland landscapes (a soil series is like a plant species). Instead, individual areas are mapped as "complexes" or "associations" of two or more soil map unit components. Soil map unit components are phases of soil series. Phases of soil series are usually identified based on features important for management, such as slope, soil surface texture, surface rockiness and salinity. A soil map unit component is like a plant subspecies. The soil survey (or a professional soil scientist) can help you decide if the components in a particular map unit are sufficiently similar to be treated uniformly for monitoring purposes.

Soil series are distinguished based on soil profile characteristics. These characteristics are usually, but not always, directly related to soil function. Soil series allow us to access reference information included in Ecological Site Descriptions and other databases.

Table 2.1. Landscape stratification resources. Internet links often change. These are valid as of September 19, 2008.

Resources	Sources
Aerial photos*	• USGS at http://edcsns17.cr.usgs.gov/EarthExplorer • Companies selling USGS photos at http://nationalmap.gov/gio/viewonline.html • http://ask.usgs.gov/sils_index.html, http://ask.usgs.gov/sources.html, or call 1-888-ASK-USGS. Images newer than 1996 can be obtained from the National Aerial Photography Program (NAPP) and National High Altitude Photography (NHAP), and are searchable on Earth Explorer at http://edcsns17.cr.usgs.gov/EarthExplorer • USDA Sales Branch, USDA FSA APFO, 2222 West 2300 South, Salt Lake City, UT, 84119-2020, or (801) 844-2900, or http:www.fsa.usda.gov/FSA/apfoapp?area=apfohome&subject=landing&topic=landing
Aerial photos: Digital Orthophoto Quarter Quadrangle (DOQQ)*	• An aerial photograph that has been digitized (scanned into a computer) and georectified, giving it all the properties of a map. DOQQs are helpful when using GIS technology to stratify landscapes. • USGS or its business partners at http://eros.usgs.gov/index.html • USDA NRCS at http://www.ncgc.nrcs.usda.gov/products/datasets/index.html
Topographic maps	• 7.5 minute USGS topographic maps http://topomaps.usgs.gov • Other topographic maps can be purchased via hard copy or CD from USGS or its business partners at http://eros.usgs.gov/index.html
Digital Raster Graphic (DRG)	• A scanned USGS topographic map that has been digitized (scanned into a computer) and georectified, ready for GIS applications. • USGS or its business partners at: http://topomaps.usgs.gov/drg
Soil surveys and maps*	• Visit the local NRCS office (look under United States Government, Department of Agriculture, USDA Natural Resources Conservation Service in the blue pages of the phone book), or check the NRCS website (http://soils.usda.gov/survey) to obtain a copy of a soil survey for the county of interest. • STATSGO (State Soil Geographic Database) map coverage (1:250,000) is available for most areas. SSURGO (1:24,000) maps are in the process of being digitized. Hard copies are available through local NRCS offices. • Visit the local USFS office to obtain a Terrestrial Ecosystem Survey for the area of interest. Some offices may have this data available in digital form.
Vegetation Inventory Data*	• BLM land: Soil Vegetation Inventory Method (SVIM) maps. These are maps of field-collected vegetation inventory data. Some offices may have this data available in GIS form. • Private land: NRCS status maps and Natural Resource Inventory data are found at: www.nrcs.usda.gov/technical/dataresources
General maps	• BLM land status maps (look under United States Government, Dept. of Interior, Bureau of Land Management in the blue pages in the phone book).
Species lists	• USFS, BLM and NRCS offices (especially old monitoring records). • NRCS lists of plants: www.nrcs.usda.gov/technical/dataresources • See Ecological Site Descriptions (NRCS) below. • Look up your local chapter of the Native Plant Society at (www.nanps.org) • PLANTS national database (http://plants.usda.gov)
Ecological (Range) Site Descriptions*	• Local NRCS office (ask for descriptions as listed in the Field Office Technical Guide, or go to http://esis.sc.egov.usda.gov) • Some revised descriptions may not yet be on the web.
Geologic Maps	• USGS Geologic Maps at http://ngmdb.usgs.gov
Invasive Species Lists	• NRCS http://plants.usda.gov/java/noxiousDriver

* Landowners can also refer to their own Conservation Plan developed through the local conservation district and NRCS.

Step 2.2. Define stratification criteria

There is virtually an infinite number of strategies for stratifying the landscape into functionally similar monitoring units. Three criteria useful for a wide variety of ecosystems are: soil-landscape, current vegetation and management.

Soil-landscape criteria include topography, landscape position and soils. These criteria determine the potential of the unit to support different plant communities. Incorporating soil-landscape criteria is a very important step, especially in areas where the same plant community currently dominates much of the land. In these areas, knowledge of the underlying soils can help identify locations where there is a high recovery potential.

In most systems, historic differences in management and disturbance have generated variability in *current vegetation* within soil-landscape units. Historic management and disturbance can be used as stratification criteria, as can current and planned future *management*.

While stratification may sound complex, in reality it is relatively simple.

Step 2.3. Complete stratification: divide the area into monitoring units

This step is often broken into separate parts, based on the number of stratification criteria. In the following example, three criteria were used. Remember that a single type of monitoring unit may include many individual units scattered across a landscape.

Step 2.3(a) Divide the area into soil-landscape units (NRCS ecological sites or functionally similar units such as the unit used in the USFS Terrestrial Ecosystem Survey). Landscape units are areas that are relatively homogeneous with respect to slope, aspect and parent material (material from which the soil was formed). As a result, they generally have similar soil series, or similar soil components. Where soil series or soil components in a landscape unit are functionally similar, they are included in the same soil-landscape unit. Functionally similar soils have relatively equivalent potentials to produce a particular type and amount of vegetation under the same climate.

Soil-landscape units generally correspond to NRCS "ecological sites" (previously referred to as "range sites"). These are also similar to the units used in the USFS Terrestrial Ecosystem Survey system and to soil-landscape-based land classification systems developed in New Zealand, Australia and other countries, although some of these systems also use current vegetation (see Step 2.3b). The grouping of functionally similar soils into ecological sites has already been completed in most areas of the United States, although the specific criteria used to create unique ecological sites varies somewhat among different states.

Soil-landscape units repeat across the landscape (Fig. 2.2). For example, multiple areas on south-facing 10-15% slopes, with 30-50 cm (12-20 in) of soil over granitic bedrock, would be classified as the same soil-landscape unit.

Step 2.3(b) Subdivide the soil-landscape units into soil-landscape-vegetation units (if necessary). Vegetation is generally correlated with landscape position and soil type, but historic differences in land use can lead to the development of different plant communities on the same soil-landscape unit (Fig. 2.3; see also Ch. 24). Vegetation subdivisions are normally based on the current dominant plant species that define the community. They can also be based on the presence of critical species, such as exotic or invasive plants, or by habitat type for a particular animal. Keep in mind that while soil-landscape units are relatively persistent and use-independent, soil-landscape-vegetation units can and do change rapidly.

Step 2.3(c) Subdivide the soil-landscape-vegetation units into monitoring units based on management (soil-landscape-vegetation-management units). A monitoring unit is the largest contiguous area with the same soil type and plant community that is expected to respond similarly to management changes. Pasture borders, distance from water, prescribed fire, woody vegetation removal and recreational use can be

used to delineate monitoring units. Similar monitoring units (same type) often repeat across the landscape (Figs. 2.1 and 2.4). Figure 2.4 shows four types of monitoring units.

Step 2.4. Record each type of monitoring unit in the Monitoring Program Design Forms I and II (Chs. 1 and 4)

Each type of monitoring unit is recorded only once, even if it repeats across the landscape. Leave extra rows on Monitoring Program Design Form II below monitoring units in which you expect to include more than one monitoring plot.

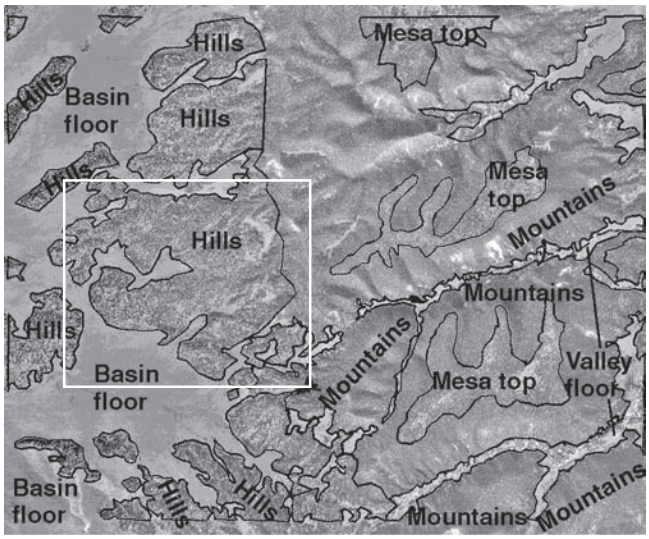


Figure 2.2. Example of landscape unit stratification. This type of stratification can only be done with aerial photos. Subdivision into soil-landscape units was not possible due to lack of soil survey information. The use of Soil Survey Maps can make this process easier and more accurate.

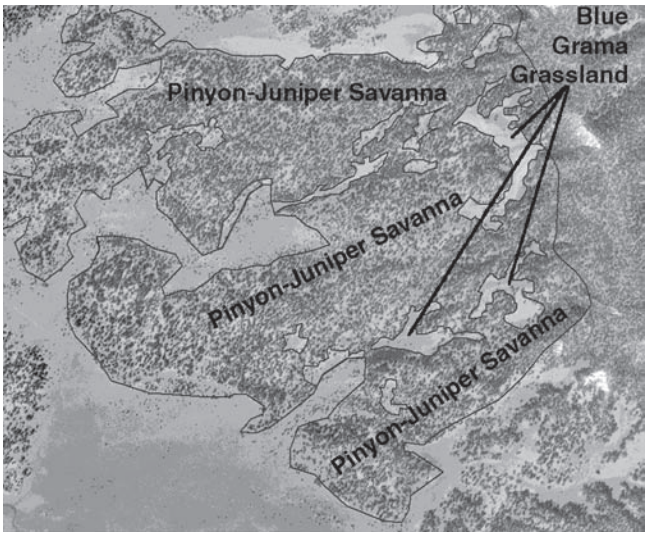


Figure 2.3. Example of the subdivision of landscape units (box in Fig. 2.2) into landscape-vegetation units. Here one of the Hills landscape units was subdivided into landscape-vegetation units.

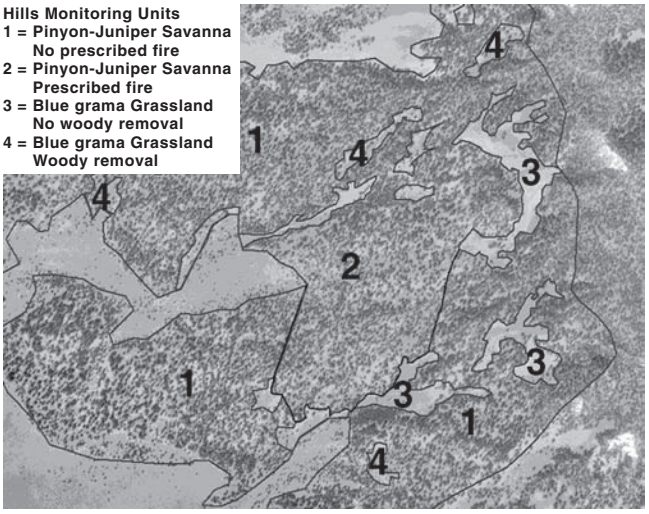


Figure 2.4. Example of the subdivision of landscape-vegetation units into different types of monitoring units (1-4) based on management. In this case, one of the Hills-Pinyon-Juniper Savanna units was subdivided based on the presence or absence of prescribed fire; and the Hills-Blue grama Grassland unit was subdivided based on whether or not woodcutting is planned.

Chapter 3

Step 3: Assess current status

Checklist

3.1. Select assessment system ..... _____
3.2. Verify that personnel have relevant qualifications ..... _____
3.3. Complete assessments ..... _____
3.4. Identify and record drivers, threats and opportunities ..... _____
3.5. Refine long-term management and monitoring objectives ..... _____
3.6. Develop/modify management strategy ..... _____

Where possible, the status of each area of each monitoring unit (or at least each type of monitoring unit) should be evaluated and recorded in the Monitoring Program Design Form I (Ch. 1). This evaluation helps determine the relative usefulness of establishing transects in each monitoring unit based on the objectives identified in Step 1.

Assessments can be qualitative or quantitative. Assessments can use current status, apparent trend, or trend based on existing monitoring data. All assessments require some kind of reference. Where trend is used, the reference is the status at some previous time. The reference for the current status is generally the site potential, which is defined based on soil and climate (e.g., in NRCS Ecological Site Descriptions as discussed in Ch. 2).

Step 3.1. Select assessment system

There are a number of protocols currently available for assessing rangelands. We have included brief descriptions of two we consider useful: *Interpreting Indicators of Rangeland Health* (IIRH) for uplands (Pellant et al. 2005; see also Pyke et al. 2002) and *Process for Assessing Proper Functioning Condition* (PFC) for riparian areas (Prichard et al. 1998a, b). These protocols were selected because they emphasize the capacity of the system to *function* relative to its potential. In other words, they reflect the current status of the same fundamental ecosystem attributes that this monitoring protocol is designed to address. They are both at present (2004) widely applied by governmental and non-governmental organizations in the United States. IIRH has been translated into Spanish and applied in Mexico.

Both of these protocols, like all qualitative systems, should be applied by a team of trained personnel with a working knowledge of the local ecosystem. Links to PDF (portable document format: documents in a format easily downloaded, viewed and printed from the World Wide Web) files of these protocols and training information are available on the Internet (http://usda-ars.nmsu.edu).

Upland areas. *Interpreting Indicators of Rangeland Health* (Pellant et al. 2005) (Fig. 3.1). This publication describes a process for using 17 qualitative indicators to generate assessments of the same three attributes addressed by this monitoring manual: soil and site stability, hydrologic function and biotic integrity. A standard or reference is established for each ecological site (type of soil-landscape unit). Reference information for each of the 17 indicators is summarized in a "Reference Sheet." Each indicator is placed into one of five categories based on its relative departure from its reference status (none to slight, slight to moderate, etc…). Specific combinations of the 17 indicators are then used to evaluate each of the three attributes.

Reference Sheets for some ecological sites have already been developed in the United States and Mexico. In the U.S., they are included in the updated NRCS Ecological Site Descriptions. Instructions for developing Reference Sheets where they do not already exist are included in the latest version of IIRH (version 4.0). This method is included *only* to assist in the identification and

selection of potential monitoring sites (Ch. 5). The indicators described should *not* be used to replace the quantitative monitoring indicators described in this manual. For additional information on how to apply this method, please refer to the IIRH publication.

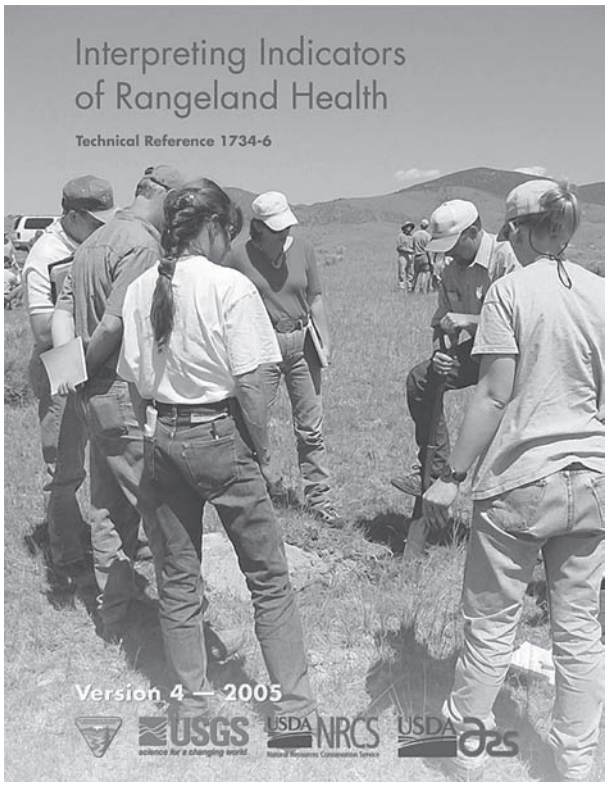


Figure 3.1. Cover of *Interpreting Indicators of Rangeland Health* (Pellant et al. 2005).

Riparian areas. *Process for Assessing Proper Functioning Condition* (Prichard et al. 1998a, b) (Fig. 3.2). This publication describes a process for developing riparian qualitative assessments. It is also based on 17 indicators. There are two primary differences, though, to the upland areas assessment protocol (IIRH). The first is that, instead of generating a "degree of departure" from that expected for the ecological site, the evaluation is designed to rate a stream reach as functional, at risk or non-functional. The second difference is that there is no standard reference. The team completing the evaluation must develop a unique standard for each area to be evaluated. For this reason it is essential that a diverse team of trained, knowledgeable and experienced individuals complete the evaluations for riparian areas.

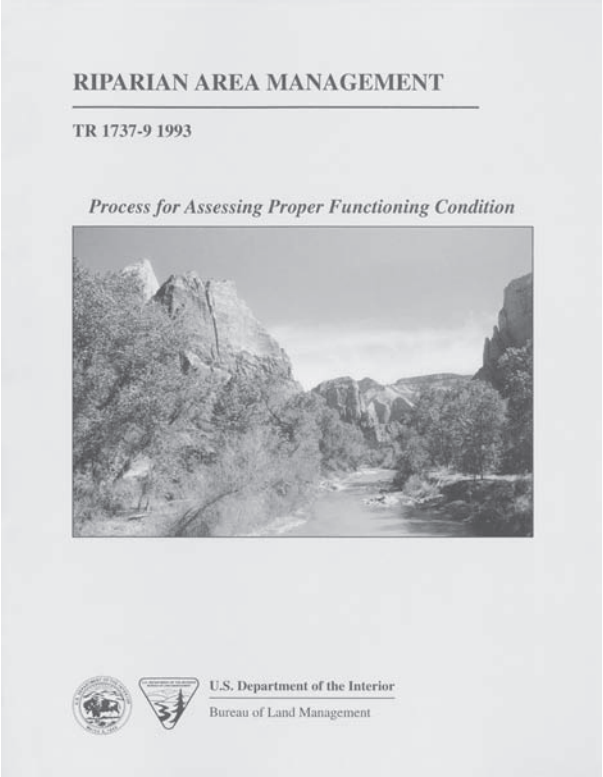


Figure 3.2. Cover of *Process for Assessing Proper Functioning Condition* (Prichard et al. 1998a, b).

Step 3.2. Verify that personnel have relevant qualifications

Relevant evaluator qualifications are listed in each document. It is important to recognize that experience and long-term knowledge of the ecosystem is often as important as academic qualifications. Academically trained individuals with little field experience will find it difficult to accurately and consistently apply assessment protocols.

Step 3.3. Complete assessments

Paper and electronic forms are available for completing the assessments.

Where? It is more important to complete assessments in areas where the value of monitoring and/or a change in management is uncertain. If you already know that an area is in a relatively stable state, it's usually not worth completing an assessment. Be sure to justify all assessments with comments and observations.

Both the upland and riparian assessment systems are designed to evaluate individual locations. Record additional notes of off-site effects and impacts to describe relationships among monitoring units. For example, excessive runoff in one monitoring unit may reflect problems in an upslope monitoring unit, or the presence of invasive species on one monitoring unit may pose a risk to adjacent monitoring units.

Step 3.4. Identify and record drivers, threats and opportunities

A critically important part of the assessment process is identifying drivers, and current and future threats and opportunities. Both of the assessment protocols are limited to current status only. Areas likely to be threatened by future activities, or where future activities present new opportunities, should be considered for monitoring because of their potential for change.

Drivers. Drivers include all factors that can contribute to changes in the properties and processes to be monitored. Typical drivers in rangeland ecosystems are listed in Figure 0.1. Drivers may or may not be threats.

Threats. Threats are drivers that might *negatively* impact the land in the future. Future threats might include increased off-road vehicle activity, invasive plants that have been identified in the area, cultivation (see Fig. 1.2), overgrazing by wildlife/livestock associated with a change in management, or drought and insect damage. The level of each threat usually varies among monitoring units. For example, off-road vehicle activity is less likely to be a threat on isolated mesas, and the threat of insect damage is frequently greater in grass-dominated ecological sites. Gully formation is more likely to occur in monitoring units located downslope of areas where an increase in runoff (e.g., associated with road construction) is anticipated.

Invasive species sometimes pose a high threat in particular soil types. Disturbance can favor the establishment of invasive species. For example, road graders can disperse African rue (*Peganum harmala*) rhizomes. Additionally, cheatgrass (*Bromus tectorum*) seeds are often dispersed by grazing animals. Thus it pays to consider all potential threats and drivers when designing a monitoring program.

Opportunities. New opportunities are often more difficult to predict than threats, but are at least as important to address in a monitoring program. Opportunities might include grants for restoration that can only be applied to particular areas (e.g., riparian). A new neighbor or the development of a grass bank in the region might bring new opportunities for cooperative livestock management. Climate change and even short-term weather patterns can be viewed as both threats and opportunities.

Identifying known or potential future opportunities for a monitoring unit may influence your decision to monitor. Knowledge of such opportunities can allow flexible management to use them. If monitoring data are collected prior to and following a management change, the effects of the new management can be quantitatively evaluated.

3.5. Refine long-term management and monitoring objectives

New information can be provided by on-site assessments and the development of a list of threats and opportunities for each monitoring unit. This information can be used to refine management and monitoring objectives. These changes should be recorded in the Monitoring Program Design Form I (Ch. 1).

3.6. Develop/modify management strategy

The management plan should be finalized (to the extent possible) before beginning site and indicator selection. At the risk of redundancy, we repeat that *in order for monitoring to be cost-effective, it must focus on those areas, properties and processes that are likely to change in response to management (including lack of active management).*

Chapter 4

Step 4: Select indicators and number of measurements

Checklist

4.1. Select monitoring indicators ..... _____
4.2. Define number of monitoring plots ..... _____
4.3. Define measurement frequency ..... _____
4.4. Estimate time requirements ..... _____

Indicator selection should be based on the objectives defined in Step 1 (see Ch. 1). It is important to think carefully about what you need to learn from your monitoring program, and how precise the data need to be.

Types of indicators

Two basic types of monitoring indicators are addressed in this manual: short-term and long-term. Some (like plant cover) can serve as short- and long-term indicators. The difference between short- and long-term indicators is discussed in Quick Start and in Step 4.1.

In addition to the short- and long-term indicators described in this manual, you may want to include indicators of potential threats and new opportunities. These are briefly described in Chapter 3. Information on threats and opportunities can be used to anticipate future changes and adapt monitoring and management accordingly.

Reducing monitoring costs

The most effective way to reduce monitoring costs is to minimize the number of measurements. Selecting measurements that generate indicators addressing multiple objectives can minimize costs. For example, the Line-point intercept method described in Quick Start can be used to generate ground cover indicators that are important (1) for erosion prediction; (2) for plant cover and species composition; and (3) as an indicator of wildlife habitat structure. Habitat structure requires the addition of height measurements to the Line-point intercept method (Ch. 15).

The measurements described in Quick Start are sufficient to generate all of the indicators required for most monitoring objectives. In many cases, indicators generated from the Quick Start measurements can substitute for the more time-consuming measurements described in the following chapters. For example, the Single-ring infiltrometer (Ch. 8) is a direct measurement of how quickly water will soak into the soil (infiltration capacity), but it is very time consuming. The Soil stability test (Quick Start) is less time consuming and, together with indicators calculated from the Line-point and Gap intercept measurements, can generate information relevant to the infiltration capacity of the soil (see Section III). Another option is to make the more time-consuming measurements (generally Level 4 in Table 4.1) at a few high-priority locations.

Monitoring Intensity (Table 4.1). Where only qualitative documentation of change is required, photographs (Level I) are often sufficient. Level II monitoring intensity (semi-quantitative) is

Note: Steps 4 and 5 (Chs. 4 and 5) are often completed simultaneously. The number of transects that can be monitored often depends on where they are and how many different types of measurements are to be made on each transect. Different types of monitoring units sometimes require different measurements. We suggest reading through Chapter 5 before actually beginning the tasks listed in Chapter 4.

Table 4.1. Levels of monitoring intensity.

Level	Objective	Measurements
I	Qualitative documentation of large changes in vegetation structure.	Photographs at standard photo points.
II	Semi-quantitative documentation of changes in vegetation composition, structure and soil stability (less repeatable than Level III).	Semi-quantitative alternatives to basic measurements (described in Quick Start).
III	Quantitative documentation of changes in vegetation composition, structure and soil stability.	One or more of four basic quantitative measurements described in Quick Start: Line-point intercept, Gap intercept, Soil stability test and Belt transect.
IV	Quantitative documentation of changes in the status of specific issues (e.g., compaction, water infiltration, vegetative production or streambank stability).	Various. See Chapters 7-15.

appropriate where only the core indicators included in Quick Start are required, and where the data will always be collected by the same person. Level III monitoring intensity is the same as Level II (i.e., Quick Start methods), except that the measurements are more precise and repeatable.

In many cases, only a subset of Level II or III measurements is necessary. For example, where the primary concern is a change in woody shrub cover, Line-point intercept (Level III) or step-point (Level II) alone is often sufficient if woody species comprise at least five percent of the foliar cover. The Belt transect (Level II or III) is appropriate where the only concern is early detection of undesirable plant establishment, or when the species/ functional group you wish to monitor is very sparse (less than five percent cover).

Level IV measurements are usually included to address specific concerns or objectives that cannot be addressed using the basic measurements.

Step 4.1. Select monitoring indicators

The monitoring indicators selected will determine which measurements are needed. Selecting measurements that generate multiple indicators, or that generate indicators that address multiple objectives, can often reduce costs.

Table 4.2 lists the measurements described in both volumes of this manual and briefly describes the relevant monitoring objectives for each. It also includes some of the indicators that can be generated from each measurement. Use Monitoring Plot Design Form II (end of Ch. 4) and Table 4.2, together with your objectives (outlined in Monitoring Program Design Form I, Ch. 1) and the results from your assessment, to select the appropriate measurements for each monitoring unit.

Short-term. Short-term indicators should reflect short-term management objectives. Most management plans require very few short-term indicators. For example, if management calls for eliminating off-road vehicle traffic from an area, the only indicator you need to monitor is vehicle tracks (modified Belt transect, Gap intercept or simply recording the number of tracks per 100 paces). For livestock grazing in arid and semi-arid ecosystems, residual ground cover (step-point transect), together with stocking rate information, is often sufficient. Typical short-term indicators are listed on the form at the end of the Quick Start volume.

Long-term. Long-term indicators should reflect long-term changes in the landscape caused by changes in management, climate and so on. Monitoring objectives (Ch. 1), together with assessment results (Ch. 3) and state and transition models (Ch. 24), can be used to help identify appropriate indicators.

Table 4.2. Overview of measurements and indicators. Appendix C includes estimated measurement requirements for the indicators listed in **bold**. See Chapter 17 or the Glossary for a definition of each indicator.

Measurement	Include...	Indicator	Attributes: Soil & Site Stability	Attributes: Hydro-logic Function	Attributes: Biotic Integrity
Line-point intercept (Quick Start and Ch. 15)	...for soil erosion risk, water infiltration, changes in species composition or cover (i.e., in nearly all monitoring programs)	**Foliar cover (%)**	X	X	X
		Basal cover (%)	X	X	X
		Bare ground (%)	X	X	X
		Ground cover (%)	X	X	
		Species richness (minimum estimate) (no.)		X	X
		Proportion of dead plant intercepts (by species)			X
		Cover by functional group, or species resistant to fire, grazing, traffic, etc. (%)			X
		Litter cover (%)		X	X
		Visual obstruction and foliage height diversity (when height measured)			X
Plant and Basal Gap intercept (Quick Start)	...for wind erosion and exotic plant invasion risk (canopy), and for soil water erosion risk and water infiltration (basal)	**Soil surface in canopy gaps > 25 cm (%)**	X	X	X
		Soil surface in canopy gaps > 50 cm (%)	X	X	X
		Soil surface in basal gaps > 50 cm (%)	X	X	X
		Soil surface in basal gaps > 100 cm (%)	X	X	X
		Soil surface in gaps > ___ cm or ___ ft	X	X	X
Soil stability test (Quick Start)	...for soil erosion risk (both), organic matter cycling (subsurface) and microbiotic crust development (surface)	**Surface stability (class)**	X	X	X
		Sub-surface stability (class)	X	X	X
		Proportion of surface values = class 6	X	X	X
Belt transect (Quick Start)	... to detect changes in species with low cover or density (e.g., early detection of invasives)	Plant density			X
		Plant density by size class			X
Compaction test – impact penetrometer (Ch. 7)	...when soil compaction is a current or potential problem	**Number of strikes per depth increment**	X	X	X
		Ratio of interspaces:under-plant canopies	X	X	X
Single-ring infiltrometer (Ch. 8)	...where infiltration is currently or potentially limited by soil structure	**Infiltration rate (mm/hr)**		X	
		Ratio of interspaces:under-plant canopies		X	
Plant production (Ch. 9)	...for herbivore carrying capacity estimates and ecosystem energy flow	Total production and production by plant species and functional groups (e.g., forage)		X	X
		Species richness (minimum estimate)		X	X
Plant species richness (Ch. 10)	...for precise estimates of species richness (see Line-point intercept and Plant production)	Species richness			X
Vegetation structure (Ch. 11)	...for standard indicator of habitat cover (see Line-point intercept)	Visual obstruction			X
		Foliage height diversity			X
Tree density (Ch. 12)	...for populations too widely dispersed for Belt transects	Plant density			X
		Plant density by size class			X
Riparian channel vegetation survey (Ch. 13)	...for documenting vegetation change along streambanks	Foliar cover (%)	X	X	X
		Cover by functional group (e.g., woody, bank-stabilizing species, etc.) (%)	X	X	X
Riparian channel and gully profile (Ch. 14)	...where channel morphology is expected to change or gullies are deepening or recovering	Width-depth ratio	X	X	
		Bank angle	X	X	

For example, many land managers in the western United States need to identify and monitor grass-dominated states that are at risk of changing to shrub-dominated states, which are associated with higher erosion rates. State and transition models define the states and transitions for the area of interest. The assessment would help identify areas potentially at risk of a change in state. The assessment, as well as the state and transition model, assist in identifying indicators associated with a state change (e.g., grass mortality, reduced infiltration and/or shrub establishment). The qualitative indicators included in the *Interpreting Indicators of Rangeland Health* protocol help focus attention on processes and the associated properties that should be monitored (Pellant et al. 2005).

Step 4.2. Define number of monitoring plots

Defining the number of monitoring plots is a balancing act between what changes need to be detected (benefits) and the resources available (costs). Use the factors listed below, along with Appendix C, to determine the number of plots needed. The number of short-term monitoring plots should be determined separately from the number of long-term monitoring plots. After determining time estimates (Step 4.4), it may be necessary to revisit this step to reduce costs.

Short-term. Use the recommendations listed for long-term measurements (below and in Appendix C) as a general guide for how many measurements you need. As with long-term measurements, monitoring more locations (plots) is generally better than increasing the number of measurements at each plot.

Long-term. The number of measurements required depends on four factors:

(1) the amount of variability within the ecological site (lower variability requires fewer measurements);
(2) the size of the change you want to detect (larger minimum changes require fewer measurements for detection);
(3) how sure you want to be that if you say a change has occurred (or has not occurred), you'll be right (statistical certainty – less certainty requires fewer measurements);
(4) whether you want to detect change at the plot scale (a plot selected to represent the soil-landscape-vegetation management unit) or at the landscape scale (ranch or watershed level). Fewer measurements are required to detect change at the plot scale than at the landscape scale. However, to detect change at the landscape scale, fewer measurements are required per plot because multiple plots are used.

Appendix C describes three options for estimating the number of vegetation transects and soil measurements you will need. It includes tables that allow you to create unique recommendations based on each of the four factors listed above. These tables are based on spreadsheets that allow even more flexibility in monitoring program design. The downloadable (http://usda-ars.nmsu.edu) spreadsheets will allow you to change transect length and number of points per transect, as well as minimum detectable change and statistical parameters.

Table 4.3 lists one set of recommendations for a semiarid grassland monitoring unit, based on Option 2 in Appendix C. Each of the long-term factors listed above affects measurement recommendations. For example, referring to the information presented in Table 4.3, if we wanted to detect a minimum change of five percent bare ground we would need four plots, while for a change of ten percent, only two plots are needed.

Step 4.3. Define measurement frequency

Measurement frequency should be matched to expected rates of change based on minimum detectable change selected in Step 4.2. If the smallest change in basal cover you can detect is five percent and it takes at least five years for this change to occur, it's a waste of time to repeat measurements more frequently.

Step 4.4. Estimate time requirements

Use Monitoring Program Design Form II to estimate total time requirements. Time requirements can vary by a factor of four or more, depending on vegetation structure, species identification requirements, weather, and observer experience and condition. Some people prefer to work by themselves, while others prefer a data recorder. Expect to double total time requirements for the first year to allow for plot establishment and characterization. Double them again if it is the first time a person has established plots and completed these measurements.

If the time requirements seem too high, don't give up! Carefully review the assumptions you have made about the indicators needed and statistical precision required. Review your objectives. Many indicators are interesting, but often just a few are essential.

Table 4.3. Number of plots required to detect change within a semi-arid grassland monitoring unit (landscape scale). These estimates were based on Tables C.15-C.17 in Appendix C (Option 2), using the median (middle estimate) for stoloniferous grassland (sandy soil), mixed rhizomatous/stoloniferous grassland and stoloniferous grassland (degraded) for three 50 m transects per plot.

Measurement (indicator)	Minimum Detectable Change*	Plots	Minimum Detectable Change*	Plots
Line-point intercept (bare ground: 50 points per transect)	5%	2,6,4 Median=4	10%	2,2,2 Median=2
Line-point intercept (foliar cover: 50 points per transect)	5%	2,7,6 Median=6	10%	2,2,2 Median=2
Canopy Gap intercept (gaps > 50 cm [~1.7 ft])	5%	8,6,11 Median=8	10%	2,2,3 Median=2
Soil stability test (surface stability: 6 measurements per plot)	1 unit	6,2,3 Median=3	2 units	2,2,2 Median=2

*p = 0.2; power = 0.8; rho = 0.5; see Appendix C for explanation.

Monitoring Program Design Form II. List of monitoring plots and number of transects planned for each plot. Use this list and the equipment list in Chapter 6 to plan time and equipment requirements. Describe site selection approach and list rejection criteria (Ch. 5) on the back of this form.

Standard transect length:____(m or ft) circle one			**Record number of transects per plot in each cell**									
Monitoring Unit Name (from Monitoring Program Design Form I)	**Plot (name or no.)**	**GPS Datum/Zone:____ UTM or Lat/Long?**	**Transect(s) compass directions (azimuths)**	**Photo Points** photos/ transect: _____	**Line-point intercept** pts/ transect: _____	**Gap intercept** min. canopy gap: _____cm or ft min. basal gap: _____cm or ft		**Soil stability** measurements/ transect: _____		**Belt transect** width: _____ (**ft** or **m**) circle one	**Other measure-ment:**	**Other measure-ment:**
		Coordinates				**Canopy**	**Basal**	**Surface**	**Sub-surface**			
Total:												
Time/measurement or transect[1]:												
Total time[2]:												

[1] Most accurate if based on time required after at least three days of experience. Most people need two to four times as much time on the first day.
[2] Multiply "Total" by "Time/measurement or transect."

Plot rejection criteria (see Ch. 5):

Chapter 5

Step 5: Select monitoring plot locations

Checklist

Step 5.1. Choose and apply site selection approach ..... _____
Step 5.2. Select "rejection criteria" and use to eliminate unsuitable locations. _____

Step 5.1. Choose and apply site selection approach

There are three approaches to selecting monitoring plot locations: (a) random, (b) stratified random and (c) subjective. Each approach has advantages and disadvantages. The one you select depends on your monitoring objectives, knowledge of the area to be monitored and the number of plots you can afford to monitor. In most cases, we recommend the stratified random approach for developing cost-effective, statistically valid monitoring programs.

Regardless of the site selection approach you choose, use Monitoring Program Design Form II (Ch. 4) to record information for each plot selected. Describe the approach used to select the transects, and any rejection criteria, on the form.

Step 5.1(a) Random Plot Selection. Plots can be randomly selected using any map or aerial photograph. Simply create a fine-scale grid and place it on top of the map or photo. This can be easily done by placing one ruler on the bottom of the map with the "0" end in the lower left corner and a second ruler perpendicular to it along the left edge, again with the "0" end in the lower left corner. Randomly select two distances on each ruler (e.g., 6.1 and 10.7 in Fig. 5.1) and find the point where the two lines intersect. Repeat until you have selected all plot locations. Make sure each plot is at least 200 m from the closest neighboring plot.

If a DOQQ or other orthorectified image is available, the same process can be applied using a grid of UTMs instead of the ruler. These coordinates can then be entered directly into a GPS unit.

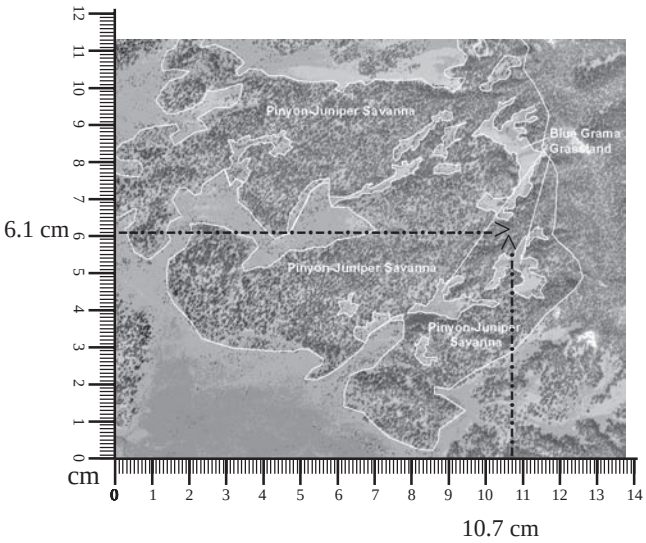


Figure 5.1. Random selection of monitoring locations using rulers and an aerial photo. The numbers 10.7 and 6.1 were randomly selected (see text).

Advantages

- Can be representative of all areas (if sufficient number of plots included).
- Easy to apply.
- Statistically valid.
- Is clearly "unbiased."

Disadvantages

- Not very cost-effective.
- Rarely includes locations in sensitive areas or areas of special concern because they usually represent a relatively small proportion of the total land area.
- Not sensitive enough to monitor degradation and recovery except where changes are occurring throughout all parts of the monitoring unit.

Step 5.1(b) Stratified Random Plot Selection. Stratified random sampling is identical to random sampling except the number of plots in each type of monitoring unit is predetermined. Plot location within each type of monitoring unit is randomly selected. This allows monitoring to focus on areas with a high degradation risk or recovery opportunity.

For example, in Figure 5.1, if the primary objective is to monitor for degradation risk and the primary degradation process is tree invasion, then a higher proportion of the plots should be located in the blue grama grassland, even though most of the monitoring unit is pinyon-juniper savanna.

Calculating indicator averages is slightly more complicated with stratified random than with random. For stratified random, calculate the average value for each type of monitoring unit. Then multiply each average value by the proportional area covered for the corresponding type of unit (e.g., 0.3 for a type of unit covering 30% of the total area monitored). The average for the total area monitored is the sum of all the products (monitoring unit x proportion of area). The example in Table 5.1 shows that it's easier than it sounds.

Table 5.1. Calculating average bare ground for a watershed with three types of monitoring units (based on stratified random plot selection approach).

Unit Type	Proportion Total Area	Average Bare Ground	Proportion x Average Bare Ground
A	0.8	20%	16%
B	0.1	50%	5%
C	0.1	40%	4%
Avg.			25%

Advantages
- Can be representative of all areas (if sufficient number of plots included, plots are located in all types of monitoring units, and the total area of each type of monitoring unit is known).
- Statistically valid.
- Cost-effective.
- More sensitive to areas with a high probability of change (degradation and/or recovery).

Disadvantages
- Requires pre-stratification (this should already be done as part of the design process. See Ch. 2).

Step 5.1(c) Subjective Plot Selection. Subjective plot selection includes all approaches in which the person designing the monitoring program decides where to locate the plots without using a grid system. This nonrandom approach has been used to select a majority of existing monitoring plots. Most historic USFS and BLM monitoring transects were selected subjectively by experienced range conservationists using the "key area" concept discussed below.

Subjective site selection can result in much more sensitive and representative monitoring programs. However, this is only possible where qualified personnel with a good understanding of local soil and vegetation patterns and processes design such monitoring programs.

Advantages
- Sensitive to local patterns and land use.
- Does not necessarily require access to maps and photographs.
- Inexpensive.

Disadvantages
- High potential for bias.
- Difficult to extrapolate.

Key areas
A key area is a tract of land that is assumed to be representative of much larger areas ***and*** is likely to reflect the effects of management changes on these larger areas. Key areas are often used in subjective plot selection.

Key areas have been used in the design of many monitoring programs throughout the world. Key areas, like any subjective approach, can be extremely effective when applied by qualified personnel.

Where used for monitoring livestock grazing effects, key areas are usually placed in an area that reflects typical livestock use. They are not located near watering points, mineral supplements, fences, trails or isolated areas of a pasture that are infrequently visited. The recommended distance from water varies with topography, vegetation and species or class of livestock.

Step 5.2. Select "rejection criteria" and use to eliminate unsuitable locations

List the rejection criteria in the space at the bottom of the Monitoring Program Design Form II (Ch. 4). Thoroughly describe the reasoning used to select these criteria. This is important because the criteria are used to help define how the monitoring data will be extrapolated and because what seems intuitive to us today may not seem intuitive to other individuals, or even to ourselves, many years later.

Rejection criteria can be based on almost anything. Many monitoring programs exclude areas that are thought to be anomalous because they receive unusually high or low levels of disturbance. Examples of rejection criteria include: (1) plots must be located a minimum of 100 yards from a road or watering point (to avoid unrepresentative high disturbance areas); (2) no plots on rock outcrops or slopes greater than 50 percent (these areas are unlikely to be disturbed).

Specific locations may also be anomalous because of landscape position. For example, areas that receive unusual amounts of runoff or have unusually dense stands of trees in a savanna may be rejected because they are not representative of larger areas.

Large areas that are not expected to change because they have crossed a threshold are also often omitted from monitoring programs. The state and transition model and indicators used to justify omission of these areas should be listed.

Rejection criteria should be carefully selected to ensure areas that should be monitored are not omitted. Also, the most unusual areas are often those that change the most quickly and may serve as early-warning indicators of degradation or recovery in other parts of the landscape. Rather than excluding these anomalous areas, we suggest that a stratified random site selection approach be used where possible. This allows apparently anomalous areas to be clearly identified as part of the monitoring program and potentially included in a future expansion of the monitoring program. Where there are areas of less interest (e.g., the post-threshold areas), monitoring may be limited to a few photo points.

It is highly recommended that a list of rejection criteria be developed prior to selecting and visiting monitoring locations. Deciding to reject areas after visiting them because they "don't look right" introduces bias. See Chapter 17 for additional guidance on the use of soil and landscape features to improve monitoring data interpretation.

Chapter 6

Step 6: Establish monitoring plots

Checklist

6.1. Establish and permanently mark plots and transects ..... _____
6.2. Describe monitoring plots and record GPS locations, including coordinate system, datum and zone ..... _____
6.3. Record long-term data ..... _____
6.4. Error check and copy the data and keep copies in different locations ..... _____

After you have gone through the previous five steps, this one should seem easy. It's important to carefully mark and describe each monitoring plot for two reasons: so you can find it again and so you can compare your data against data collected on plots with similar soils, topography and climate — all of the things that determine site potential. Use the equipment checklist for pre-field planning.

Step 6.1. Establish and permanently mark plots and transects

By now you should have already selected where the plots are to be located (Ch. 5). Be sure to verify that the site is suitable by checking it against the "rejection criteria" you list on the back of the Monitoring Program Design Form II (Ch. 4).

Step 6.1(a) Upland spoke design plots (Fig. 6.1). Place a permanent stake into the ground at the center of the monitoring plot. This stake will also serve as the photo point (Quick Start).

Using a randomly selected azimuth (compass direction: 1° to 360°), extend a tape in the azimuth direction to a distance of 5 m (15 ft) further than the length of the transect. Install a stake at the 5 m mark. This will serve as the 0 m end of your transect, because the transect begins 5 m from the center point (Fig. 6.1). Mark the far end of the transect with a stake.

Repeat transect establishment at regular intervals in a circle around the plot. The interval depends on the number of transects. For most applications, there will be three transects, with 120° between each.

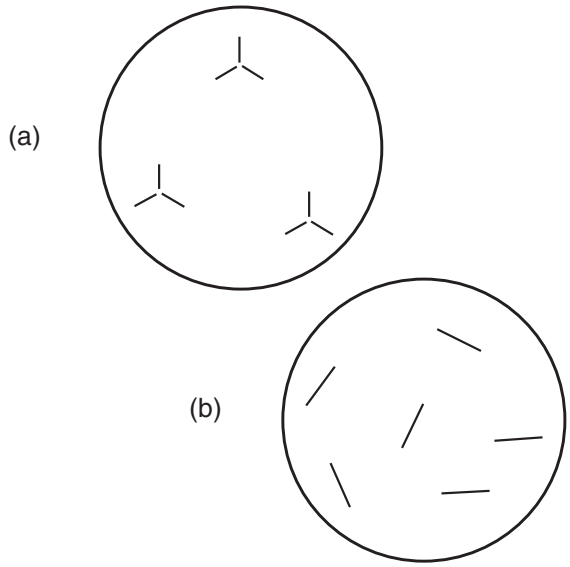


Figure 6.1. (a) Three spoke design plots located within an upland monitoring unit. The starting point of each transect is 5 m from the plot's center. (b) Single transect design maximizes spatial distribution across the landscape.

Step 6.1(b) Single transect upland plots. Anchor and mark the 0 m end of the transect. Using a randomly selected azimuth (compass direction: 1° to 360°), extend a tape in that direction the length of the transect. Mark the far end of the transect with a stake.

Step 6.1(c) Single transect riparian plots *(Fig. 6.2).* Anchor and mark the 0 m end of the transect. Ensure the 0 m end is placed such that the transect will cross the riparian channel perpendicular to the channel, and the 0 m end is 5 m beyond the riparian zone. Extend the tape perpendicular to the riparian channel. Mark the far end of the transect with a stake.

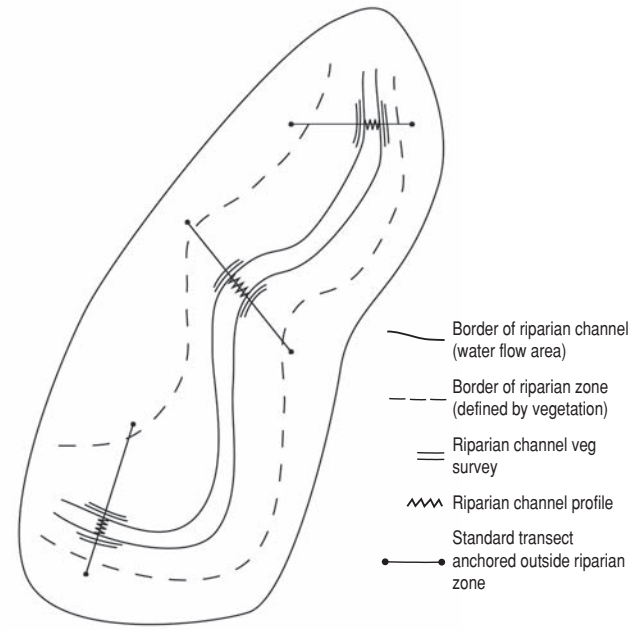


Figure 6.2. Single-transect plots crossing a stream within a riparian monitoring unit. Note that transects are anchored outside the riparian zone. See Chapters 13 and 14 for the Riparian channel vegetation survey and the Riparian channel profile measurements associated with riparian transects. Single-transect plots can be used in upland areas.

Step 6.2. Describe monitoring plots and record GPS locations, including coordinate system, datum and zone

At a minimum, fill out the Required section of the Monitoring Plot Description Form (found at the end of this chapter) when you establish each monitoring plot. This will ensure the same physical location is always monitored.

The Recommended section provides information regarding the plot's potential to support a given plant community, and enables you to verify the plot is on the mapped soil and ecological site. The data in this section allow you to determine how similar this plot is to other plots within the same ecological site. The information gathered here can help identify potential offsite influences. Data gathered in this section also assist in determining applicability of extrapolating plot data to the landscape level.

The Optional section addresses plot disturbances and management history. This information is valuable for data interpretation. It can help identify potential causes of trends and assist with important land management decisions.

The Recommended and Optional sections of the data form are important for data interpretation. It is best to fill out this information when you establish the plot, as you need to be on the plot to complete these sections. However, if you have time constraints, these sections can be completed during a second plot visit.

Required Section. Record the site, management unit and/or pasture name where the monitoring plot is located. A site, management unit or pasture is a distinct geographic unit typically with the same landowner and a relatively homogeneous management/disturbance regime. There are often multiple plots located within the same site, management unit or pasture.

Complete the remaining portions of the Required section to ensure a permanent record of plot and transect locations. Record the locations (e.g., GPS coordinates) on the Monitoring Program Design Form II and the Monitoring Plot Description Form. If you are using GPS coordinates, make sure to record the coordinate system, datum and zone, and whether the data are in English or metric units. Record geographic locations of the plot's center and the beginning and end of each transect. Document each transect's compass azimuth and record the declination used, if any.

Recommended Section. Record the average long-term precipitation under "Avg. Precip," indicating whether the units are English or metric. Determine the soil series by comparing soil observations (recorded in the table) with a soil survey. Do not rely on soil maps alone, although they can be used as guides. Soils can be extremely variable within broadly defined map units.

Dig a small pit at the plot's center and at the end of each transect. The pit should be deep enough to detect soil horizons that significantly affect plant growth. An auger or soil probe can be used instead of a pit if you are already familiar with the soils in the area. Any soil information is

helpful. Don't worry if you are not sure how to distinguish soil horizons.

If you suspect there may be more than one type of soil within your plot boundaries, be sure to locate at least one of your mini pits within each soil type. It is very important to record the soil depth. Record the depth to any horizon that is likely to restrict water movement or root growth. If no restricting horizon is encountered, record the maximum depth of the pit and write "no restricting horizon."

Record the upper and lower boundary of each major horizon under soil depth (e.g., "Btk horizon" or "horizon with clay and carbonate accumulation" from 23 to 40 cm) (refer to USDA-NRCS 1999). Record information about each horizon in a separate row on the data form. Refer to *The Field Book for Describing and Sampling Soils,* Version 2.0 (Schoeneberger et al. 2002), for additional guidance.

If available, the soil survey will also provide information on soil parent material. For areas in the United States that have been mapped by the NRCS, the ecological site can be determined by looking up the soil series online (http://esis.sc.egov.usda.gov) or by consulting the Field Office Technical Guide in your local NRCS office or NRCS website. If ecological sites have not been developed, this space can be used to record any other land classification information (e.g., USFS Terrestrial Ecosystem Unit) that may assist with data interpretation.

Record the slope using a clinometer or other instrument. Record the slope's aspect, looking downslope, in compass degrees (e.g., 108°) or cardinal direction (SE). Record the slope shape as convex (⋂), concave (⋃) or linear (straight, not curved) (Lal 2003).

Record the landscape unit on which your plot is located. If the plot is located on a hill/mountain, select the appropriate hillslope profile component (see list on data form). If the plot is located on a terrace, indicate whether it is on the riser (fairly short, steep, linear slope that forms the sideslope of the terrace) or the tread (a broad, relatively level planar portion forming the top of the terrace that can extend laterally for great distances). Refer to any of the following for assistance: *Encyclopedia of Soil Science* (Lal 2003), the *Field Book for Describing and Sampling Soils* (Schoeneberger et al. 2002), *Landforms of the Basin and Range Province* (Peterson 1981), *Geomorphology of Soil Landscapes* (Wysocki and Zanner 2003) and *National Soil Survey Handbook,* Part 629, Glossary of Landform and Geologic Terms, online at http://soils.usda.gov/technical/handbook/detailedtoc.html#629 (USDA-NRCS 2003).

Optional Section. Record recent weather patterns for the previous 12 months and the year prior. Record any disturbances and management information that might impact the plot. Describe all known or observed wildlife and livestock use, including utilization, seasonality, intensity and residual cover. Describe previous management history dating as far back as possible. Describe offsite influences, including, but not limited to (a) unusually high runoff or erosion from upslope areas, (b) management practices, (c) presence of invasives in the area, and (d) roads. Document any other pertinent information under "Other comments." Draw a depiction of the plot and record all potential drivers and other influences.

Step 6.3. Record long-term data

There are four options:

(1) Enter data onto paper data forms photocopied from each chapter.
(2) Enter data onto paper Microsoft® Excel spreadsheet forms printed from the website listed below.
(3) Enter directly onto downloaded Excel spreadsheet forms using a laptop or tablet computer.
(4) Enter directly into a database (see website for future download at http://usda-ars.nmsu.edu).

Step 6.4. Error check and copy the data and keep copies in different locations

All data should be checked for errors, using the steps below. This process can and often should take as long as data entry.

Step 1. Before leaving the plot, review all forms for completeness and legibility. If you used a digital

camera, review all of the photos to be sure that plot information is visible. If the data were entered directly into a computer, open and inspect each file and make a backup copy on a separate device.

Step 2. Immediately upon returning from the field, copy the data and store in at least two different buildings. This is especially important if you are using electronic data entry. Unless you have at least one backup copy on media that you are sure will be readable in the future (remember $5^1/_2$ in disks, punch cards and tape drives?), then we recommend printing copies of your data for archiving. Be sure that someone else knows where the extra copies are.

Step 3. Review all data for obvious errors. For example, check to see that each column on the Line-point intercept form includes only those codes assigned to that column. Gap intercepts should not overlap. Soil stability values should be between 1 and 6. See Table 6.1 for an example of a Compaction test (Ch. 7) dataset that includes potential outliers (extreme values) at positions 3 and 6 that may or may not be errors. If we know that this site had shallow soil or large rocks or near-surface bedrock, we could justify deleting the two bolded data points by assuming that the penetrometer struck a rock. We could also delete them if we were fairly certain that the data recorder had lost count. However, it is also possible that both measurements were made on a game or livestock trail. In this case, they should be retained. When in doubt, retain the data and make a note.

Step 4. If the data were originally recorded on paper forms, re-check each value after computer entry. One way to do this is for one person to read the values aloud from the data form while another checks the values in the spreadsheet or database. Your data are now ready for indicator calculation (Ch. 16 and individual methods chapters) and interpretation (Ch. 17).

Table 6.1. Example of Compaction test data with two outliers (in bold type) that may or may not be "out-and-out liars."

Pos on Line	Cumulative Strikes			
	5cm	10cm	15cm	20cm
1	5	11	18	28
2	3	9	18	30
3	4	10	20	**74**
4	4	11	22	30
5	6	11	19	27
6	5	10	24	**98**
7	4	12	22	33
8	3	9	17	26
9	4	12	19	27
10	5	13	20	29

"Outliers"

Values that are clearly outside the range of expected variation may be omitted if it is clear that these values were due to measurement or data recording errors. Extreme care should be taken to ensure that these values are in fact mistakes before omitting them.

A famous ecologist once said, "There are data that are outliers (meaning that they lie outside the normal range of variation) and then there are "*out-and-out liars.*" Be sure that you only exclude the "out-and-out liars." The other outliers may be extremely important in defining the current status of the system.

Equipment checklist. All items included in this list are required each time measurements are made, except for those items found only in the "Plot Establishment and Description Equipment" list. Add columns for supplementary methods and rows for additional equipment. See Ch. 6 for more detail on monitoring plot establishment.

Plot Establishment and Description Equipment	Have?
Clipboard, data forms, pencils OR field computer with data entry software	
Clinometer	
Compass	
GPS unit, with waypoints entered, or map of monitoring plots	
Hammer for pounding in rebar	
Keys and gate combinations	
Landowner notified (if necessary)	
Measuring tape (5 m longer than the transect length) – at least 1, ideally 3, for "spoke" layout	
Metal tape measure (for soil depth)	
Rebar (3 ft) or other stakes for marking transect ends	
Shovel	
Soil characterization tools	
Steel stakes: 2-6 (tape anchors)	
Water for moistening soil for soil texture estimates	
1 M HCl (hydrochloric acid) for effervescence (only needed where soil carbonates used for soil identification). **Caution: HCl can cause burns. If used, obtain MSDS (Materials Safety Data Sheet) and follow all safety guidelines.**	

Basic Equipment (needed for nearly all data collection)	
Compass	
GPS unit with waypoints entered, or map of monitoring plots	
Keys and gate combinations	
Landowner notified (if necessary)	
Measuring tape (transect length) - at least 1, ideally 3 for "spoke" layout	
Steel stakes: 2-6 (tape anchors)	

Additional Equipment Required for Each Measurement/Method

Equipment	Photo points	Line-point intercept	Gap intercept	Soil stability test	Belt transect	Other:	Other:	Other:
PVC pole: 1.5 m (5 ft) long	X							
Camera	X							
Whiteboard, chalkboard or Photo point ID card	X							
Thick marking pen	X							
Clipboard, data forms, pencils OR Palmtop/field computer with data entry software	X	X	X	X	X			
Pin flag or other pointer (tip <1 mm [$^1/_{25}$ in] diameter)		X						
Meter stick, pinning stake or other stiff stick or rod			X					
Soil stability kit				X				
Deionized water: 1 liter (32 oz) per test (18 samples)				X				
Stopwatch				X				
PVC pipe (at least $^1/_2$ of Belt transect width)					X			

Monitoring Plot Description Form (Page 1 of 2)

Required

Site / Management Unit / Pasture: _____ **Date:** _____ **Line Length:** _____(m or ft?)

GPS Coordinate System: _____ **Datum:** _____ **Zone:** _____ **m or ft?** _____

Plot / Line	Azimuth	Location: _____ (e.g., 0 m end)		Location: _____ (e.g., 50 m end)		Elevation m or ft?
		Northing/Latitude	Easting/Longitude	Northing/Latitude	Easting/Longitude	

Directions to plot: _____

_____

Recommended

State: ____ **County:** _____ **Avg. Precip:** _____ **Ecol. Site:** _____

Soil Series/Map Unit (verify on site): _____ **Parent Material:** _____

Vertical Slope Shape: ____ Convex ____ Concave ____ Linear

Slope: _____% **Aspect:** _____ **Horizontal Slope Shape:** ____ Convex ____ Concave ____ Linear

Mini pit location	Soil depth (cm / in)	Texture	Rock fragments (%)	Efferves-cence	Color	Structure Grade	Structure Shape	Consistence Strength (dry or moist)

Landscape Unit:

___Hills/Mountains* ___Fan Piedmont ___Floodplain/Flood basin ___Terrace** ___Flat plain

***Hillslope Component:** __Summit __Shoulder __Backslope __Footslope __Toeslope __Other: _____

****Terrace Component**: ___Riser ___Tread ___Other:_____

Disturbances and Management History

(Monitoring Plot Description Form Page 2 of 2)

Optional

Recent weather: **Past 12 months:** **Drought:** _____ **Normal:** _____ **Wet:** _____

Previous 12 months: **Drought:** _____ **Normal:** _____ **Wet:** _____

Recent Disturbances (check all that apply):

___Wildfire

___Small rodents

___Larger mammals (not rodents)

___Water

___Wind

___Soil deposition from water

___Soil deposition from wind

___Underground utilities

___Overhead transmission lines

___Other (describe):_____

Describe wildlife and livestock use:_____

_____

_____

Describe management history (i.e., grazing plan, prescribed fire, shrub control, seeding, plowing, water units):_____

_____

Describe offsite influences on this plot: _____

_____

_____

Other comments: _____

_____

_____

Draw plot and surrounding landscape. Describe all off-site and on-site drivers and other influences.

Section II: Supplementary methods

Quick Start (Vol. I) describes the four basic monitoring methods relevant to most monitoring programs. This section describes supplementary methods that address more specific objectives. They are generally used in addition to the basic measurements described in the Quick Start. This section also includes alternative Line-point intercept methods.

Supplementary Methods (in Section II)

Compaction test (Ch. 7)

Vegetation structure (Ch. 11)

Infiltration test (Ch. 8)

Tree density (Ch. 12)

Plant production (Ch. 9)

Riparian vegetation (Ch. 13)

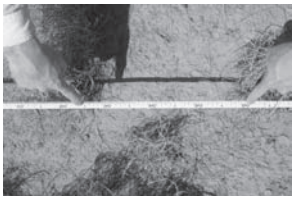
Species richness (Ch. 10)

Channel/gully profiles (Ch. 14)

Core Methods
(Quick Start)

Photo points

Line-point intercept
(also in Vol. II, Ch. 15)



Gap intercept

Soil stability test

Belt transect

Chapter 7

Compaction test

The impact penetrometer is used to monitor changes in soil compaction that can limit water infiltration, root growth and microorganism activity. Because penetrometer measurements are very sensitive to soil moisture, measurements can be compared among years only if soil moisture content is the same during each sampling period. Use Table 7.1 to decide whether or not to include this measurement.

Table 7.1. Checklist for impact penetrometer use. If all items are checked, consider including the penetrometer.

Cobbles or stones (>7.6 cm or 3 in diam.), uncommon*	_____
Compaction present, or compaction risk exists (e.g., off-road vehicle use)	_____
Compaction is affecting, or is likely to affect, water infiltration and/or plant growth	_____

* The impact penetrometer can be used in soils with a higher gravel content than a traditional strain gauge penetrometer, but should not be used in soils with large (>10 cm [4 in]) rocks near the surface.

The penetrometer can help determine whether or not a soil is currently compacted, if reference data for similar soils with the same moisture content are available. However, qualitative methods (e.g., Pellant et al. 2005) are generally more reliable for determining whether soil is compacted. For example, platy soil structure and abrupt changes in root growth patterns not related to a texture change are good indicators of compaction.

Caution!

- Never use this instrument near buried power or pipelines.
- Wearing earplugs and heavy leather gloves is highly recommended.
- Always keep hands away from the strike plate when operating the penetrometer.

Figure 7.1. Impact penetrometer with sliding hammer elevated.

Materials

- The same transect(s) used for Line-point and Gap intercept
- Impact penetrometer (see Appendix A for specifications)
- Thick leather gloves
- Clipboard, Soil Compaction - Impact Penetrometer Data Forms and pencil(s)

Standard methods (rule set)

1. Define hammer drop height and record at the top of the form.

Rules

1.1 Standard drop height is 40 cm. Drop height can be increased for compacted soils and decreased for loose (low bulk density) soils.

2. Define maximum depth.

Rules

2.1 Maximum depth should be at least 10 cm and include qualitatively identified compaction zones (e.g., lateral root growth).

3. Randomly select the sample locations you plan to measure.

Rules

3.1 Use randomly selected points along the transects used for Line-point and Gap intercept measurements.

3.2 Record sampling locations (positions) on the data form in the "Position on line" column.

3.3 Make measurements at least 1 m (3 ft) from the transect to avoid affecting vegetation measurements.

3.4 Penetrometer resistance cannot be measured on plant bases or surface rocks. If you encounter a rock or plant base, move measurement 1 m (1 yd) down the transect. The sample points have to be at least 1 m from each other.

3.5 In areas with duff or embedded litter (e.g., under coniferous trees), clearly define a standard depth to which litter will be removed, based on soil and litter characteristics (e.g., depth at which there is 80 percent mineral soil by volume), *OR* leave litter in place, *OR* exclude these areas. Exclude sample points where a stick is embedded in the soil.

3.6 Clearly record which of the three options listed in Rule 3.5 was applied.

4. Determine soil moisture.

Rules

4.1 Check at least three different locations on the plot for soil moisture by digging a small pit or using an auger and assessing soil moisture by touch.

4.2 Record soil moisture for each depth by circling the appropriate category on the Soil Compaction - Impact Penetrometer Data Form.

4.3 If possible, determine soil moisture quantitatively by measuring wet and oven-dry weights of at least three soil samples. Percent soil moisture is: wet weight minus oven-dry weight divided by oven-dry weight and multiplied by 100% or

$$\frac{\text{(wet wt)} - \text{(oven-dry wt)}}{\text{(oven-dry wt)}} \times 100\%$$

5. Record the dominant vegetation cover class in the "Veg class" column of the Soil Compaction - Impact Penetrometer Data Form.

Rules

5.1 The area to be classified is a circle with the same diameter as the top of the penetrometer cone (see Appendix A).

5.2 Use one of the following cover classes:

- **NC** = no perennial grass, shrub or tree canopy cover
- **G** = perennial grass canopy and grass/shrub canopy mixture
- **F** = perennial forb
- **Sh** = shrub canopy
- **T** = tree canopy

6. Check hammer drop height.

Rules

6.1 Measure the distance from the bottom of the hammer to the stop collar (Fig. 7.2).

6.2 Be sure that the distance is identical to the height recorded at the top of the data form.

6.3 Adjust stop collar if necessary.

6.4 There should be an average of at least three strikes per depth increment. Lower drop heights (more strikes) increase sensitivity. Higher heights increase efficiency by reducing the number of strikes per depth increment.

Figure 7.2. Hammer height is the distance from the hammer to the strike plate.

7. Determine the cumulative number of strikes required for each 5 cm (2 in) depth increment.

Rules

7.1 Wearing thick leather gloves and ear protection is highly recommended. Always keep hands away from strike plate when operating the penetrometer.

7.2 Press the cone into the soil so the top of the cone is flush with the soil surface (Fig. 7.3).

Figure 7.3. The top of the cone is flush with the soil surface.

7.3 Keep the penetrometer vertical at all times. On slopes, this means that the penetrometer will be at less than a 90° angle to the soil surface.

7.4 Raise the hammer to the stop collar and release (Fig. 7.1). Do not exert any downward pressure on the hammer while releasing it.

7.5 Repeat until the penetrometer rod is inserted 5 cm (2 in) into the soil (Fig. 7.4), the first increment.

7.6 Record the number of strikes to 5 cm on the Soil Compaction - Impact Penetrometer Data Form.

7.7 If a strike pushes past a 5 cm (2 in) mark, record it as a half strike (e.g., 9.5 strikes instead of 10).

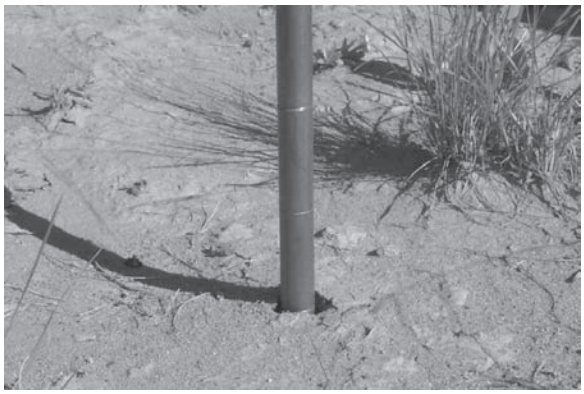


Figure 7.4. Record the number of strikes required to reach each 5 cm (2 in) increment (marked by the scribed marks on the rod).

7.8 Repeat for the next increment and record the cumulative (total) number of strikes.

7.9 A change in tone, together with sudden increased resistance in stony soils, indicates a stone or other hard object has been intercepted. Stop hammering and record "rock" for that depth on the Soil Compaction - Impact Penetrometer Data Form.

8. Remove the penetrometer.

Rules

8.1 Pull straight up on the penetrometer.

8.2 If this doesn't work, try tapping the penetrometer at the soil surface with a rubber mallet, or rotating it in an increasing radius circle (Fig. 7.5), being careful not to bend it. Then pull straight up.

8.3 At least one of the manufacturers (Synergy) will include a second sliding hammer below the strike plate to assist with removal.

9. Tighten cone if necessary.

Rules

9.1 If cone loosens from rod, apply Loctite™ or a similar material to the cone threads and tighten.

9.2 Because the cone has been hardened, it is more brittle than the rod. It can break at the threads if it becomes loose.

10. Repeat steps 2 through 9 for all sample positions.

Figure 7.5. Gently rotating or tapping the penetrometer at the soil surface can help remove it.

Compaction test indicator calculations

These instructions are used to calculate the average number of strikes, which are linearly related to resistance. For example, twice as many strikes are the same as twice the resistance. For equations to convert the number of strikes to resistance, see Herrick and Jones (2002), Minasny and McBratney (2005) and Herrick (2005). To make this conversion, you will need the drop height and the mass (weight) of the hammer.

1. **Calculate the average number of strikes for each depth (Average No. of Strikes, All).**

Rules

1.1 Add all values in each column and record the total in the "Sum no. of Strikes, All" row of the Soil Compaction - Impact Penetrometer Data Form.

1.2 Count the number of values in each column and record that number in "Measurement no., All" row.

1.3 For each column, divide "Sum no. of Strikes, All" in rule 1.1 by "Measurement No., All" in rule 1.2, and record in "Average no. of Strikes, All" row.

2. **Calculate the average number of strikes for each depth, using measurements with no vegetation cover (NC).**

Rules

2.1 Add all values with no vegetation cover in each column and record the total in the "Sum no. of Strikes, NC only" row of the Impact Penetrometer Data Form (Veg class = NC).

2.2 Count the number of values in each column and record that number in "Measurement no., NC only" row.

2.3 For each column, divide "Sum no. of Strikes, NC only" in rule 2.1 by "Measurement No., NC only" in rule 2.2, and record in "Average no. of Strikes, NC only" row.

3. **Calculate the average number of strikes for each depth, using measurements under vegetation cover (G, F, Sh, T).**

Rules

3.1 Add all values with vegetation cover in each column and record the total in the "Sum no. of Strikes, Veg only" row of the Impact Penetrometer Data Form (Veg class = G, F, Sh or T).

3.2 Count the number of values in each column and record that number in "Measurement no., Veg only" row.

3.3 For each column, divide "Sum no. of Strikes, Veg only" in rule 3.1 by "Measurement No., Veg only" in rule 3.2, and record in "Average no. of Strikes, Veg only" row.

4. **Calculate the ratio of the number of strikes in areas without and with vegetation (ratio of interspaces: under-plant canopies), and record in the last row.**

Rules

4.1 For each depth, divide the average number of strikes for samples with no cover by the average number of strikes for samples with cover.

4.2 Using data from the example data form, 5 cm depth, we divide 5.3 by 4.8 to get a Ratio of NC / Veg of 1.1.

Example

Soil Compaction - Impact Penetrometer Data Form

Monitoring plot: 5 **Date:** 4 June 2003

Observer: Jane Smith **Recorder:** Dave Miller **Hammer height:** 20 **(cm or in?)** circle one

Veg Class:

NC = No perennial canopy
G = Perennial grass or grass/shrub mix
F = Perennial forb
Sh = Shrub
T = Tree

Soil moisture (circle one for each depth):

Surface	**Dry**	**Moist**	**Wet**
0-5 cm	**Dry**	**Moist**	**Wet**
5-10 cm	**Dry**	**Moist**	**Wet**
10-15 cm	**Dry**	**Moist**	**Wet**
15-20 cm	**Dry**	**Moist**	**Wet**
_____	**Dry**	**Moist**	**Wet**

Line	Position on line	Veg class	Number (no.) of cumulative strikes (lower depths optional)								
			5cm	10cm	15cm	20cm					
1	5.5	NC	5	9.5	23	30					
1	15.5	G	4	8	Rock	Rock					
1	25.5	NC	6.5	11	26	32					
1	35.5	Sh	5	10	15.5	21					
1	45.5	G	5.5	10.5	16	Rock					
1	49.5	NC	4.5	9	22	27					
Sum no. of strikes, All			30.5	58.0	102.5	110.0					
Measurement no., All			6	6	5	4					
Avg. no. of strikes, All (Avg. All)			5.1	9.7	20.5	27.5					
Sum no. strikes, NC only			16.0	29.5	71.0	89.0					
Measurement no., NC only			3	3	3	3					
Avg. no. strikes, NC only (Avg. NC)			5.3	9.8	23.7	29.7					
Sum no. strikes, Veg only			14.5	28.5	31.5	21.0					
Measurement no., Veg only			3	3	2	1					
Avg. no. strikes, Veg only (Avg. Veg)			4.8	9.5	15.8	21.0					
Ratio of NC / Veg (= Avg. NC ÷ Avg. Veg)			5.3/4.8= 1.1	1.0	1.5	1.4					

Soil Compaction - Impact Penetrometer Data Form

Monitoring plot: _____ **Date:** _____

Observer: _____ **Recorder:** _____ **Hammer height:** _____**(cm or in?)**
circle one

Veg Class:

NC = No perennial canopy
G = Perennial grass or grass/shrub mix
F = Perennial forb
Sh = Shrub
T = Tree

Soil moisture (circle one for each depth):

Surface	**Dry**	**Moist**	**Wet**
0-5 cm	**Dry**	**Moist**	**Wet**
5-10 cm	**Dry**	**Moist**	**Wet**
10-15 cm	**Dry**	**Moist**	**Wet**
15-20 cm	**Dry**	**Moist**	**Wet**
_____	**Dry**	**Moist**	**Wet**

Line	**Position on line**	**Veg class**	**Number (no.) of cumulative strikes (lower depths optional)**								
			5cm	**10cm**	**15cm**	**20cm**					
Sum no. of strikes, All											
Measurement no., All											
Avg. no. of strikes, All (Avg. All)											
Sum no. strikes, NC only											
Measurement no., NC only											
Avg. no. strikes, NC only (Avg. NC)											
Sum no. strikes, Veg only											
Measurement no., Veg only											
Avg. no. strikes, Veg only (Avg. Veg)											
Ratio of NC / Veg (= Avg. NC ÷ Avg. Veg)											

Chapter 8

Single-ring infiltrometer (for water infiltration)

Infiltration rate is a measure of how fast water enters the soil. Water entering too slowly may lead to ponding on level areas or to erosion from surface runoff on sloped areas. A Single-ring infiltrometer provides a *relative* indication of infiltration capacity under saturated conditions.

Infiltration cannot be measured with this method on very rocky/gravelly sites, steep slopes or areas with dense root mats at the surface.

Materials

- The same transect(s) used for Line-point and Gap intercept
- Six infiltrometer rings (see Appendix A, diameter = 12.5 cm)
- Six 25 x 50 cm (10 x 20 in) terrycloth towels
- Two 370 ml (12.5 oz) cups*
- Two 30 x 30 cm (12 x 12 in) sheets of plastic (e.g., grocery bags)
- Five gallons of water
- One 15 cm (6 in) ruler
- Stopwatch
- Six infiltration bottles full of water (diameter = 8.7 cm) (see Appendix A for construction instructions)
- Clipboard, Single-ring Infiltrometer Data Forms and pencil(s)

*Based on volume required for 3 cm depth in a 12.5 cm diameter ring. For other ring diameters, volume = 9.4 x r^2, where radius equals one-half the diameter ($r = {}^1/_2\ d$).

Standard methods (rule set)

1. Determine locations for the tests.

Rules

1.1 Randomly select points along the transects used for Line-point and Gap intercept (Fig. 8.1).

1.2 Record sampling locations (positions) on the data form in the "Position on line" column.

1.3 If you are also making vegetation measurements, move the infiltration measurements at least 1 m (1 yd) from the transect, and move the infiltration measurement at least 1 m from any penetrometer measurement(s).

2. Record the vegetation class for the sample point in the "Veg class" column of the Single-ring Infiltrometer Data Form.

Rules

2.1 Lay down the infiltrometer ring on the sample point and record the dominant cover class for the sample area:

NC = no perennial grass, forb, shrub or tree canopy cover
G = perennial grass canopy and grass/shrub canopy mixture
F = perennial forb canopy
Sh = shrub canopy
T = tree canopy

2.2 If the soil surface is protected by a rock or embedded litter that prevents ring insertion, select another sample point 1 m (1 yd) down the transect and note the move.

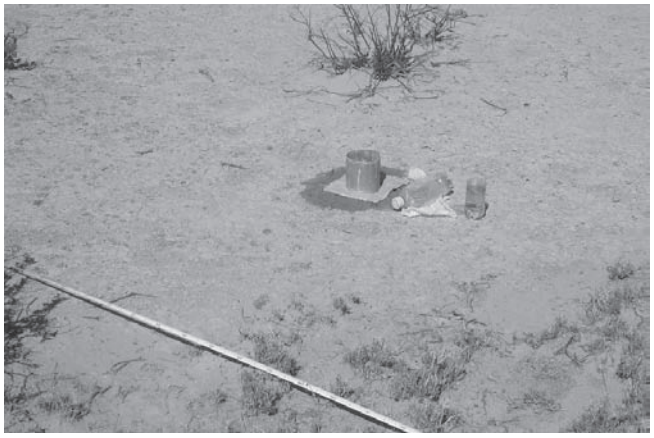


Figure 8.1. Infiltrometer supplies and sample location.

3. Remove the aboveground vegetation (Fig. 8.2).

Rules

3.1 If the sample point is located on a plant, carefully remove aboveground vegetation to within 1 cm of ground level, using a serrated knife and cutting with a sawing motion.

3.2 Do not disturb the soil crust in or around the plant.

3.3 Gently remove loose (not embedded) litter obstructing the edge of the ring.

3.4 In areas with duff (e.g., under coniferous trees), clearly define a standard depth to which litter will be removed, based on soil and litter characteristics (e.g., depth at which there is 80 percent mineral soil by volume), *OR* leave litter in place and insert ring to standard depth in the mineral soil, *OR* exclude these areas. If pieces of litter create a visible hole in the soil when the ring is inserted, select another sample point at least 1 m (1 yd) down the transect and note the move. This is necessary because the ring will not seal.

3.5 Clearly record which of the three options in rule 3.4 was applied.

Figure 8.2. Remove aboveground vegetation.

4. Pre-wet the soil to a depth of at least 4 cm (1.5 in) (Fig. 8.3).

Rules

4.1 Fold a moistened towel in half and lay over the sample area.

4.2 Using the 370 ml cup, pour water slowly on the towel in a series of applications.

4.3 Wait several minutes between applications.

4.4 Minimize water runoff from under the towel.

4.5 Continue adding water until soil is wet to 4 cm (1.5 in). The required volume varies with soil texture and structure, but should be approximately 740 ml (25 oz), or two cupfuls.

Figure 8.3. Pre-wet the soil to a 4 cm depth.

5. Insert the infiltration ring to a depth of 3 cm ($1^3/_{16}$ in) (Fig. 8.4).

Rules

5.1 Distribute pressure evenly on as much of the ring as possible. If necessary, twist the ring very slightly while pushing.

5.2 Test if the ring is set securely in the soil by gently wiggling the sides. If there is any movement, push the ring into the ground an additional 0.5 cm ($^3/_{16}$ in).

Figure 8.4. Insert infiltration ring to 3 cm.

6. Add water to the ring without disturbing the soil surface (Fig. 8.5).

Rules

6.1 Line the bottom and sides of the ring with the plastic sheet.

6.2 Pour sufficient water onto the sheet to bring the water depth to approximately 3 cm (1.25 in) and gently pull out the plastic sheet (Fig. 8.5). For a 12.5 cm ring, this is 370 ml water.

Figure 8.5. Add 370 ml water, using plastic sheet.

7. Watch for leaks (Fig. 8.6).

Rules

7.1 Observe the ring, watching for obvious leaks. Wetting at the soil surface around the ring is normal and does not constitute a leak.

7.2 Water should not pond on the soil surface or glisten around the outside edge of the ring (Fig. 8.6). If either of these occurs, the ring is leaking.

7.3 If a leak occurs, gently push the ring in 0.5 cm ($^3/_{16}$ in) more and see if the leak stops.

7.4 If the leak persists, remove the ring and relocate the sample at least 1 m (1 yd) away in the same vegetation class (up or down the transect line). Note the move.

8. Place bottle in ring (Fig. 8.7).

Rules

8.1 Push the infiltration pipette almost all the way into the bottle.

8.2 Open the cap on the bottle so that water will come out when it is upside down, but the cap will not fall off. The cap should be very loose.

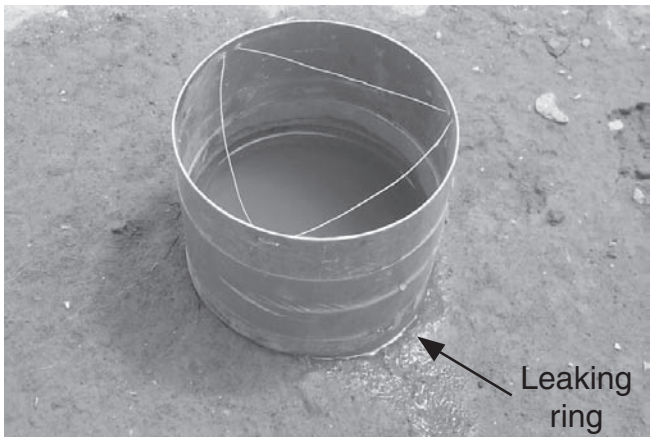


Figure 8.6. Water leaking from the ring.

Figure 8.7. Suspend bottle inside the ring.

8.3 Gently place the infiltration bottle in the ring so the silicone beads on the bottle catch on the ring suspension wires.

8.4 The bottle should be suspended in the ring with the cap end completely submerged *but not touching the soil surface*.

9. Adjust the pipette to maintain the water in the ring at 3 cm (1.25 in) depth (Fig. 8.8).

Rules

9.1 It is crucial to keep the water level inside the ring at 3 cm ($1^3/_{16}$ in) or a similar standard depth, such as 5 cm (2 in). For 3 cm, a range of 2.5 to 3.5 cm is allowed. The bottle will do this automatically after the pipette is adjusted. *To increase depth* follow rules 9.2 through 9.6. *To reduce depth* follow rules 9.7 through 9.11.

9.2 *To increase the depth*, raise the pipette. Supporting the bottle carefully with one hand, gently twist and pull the pipette upwards with the other hand until air bubbles come from the lower end of the pipette.
9.3 At this point, stop pulling up on the pipette and start pushing down a tiny distance, until the bubbles stop. This often amounts to less than 1 mm of movement.
9.4 Wait several seconds for the bubbles to start again. Bubbles should emerge at a constant rate within 10 seconds to one minute.
9.5 If no bubbles appear within one minute, slowly pull the pipette upwards and readjust its level (i.e., repeat 9.2 through 9.4).
9.6 Measure water depth. If too shallow, repeat 9.2 through 9.6. If too deep, follow 9.7 through 9.10.
9.7 *To reduce water depth*, push the pipette down. Supporting the bottle carefully with one hand, gently twist and push the pipette downwards. ***Caution: Grasp the side of the pipette only. Do not place your palm on top of the pipette.***
9.8 Wait until bubbles appear. This often takes several minutes, because water must drain from the ring into the soil.
9.9 If no bubbles appear within several minutes, measure the water depth. If the desired depth has been reached, pull the pipette upwards and follow steps 9.2 through 9.6.
9.10 When bubbles appear, measure water depth. If too shallow, repeat steps 9.2 through 9.6. If too deep, follow steps 9.7 through 9.10.

Figure 8.8. Adjust the pipette.

10. Move the rubber band to mark the water level and record the start time (Hours:Minutes:Seconds) in the "Start Time" column.

Rules

10.1 The top of the rubber band should mark the bottom of the meniscus where it intersects the vertical line of the bottle.
10.2 The "meniscus" is the bottom of the curved line formed by the surface of the water inside the bottle.
10.3 Record the start time.
10.4 Check for leaks during the run (defined in 7.2 above).
10.5 If a leak occurs, you must start over.

11. Wait for the water level in the bottle to drop at least 50 mm (2 in).

Rules

11.1 Make sure the water level inside the ring stays at a 3 cm ($1^3/_{16}$ in) depth (± 0.5 cm or $^3/_{16}$ in).
11.2 If water inside the ring drops below the allowable level, carefully pour water into the ring and adjust the pipette if necessary.

12. Record the infiltration end time and measure the distance the water level has dropped.

Rules

12.1 Simultaneously record the infiltration end time and the distance.
12.2 Record infiltration end time as Hours:Minutes:Seconds.
12.3 Record infiltration distance as the distance between the top of the rubber band and the meniscus (in mm or 16^{th}s of an inch).
12.4 Measure infiltration distance along the straight portion of the bottle only. Use the vertical line on the infiltration bottle as a guide.
12.5 You can safely make measurements as far down the bottle as you like, as long as the final measurement is greater than 50 mm (2 in) and the water level inside the bottle does not go past the curve in the bottle.

Bottleless Infiltration Method (Semi-quantitative Alternative)

Pre-wet sample point, insert ring, and pour water into the plastic bag just as with the standard Single-ring infiltration test (Steps 1-6). Carefully remove bag and record start time. Allow water to infiltrate. When 95% of the soil surface inside the ring is not shining, quickly insert the plastic bag and add another cup of water. Record the start time when the bag is removed. Record the end time when 50% of the soil surface is not shining. The difference between the start and end time is the time required for 3 cm (1.25 in) to infiltrate the soil.

Single-ring infiltrometer indicator calculations

If you use the ring and bottle sizes specified in Appendix A, your correction factor is 0.48 and you may skip to step 4. Otherwise please begin at step 1.

1. Calculate the cross-sectional area of the bottle.

Rules

1.1 The formula for area is: Area = $\pi \times r^2 \approx 3.14 \times r^2$

Area $\approx 3.14 \times (d \div 2) \times (d \div 2)$

r = radius = $^1/_2$ d

d = diameter (width)

1.2 If you don't know the bottle diameter, you can calculate if from the circumference, C.

$d \approx C \div 3.14$

1.3 Record on the Single-ring Infiltrometer Data Form.

2. Calculate the cross-sectional area of the ring (see Step 1).

Rules

2.1 The formula for ring area is: Ring area = $3.14 \times r^2$

or = $3.14 \times r \times r$

or = $3.14 \times (d \div 2) \times (d \div 2)$

2.2 Bottle area = $3.14 \times r^2$

2.3 Record on the Single-ring Infiltrometer Data Form.

3. Calculate the correction factor for the difference between the area of the bottle and the area of the ring.

Rules

3.1 Correction factor = bottle area ÷ ring area.

3.2 Record on the Single-ring Infiltrometer Data Form.

4. Calculate the infiltration time in hours.

Rules

4.1 Subtract the end time from the start time.

4.2 Record in "Total time (min)."

4.3 Convert to hours by dividing by 60.

4.4 Record in "Total time (hr)."

4.5 Example: Start time = 12:55:01, End time = 1:04:31. Time elapsed (min) = 1:04:31 – 12:55:01 = 9.5 min. Time elapsed (hr) = (9.5 min) ÷ (60 min/hr) = 0.1583 hr.

5. Calculate the bottle infiltration rate in mm/hr.

Rules

5.1 Infiltration rate = distance the water dropped (in mm) divided by the amount of time it took to drop (in hours).

5.2 Record the bottle infiltration rate in "Bottle rate" column of data form.

5.3 Example:

Distance traveled was 5.1 cm.

Convert 5.1 cm to mm:

(5.1 cm) x (10 mm/cm) = 51 mm.

Divide distance traveled by time:

51 mm ÷ 0.1583 hr = 322.17 mm/hr.

6. Calculate the soil infiltration rate (corrected for the difference in area between the ring and the bottle).

Rules

6.1 Multiply the infiltration rate (from step 5) by the correction factor (from step 3).

322 mm/hr x 0.42 = 135 mm/hr.

6.2 Record in "Infil rate (mm/hr)" column of data form.

Single-ring vs. double ring infiltrometers

While double ring infiltrometers are sometimes recommended, it has been clearly shown (both theoretically and experimentally) that they provide little advantage over single-ring infiltrometers (Bouwer 1986), and the measurements take much longer. The best way to improve the accuracy of ponded infiltration measurements is to increase ring diameter, provided that this does not increase the risk of leaks (e.g., in soils with gravel or woody litter).

Example

Infiltration Data Form

Monitoring plot: East Pasture 1

Date: 15 September 2003

Observer: Tara North

Recorder: Tim White

Veg Class:

NC = No perennial canopy
G = Perennial grass or grass/shrub mix
F = Perennial forb
Sh = Shrub
T = Tree

Soil moisture (circle one for each depth):

Surface	(Dry)	Moist	Wet
0-5 cm	(Dry)	Moist	Wet
5-10 cm	(Dry)	Moist	Wet
10-15 cm	(Dry)	Moist	Wet
15-20 cm	(Dry)	Moist	Wet
20-25 cm	Dry	(Moist)	Wet

Ring diameter: 12.5

Bottle diameter: 8.7

Correction factor (CF): 0.48
CF = Bottle area ÷ ring area

Ring area: 122.7

Bottle area: 59.4

Ring insertion depth (cm): 3

Record time to the nearest second.

Line	Position on line	Veg class	Begin time	End time	Distance (mm)	Total time (min)	Total time (hr)	Bottle rate[1]	Infil rate[2] (mm/hr)
1	2.5	G	12:55:01	13:04:31	52	9.5	0.16	328	158
1	12.5	NC	12:58:05	13:12:02	48	13.9	0.23	206	99
1	22.5	NC	13:01:29	13:16:59	55	15.5	0.26	213	102
1	32.5	G	13:04:53	13:11:33	60	6.7	0.11	540	259
1	42.5	T	13:08:24	13:19:30	58	11.1	0.19	314	150
1	49.5	NC	13:11:05	13:25:05	50	14	0.23	222	107

Average infiltration rate (sum all numbers in column ÷ number of measurements): 146

[1] Bottle rate = Distance (mm) ÷ Total time (hours)
[2] Infil rate = Bottle rate x Correction factor

Notes:

Infiltration Data Form

Monitoring plot: _____ **Date:** _____

Observer: _____ **Recorder:** _____

Veg Class:

NC = No perennial canopy
G = Perennial grass or grass/shrub mix
F = Perennial forb
Sh = Shrub
T = Tree

Soil moisture (circle one for each depth):

Surface	Dry	Moist	Wet
0-5 cm	Dry	Moist	Wet
5-10 cm	Dry	Moist	Wet
10-15 cm	Dry	Moist	Wet
15-20 cm	Dry	Moist	Wet
20-25 cm	Dry	Moist	Wet

Ring diameter: [ ] Bottle diameter: [ ] **Correction factor (CF):** [ ]
CF = Bottle area ÷ ring area

Ring area: [ ] Bottle area: [ ] Ring insertion depth (cm): [ ]

Record time to the nearest second.

Line	Position on line	Veg class	Begin time	End time	Distance (mm)	Total time (min)	Total time (hr)	Bottle rate[1]	Infil rate[2] (mm/hr)

Average infiltration rate (sum all numbers in column ÷ number of measurements): [ ]

[1] Bottle rate = Distance (mm) ÷ Total time (hours)
[2] Infil rate = Bottle rate x Correction factor

Notes:

Chapter 9

Plant production

Total annual production, which includes woody material, is an expression of all aboveground plant production during a single growing year, regardless of accessibility or palatability to grazing animals.

Total annual forage production is the amount of total annual production composed of forage species, or species likely to be used by grazing animals.

Annual production can be divided into many different classes, such as herbage production for herbaceous species (grasses, sedges, rushes and forbs) or woody plant production for woody species (trees and shrubs). For woody plant production (trees, shrubs and half-shrubs), annual growth includes only leaders, leaves and fruit, or seed production for the current growing season, not the entire plant.

Annual production is an attribute of rangeland vegetation that is very difficult to quantify, but is important for management. There can be tremendous variation in annual production within a single pasture or management unit. As plants grow at different times of the year, determining when to quantify annual production and how to adjust for material that has not yet been produced or has been removed can be very difficult. In addition, total aboveground production can vary tremendously from year to year due to climatic variations (especially seasonal differences in precipitation), irrespective of management actions. Because of these challenges, and the time involved in data collection, most monitoring programs do not include annual or forage production methods.

When estimates of annual production are needed or desired, there are three basic methods for collecting data: (1) estimating (by weight units); (2) double sampling (an approach that includes estimating and harvesting to correct estimates); and (3) harvesting, an approach that uses clipping of plots and air drying harvested material to obtain a measure of dry matter production. Double sampling is recommended because it combines the efficiency of estimation with the accuracy of harvesting. All three methods are detailed in the NRCS *National Range and Pasture Handbook*, Chapter 4, Inventory and Monitoring Grazing Land Resources, pages 4-3 through 4-13 (USDA-NRCS 1997). The double sampling method is described below.

Figure 9.1. Weighing a clipped sample.

The methods described here:

- Follow standard USDA-NRCS national protocols.
- Are based on English units, in order to maintain consistency with USDA-NRCS protocols. For metric conversions, please see Appendix B.
- Allow the inclusion of correction factors for material that has not yet been produced or has been removed.
- Generate production estimates for a single, user-determined (usually calendar) year.

Materials

- The same transect(s) used for other measurements
- 1 pair grass clippers
- 1 pair pruning shears for woody vegetation
- Quadrat frames (1.92, 4.8 or 9.6 ft^2)
- Paper bags for weighing samples
- Gram spring scales: 0-60 g; 0-100 g x 1 g, 0-300 g x 2 g; 0-600 g x 5 g
- Plant identification guides
- Ecological Site Descriptions
- Clipboard, Plant Production Data Forms and pencil(s)

Standard Methods (Rule Set)

1. Establish subplots. (For this example we chose 10 – any number is possible.)

Rules

1.1 Randomly locate 10 sample locations. These can be located on the transect(s) used for other measurements.

1.2 The number of subplots commonly recommended is 10. The formulas in Appendix C can be used to calculate the optimum number of subplots. Additional guidance will be posted on the Internet when available (http://usda-ars.nmsu.edu).

1.3 Separate sample locations by at least 10 m (33 ft).

1.4 Record the sample location for each subplot on the data form under "Subplot position."

1.5 Place subplots with the edge of the sampling frame adjacent to the transect.

1.6 Locate subplots on the side of the transect not walked along for other vegetation measurements.

1.7 Determine production of herbaceous and half shrub species using 1.9, 4.8 or 9.6 ft^2 subplots. In most arid and semi-arid areas, 9.6 ft^2 is the best size. As production and plant density increases, smaller frame sizes are appropriate. For example, the 9.6 ft^2 is more appropriate in the desert, while the 1.9 ft^2 or 4.8 ft^2 would be more appropriate in tallgrass prairie and pasture ecosystems.

1.8 Where total production and/or woody production is of interest, expand a subset of subplots to 0.01 acre to measure tree and shrub production. The 0.01 acre expanded subplot is usually a circle with an 11 ft 10 in radius (3.6 m radius). However, you can also use a 21 by 21 ft square (6.4 m sides).

1.9 Woody production is more variable than herbaceous production. Where woody production is of interest, include a minimum of two expanded plots.

2. Record all species in a subplot.

Rules

2.1 At least 50 percent of the plant base must be located within a subplot to be recorded.

2.2 Record each species within a subplot once.

2.3 Record the species in the "Species code" column of the Plant Production Data Form, using one of the following: the PLANTS database species code (http://plants.usda.gov); a four-letter code based on the first two letters each of the genus and species; or the common name.

2.4 Record the subplot size for each species (see 1.6 and 1.7 for options).

3. Determine the weight unit for each species (for the first subplot) or determine the weight unit for each species not previously recorded (for the remaining subplots).

Rules

3.1 Within a species, a weight unit can consist of a plant part, an entire plant or a group of plants.

3.2 Grams are the unit of measure for herbaceous and half shrub species.

3.3 Pounds are the unit of measure for tree species. Grams or pounds may be used for shrubs.

3.4 Determine a weight unit appropriate for each species. Select a weight unit that is easy to identify, count and remember. Be careful not to select a weight unit that is too small, nor too large.

3.5 Select the equivalent of the weight unit and harvest it.

3.6 Determine the actual weight of the weight unit.

3.7 Repeat steps 3.4 through 3.6 until the weight unit can be accurately estimated.

3.8 Record the weight unit weight in the "Wt unit wt" column of the Plant Production Data Form.

3.9 Enter the unit of measure (grams or pounds) in the "Wt unit g or lb" column.

4. Estimate the number of weight units by species.

Rules

4.1 Enter the number of weight units located in each subplot for each species in the appropriate column of the form.

4.2 If only a trace amount of a species is detected, record "T" for that subplot.

4.3 At least 50 percent of the plant base must be located within a subplot to be recorded.

5. Repeat for all subplots and expanded plots.

Rules

5.1 Repeat steps 2 through 4 for all herbaceous subplots.

5.2 Repeat steps 2 through 4 for all woody expanded plots.

6. Clip species to allow for later calculation of the double sampling correction factor.

Rules

6.1 Select at least two of the ten subplots in which to clip and weigh each species. These subplots should include all or most of the species found in all the subplots.

6.2 Circle the subplots on the data form.

6.3 Record the clipped weight for each species in the "Clip wt" column.

6.4 Record a clipped weight for any species not found in your selected subplot(s) using a sample from another subplot. Make sure to note where the sample was collected.

6.5 Enter the appropriate values under "Clipped subplots Est wt" and "Clipped subplots Clip wt."

7. Record the subplot size conversion factor.

Rules

7.1 Record subplot size conversion factor in the "Plot Size CF" column for each species.

7.2 Convert the sampled weight to pounds per acre using the appropriate conversion factor:

CF = 50 where subplot size is 1.92 ft^2 with grams as the unit of measure

CF = 20 where subplot size is 4.8 ft^2 with grams as the unit of measure

CF = 10 where subplot size is 9.6 ft^2 with grams as the unit of measure

CF = 0.22 where subplot size is 0.01 acre with grams as the unit of measure

CF = 100 where subplot size is 0.01 acre with pounds as the unit of measure.

8. Enter the air-dry weight adjustment for each species.

Rules

8.1 Enter the appropriate air-dry weight (ADW) proportion in decimal form in the "ADW adj" column.

8.2 If available, use established charts and tables that convert green weight to dry weight based on various stages of growth. If local charts or tables are not available, vegetation can be air dried.

8.3 Repeat for each species.

9. Enter the utilization adjustment for each species where livestock and/or wildlife grazing has occurred.

Rules

9.1 Enter the proportion of the plant remaining after utilization, in decimal form, in the "Util adj" column.

9.2 Utilization can vary among subplots, so make sure to use the average utilization for the entire plot.

9.3 Example: if a plant averages 40 percent utilization, then 60 percent remains and you enter 0.60 in the "Util adj" column.

10. Enter the growth adjustment for each plant species.

Rules

10.1 Enter the cumulative proportion of growth (in decimal form) that has occurred during the current year in the "Gwth adj" column.

10.2 This proportion is relative to the total production expected *for that year*, regardless of climatic variation. The growth adjustment corrects for how much the plant has grown for that year, against its potential for the year (100 percent). For example, if growth adjustment on July 1 is 60 percent during a dry year, it is also 60 percent on July 1 during a wet year, even though the total amount of growth on July 1 of a dry year may be much less than that of a wet year.

10.3 Growth curves are available for most major rangeland species in the United States. These growth curves show the typical cumulative proportion of growth by calendar date. These curves are approximate, as they do not account for annual variability in rainfall distribution. Contact your local NRCS office or Extension office for further assistance.

11. Enter the weather (climate) adjustment for each plant species.

Rules

11.1 Enter the weather (climate) adjustment in decimal form in the "Wthr adj" column.

11.2 The weather adjustment is used to describe the kind of growing conditions that have occurred or are expected. This includes precipitation amount, intensity and timing, as well as temperature, and their relationships to one another.

11.3 Enter a value between 0.1 and 2.0.

11.4 This adjustment can be different for different species, depending on the moisture and temperature requirements of the plants.

11.5 Example: An adjustment of 1.0 would indicate that the growing conditions were normal for the site that growing year. An entry of 1.2 would indicate that the growing conditions exceeded normal by an amount sufficient to increase species productions by 20 percent. An adjustment of 0.75 would indicate that the growing conditions were only sufficient to support 75 percent of normal species productions.

Plant production calculations

1. Add the total weight units for each species.

Rules

1.1 Add the weight units in each subplot by species and enter this in the "Total wt units" column.

1.2 Record weight units to the nearest decimal.

1.3 Ignore trace amounts, or "T's."

2. Calculate the double-sampling correction factor.

Rules

2.1 For the clipped subplots only, enter the total estimated weight for each species in the "Clipped subplots Est wt" column.

2.2 Total estimated weight = total weight units (Total wt units) in the clipped subplot, multiplied by the weight unit weight (Wt unit wt).

2.3 Enter total clipped weight for each plant species for the clipped subplots in the "Clipped subplots Clip wt" column.

2.4 Calculate the double sampling correction factor by dividing the "Clipped subplots Clip wt" by the "Clipped subplots Est wt."

2.5 Enter the double sampling correction factor in the "Clip/Est CF" column.

3. Calculate pounds per acre for each plant species.

Rules

3.1 Use the following equation to calculate air-dry reconstructed weight in pounds per acre, where s = the number of subplots:

$$\text{lb/ac} = \frac{(\text{Total wt units} \times \text{Wt unit wt} \times 1/s \times \text{Plot size CF} \times \text{ADW adj} \times \text{Clip/Est CF})}{(\text{Util adj} \times \text{Gwth adj} \times \text{Wthr adj})}$$

3.2 Enter this value in the "Total wt (lb/ac)" column.

Example

Plant Produc

i lo North Pasture 1 Renee Smith Ken Fields 1 1

2 9 October 2003

Spe ies code	Subplot po i ion (meter marks on tape in the approp iate column					its for each spe ie										Total wt u its	Wt u it wt	Wt u it g or lb*	Clip wt	Clip u it g or lb*	Subplot ize ft² or ac*	Plot ize CF	ADW ad	il ad			lipped su - lots		Clip/ Est CF	Total wt lb/ac*
	Transect 1					Transect 2					Transect 3																Est wt	Clip wt		
	10	20	30	40	50	5	15	25	35	45																				
PAVA2	5.5	0	0	0	0	0.1	0	0.75	0	0						6.35	34	g	138	g	9.6 ft²	10	0.6	1	1	1	212.5	138	0.65	84.12
ERAR5	8	2	1	1	2	0	0	1	0	0						15	3	g	40	g	9.6 ft²	10	0.6	1	1	1	27	40	1.48	40
CHAL7	6	0	0	0	12	0	0	10	0	0						28	1	g	15	g	9.6 ft²	10	0.7	1	1	1	16	15	0.94	18
BOAR	2	0	9	7	0	0	0	4	0	0						22	4	g	22	g	9.6 ft²	10	0.8	1	1	1	24	22	0.92	65
AMFI	1	0	0	0	0	0	0	0	0	0						1	1	g	2.5	g	9.6 ft²	10	0.7	1	1	1	1	2.5	2.50	2
HOGL2	0	0	0	0	0	0	0	3	0	0						3	1	g	5	g	9.6 ft²	10	0.6	1	1	1	3	5	1.67	3
CYDA	2	0	0	0	0	0	8	16	0	0						26	2	g	30	g	9.6 ft²	10	0.8	1	1	1	36	30	0.83	35
MACM2	0	0	0	0	0	0	0	1	0	0						1	2	g	3	g	9.6 ft²	10	0.9	1	1	1	2	3	1.50	3
OPEN3	0.5	0	0	0	0	0	0	0	0	0						0.5	0.25	lb	0.3	lb	0.01 ac	100	1	1	1	1	0.125	0.15	1.20	2
LYEX	1.2	0	1	0	0	0	0.3	0.6	0.6	0.6						4.3	0.2	lb	0.25	lb	0.01 ac	100	1	1	1	1	0.36	0.25	0.69	6
PRVE	1	0	0	0	0	1	1.5	0	1.5	0.5						5.5	0.3	lb	0.25	lb	0.01 ac	100	1	1	1	1	0.3	0.25	0.83	14
GUSA2	2	0	2	0	0	0.5	1	1	0	0						6.5	0.08	lb	0.25	lb	0.01 ac	100	1	1	1	1	0.24	0.25	1.04	5
LATR2	0	0	0	0	0	0	0	1	0	0						1	0.09	lb	0.1	lb	0.01 ac	100	1	1	1	1	0.09	0.1	1.11	1
ACCO2	1	0	0	9	2	0	1	8	0	0						21	0.1	lb	1	lb	0.01 ac	100	1	1	1	1	0.9	1	1.11	23
OPVE	2	0	0	0	0	0	0	0	0	0						2	0.15	lb	0.25	lb	0.01 ac	100	1	1	1	1	0.3	0.25	0.83	3

Icula ions to work, you must use g and ft² or lb and a .

Total produc i lb/ac : 302.62

Plant Produc

i lo _____ _____ _____ _____ _____

_____ : _____

Spe ies code	Subplot po i ion (meter marks on tape in the approp iate column										its for each spe ie					Total wt u its	Wt u it wt	Wt u it g or lb*	Clip wt	Clip u it g or lb*	Subplot ize ft² or ac*	Plot ize CF	ADW ad	il ad			lipped su - lots		Clip/ Est CF	Total wt lb/ac*
	Transect 1					Transect 2					Transect 3																Est wt	Clip wt		

Icula ions to work, you must use g and ft² <u>or</u> lb and a .

Total produc i lb/ac : _____

Chapter 10

Plant species richness (modified Whittaker approach)

"Plant species richness" is the total number of species in an area. It is one indicator of biodiversity. This Plant species richness method is based on Stohlgren et al. (1995) and Bull et al. (1998). The Plant species richness method is very time intensive. The number of measurements may be reduced, depending on information requirements and time availability. A minimum estimate of species richness can be calculated from Line-point intercept data. The Line-point intercept estimate of species richness can be supplemented by a thorough search for exotics and other species of interest throughout the plot area.
Note: precise unit conversions are used in this chapter to facilitate calculations.

Materials

- The same transect(s) used for Line-point and Gap intercept
- 100 m (328 ft) tape
- Metal stakes and hammer for marking plot corners
- At least 120 m (400 ft) of twine to mark plot borders
- Clipboard, Plant Species Richness Data Forms, pencil(s)

Standard methods (rule set)

1. Set up plots.

Rules

1.1 Lay out the 10 by 30 m plot.

1.2 Anchor 100 m (328 ft) tape at point "a" on the plot, 5 m (15 ft 5 in) and 90° away from the "0" end of the transect (Fig 10.1).

1.3 Pull the tape out, crossing the "0" end of the transect, to 10 m (32 ft 10 in) (point "b") and wrap it around another stake (Fig. 10.2).

1.4 Continue pulling the tape out, parallel to the transect. At 30 m (98 ft 5 in), insert another stake (point "c"). The tape will read 40 m (131 ft 3 in) at this stake. Continue to point "d."

1.5 Finish by pulling the tape back to point "a."

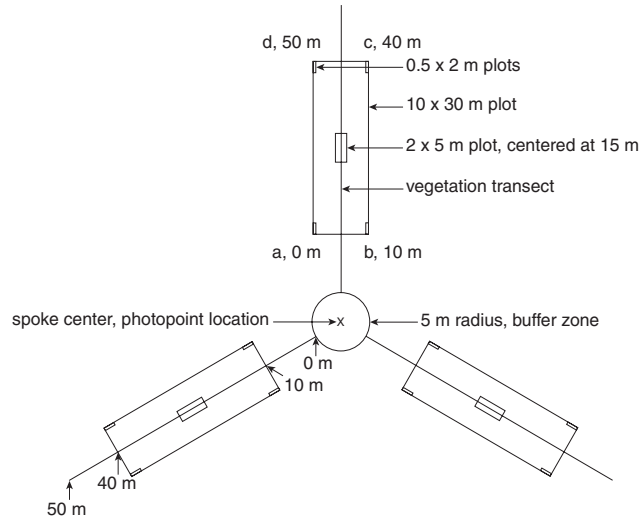


Figure 10.1. Species richness plots and their layout with respect to a monitoring plot. Drawn to scale.

Figure 10.2. Pulling out tape to set up the species richness plot.

1.6 The tape should read 80 m (262 ft 6 in) once you are done.

1.7 Pull in the tape, but leave all the stakes in place.

1.8 Anchor twine at one of the stakes and string it out where the tape was.

1.9 Continue laying out the smaller plots, using twine, as in Figure 10.1.

1.10 Center the 2 x 5 m (6 ft 7 in x 16 ft 5 in) plot at the 15 m (49 ft 3 in) position on the vegetation transect.
1.11 Place four 0.5 x 2 m (1 ft 7 in x 6 ft 7 in) plots in the corners of the large (10 x 30 m or 32 ft 10 in x 98 ft 5 in) plot.
1.12 Repeat steps 1.1 through 1.11 for the two remaining vegetation transects, if desired. Due to the high sampling costs, it is generally more cost-effective to sample fewer transects (one can be sufficient) at more locations.

2. Record number of species in each plot.
Rules
2.1 Make all observations on all species richness plots on one transect at a time. Complete observations on all transects within a plot. Then move to the next transect.
2.2 Use one data form for each transect.
2.3 Start with the smallest (0.5 x 2 m or 1 ft 7 in x 6 ft 7 in) plots.
2.4 Record all species that occur in a small plot under the appropriate column on the data form (Fig. 10.3).
2.5 At least half of a plant base must be inside the plot boundary to be recorded. Plants with less than half their bases in the plot are not recorded.
2.6 Record the species in the "Species code" column of the Plant Species Richness Data Form, using one of the following: the PLANTS database species code (http://plants.usda.gov); a four-letter code based on the first two letters each of the genus and species; or the common name.

Figure 10.3. Record each plant species within each of the four small (0.5 x 2.0 m or 1 ft 7 in x 6 ft 7 in) plots.

(Relatively) rapid alternatives

The simplest alternative is to use the minimum estimate provided by the Line-point intercept. However, this will miss most species. Another alternative is to search the 10 x 30 m plot without subplots. This is appropriate if the species-area curve is not required.

2.7 Move to the next small plot and record all species in that plot in the next column.
2.8 Repeat 2.1 through 2.7 until all four small plots are sampled.
2.9 Search the 2 x 5 m (6 ft 7 in x 16 ft 5 in) plot and record all species detected.
2.10 Search the 10 x 30 m (32 ft 10 in x 98 ft 5 in) plot and record all species detected.
2.11 Make sure to include all species already found in the smaller plots in the list for the 10 x 30 m (32 ft 10 in x 98 ft 5 in) plot.

Plant species richness calculations

1. Measure species richness.
Rules
1.1 Count all species encountered in all the plots.
1.2 Each species is counted only once, no matter how many plots it occurs in.

2. Estimate species richness (not included on data form).
Rules
2.1 This should only be calculated by someone with an understanding of linear regression. It is based on the assumption that there is a linear relationship between the number of species and the log of the area for uniform areas.
2.2 Graph the number of species found in each plot against the log of the area of each plot (0, 1 and 2.5 for the 1, 10 and 300 m^2 plots).
2.3 The equation below can be used to predict species richness in a larger area *provided that the area is relatively uniform and that the plot is representative of the area.*

Species richness = intercept + (constant) x (log [area])

2.4 For monitoring, it is strongly recommended that only measured species richness be used.

Example

Plant Species Richness Data Form

Page 1 of 1

Shaded cells for calculations

Monitoring Plot: 8 Line: 2

Observer: James Smith Recorder: Nancy Brown Date: 29 September 2002

First 0.5 x 2 m plot	Second 0.5 x 2 m plot	Third 0.5 x 2 m plot	Fourth 0.5 x 2 m plot	2 x 5 m plot		10 x 30 m plot		
PHHE	POPR	KOMA	PFO4	BOHI2	SCSC	AMCA6	ANHA	SCSC
CAEL2	ERSP		LYJU	ANHA	CALO	ROAR3	SCSC	CALO
AMPS	PAVI2		SPCR	SCSC		PHHE	PASM	
BOGR2				PASM		CAEL2	PGO1	
DIOLS				PGO1		AMPS	SOMI2	
CALO				SOMI2		BOGR2	HEPAP2	
				HEPAP2		DIOLS	OPFR	
				OPFR		CALO	PASE5	
				PASE5		POPR	PFO2	
				PFO2		ERSP	LIPU	
				LIPU		PAVI2	OPPO	
				OPPO		KOMA	HECOC8	
				HECOC8		PFO4	ASER3	
				ASER3		LYJU	PSTE5	
				PSTE5		SPCR	ANNE	
				ANNE		BOHI2		
Total:	Total:	Total:	Total:	Total:		Total:		
6	3	1	3	18		33		

Total number of plant species encountered in all plots: 33

Plant Species Richness Data Form

Page_____ of _____

Shaded cells for calculations

Monitoring Plot: _____ Line: _____

Observer: _____ Recorder: _____ Date: _____

First 0.5 x 2 m plot	Second 0.5 x 2 m plot	Third 0.5 x 2 m plot	Fourth 0.5 x 2 m plot	2 x 5 m plot		10 x 30 m plot		
Total:	Total:	Total:	Total:	Total:		Total:		

Total number of plant species encountered in all plots:

Chapter 11

Vegetation structure

The Vegetation structure method provides information on visual obstruction and habitat structure (and thus suitability) for various wildlife species. Visual obstruction methods have also been used to estimate plant biomass. A large amount of literature exists related to various uses of this method and associated indicators (e.g., Flather et al. 1992, Interagency Technical Reference 1996, MacArthur and MacArthur 1961, Robel et al. 1970, Nudds 1977).

There are many ways to measure vegetation structure based on visual obstruction. There is no standard method, nor is there a standard set of indicators. The Vegetation structure method described here is similar to methods that have been used historically for research and monitoring, such as a Robel pole, cover board, vegetation profile board or density board.

The dimensions of the cover pole can be easily modified to address different objectives.

Materials

- The same transect(s) used for Line-point and Gap intercept
- Cover pole (see Appendix A for construction)
- 1 m (3 ft) PVC sighting pole
- Clipboard, Vegetation Structure Data Forms, pencil(s)

Standard methods (rule set)

Before beginning the measurements, record the length of each segment on your cover pole at the top of the data form. The four segments are numbered from the top to the bottom of the pole. Each segment is subdivided into five equal bands. A typical segment length is 0.5 m (1 ft 8 in) on a 2 m (6 ft 8 in) pole. Each band is then 10 cm (4 in).

1. Randomly select five positions along each transect.

Rules

1.1 Record the transect or line number under "Line" on the data form.

1.2 Record each position under "Position" on the data form.

Figure 11.1. Observer stands 5 m (15 ft) from the cover pole, along the transect.

1.3 Positions must be at least 7 m (22 ft) apart.

2. Place the cover pole at the first position.

Rules

2.1 The recorder places the cover pole at the sample position.

3. Collect Vegetation structure data.

Rules

3.1 The observer stands 5 m (15 ft) from the cover pole, along the transect.

3.2 Using the "sighting pole" to maintain a constant observation height, the observer records whether or not each band is covered by vegetation.

3.3 A band is considered covered by vegetation if at least 25 percent of the band is visually obstructed by vegetation.

3.4 Record "1" on the data form if the band is visually obstructed. Record "0" if the band is not obstructed.

3.5 The observer repeats steps 3.1 through 3.4, standing 5 m (15 ft) from the cover pole in the opposite direction, along the transect.

4. Repeat steps 1 through 3 for all sample positions along a transect and for all transects.

Vegetation structure indicator calculations

1. Calculate the average percent of visual obstruction.

Rules

1.1 Add the number of bands within each segment obstructed by vegetation.

1.2 Percent visual obstruction = 100% x (number of bands obstructed ÷ total number of bands)

1.3 Calculate the plot average for each segment. Add up all percent visual obstructions (Vis. obst.). Then divide this total by the number of Vis. obst.

2. OPTIONAL. Calculate the foliage height diversity (FHD, the vertical structural diversity). ***Note: This indicator requires a calculator or computer, so it is not included on the field data form.***

Rules

2.1 The formula for foliage height diversity is:
$FHD = -\Sigma p_i \ln p_i$

2.2 For each segment at each observation, add the number of bands obstructed by vegetation.

2.3 Sum the number of bands in each segment for the entire plot.

2.4 Calculate the proportion of total hits found in each segment:
p_i = proportion of hits in the ith segment, where i = 1 to 5.

2.5 Multiply the proportion of hits in each segment (from rule 2.4) by its natural log
$p_i * \ln p_i$

2.6 Add up all $p_i * \ln p_i$.

2.7 Multiply the sum obtained in Rule 2.6 by -1.

Figure 11.2. Example of a cover pole with some visual obstruction.

Example

Vegetation Structure Data Form

Monitoring plot: 12 **Date:** 12 September 2003 **Observer:** Michelle Evans **Recorder:** Jennifer Clark

Segment 1: 0 -0.5 m or ft? **Segment 3:** 1.0-1.5 m or ft? **Obs A = 5 m or 15 ft before Position, along the transect**

Segment 2: 0.5-1.0 m or ft? **Segment 4:** 1.5-2.0 m or ft? **Obs B = 5 m or 15 ft after Position, along the transect**

Record a "1" if >25% of the band is covered/obstructed by vegetation. Record a "0" if <25% of the band is covered/obstructed.

Line: 1		Position: 5		Position: 15		Position: 25		Position: 35		Position: 45				
Segment	**Band**	**Obs A**	**Obs B**	**Obs A**	**Obs B**	**Obs A**	**Obs B**	**Obs A**	**Obs B**	**Obs A**	**Obs B**			
1	1	1	0	1	1	0	0	1	1	0	1			
1	2	0	0	0	1	0	0	1	0	0	0			
1	3	1	1	0	1	0	0	1	0	0	1			
1	4	0	0	0	0	0	0	0	0	1	1	**Segment total**	**No. of observations**	**Vis. obst.**
1	5	0	0	0	0	0	0	0	0	1	1			
Total no. of bands		2	1	1	3	0	0	3	1	2	4	17	50	34%
2	6	0	0	1	1	0	1	1	1	1	0			
2	7	0	0	1	0	0	0	0	1	0	0			
2	8	0	0	1	0	0	1	0	0	1	0			
2	9	0	0	1	0	0	1	0	0	0	0	**Segment total**	**No. of observations**	**Vis. obst.**
2	10	0	0	0	0	1	1	0	0	0	0			
Total no. of bands		0	0	4	1	1	4	1	2	2	0	15	50	30%
3	11	0	1	1	0	1	1	0	0	0	1			
3	12	0	0	0	0	0	1	0	0	0	0			
3	13	0	1	1	1	0	0	0	0	1	0			
3	14	1	0	0	0	0	0	0	0	1	0	**Segment total**	**No. of observations**	**Vis. obst.**
3	15	1	1	0	0	0	0	0	0	0	0			
Total no. of bands		2	3	2	1	1	2	0	0	2	1	14	50	28%
4	16	1	1	0	1	1	1	1	0	0	0			
4	17	0	1	0	0	1	0	0	0	0	0			
4	18	0	1	0	1	1	1	1	1	0	0			
4	19	0	0	1	1	1	1	0	0	0	0	**Segment total**	**No. of observations**	**Vis. obst.**
4	20	0	0	1	1	0	1	0	0	0	0			
Total no. of bands		1	3	2	4	4	4	2	1	0	0	21	50	42%

$$\text{Visual obstruction} = 100\% \times \frac{\text{Segment total}}{\text{No. of obs.}}$$

Notes:

Average visual obstruction: 34%

Vegetation Structure Data Form

Monitoring plot: _____ **Date:** _____ **Observer:** _____ **Recorder:** _____

Segment 1: _____m or ft? **Segment 3:** _____m or ft? **Obs A = 5 m or 15 ft before Position, along the transect**

Segment 2: _____m or ft? **Segment 4:** _____m or ft? **Obs B = 5 m or 15 ft after Position, along the transect**

Record a "1" if >25% of the band is covered/obstructed by vegetation. Record a "0" if <25% of the band is covered/obstructed.

Line:_____		Position: _____		Position: _____		Position: _____		Position: _____		Position: _____	
Segment	**Band**	**Obs A**	**Obs B**	**Obs A**	**Obs B**	**Obs A**	**Obs B**	**Obs A**	**Obs B**	**Obs A**	**Obs B**
1											
1											
1											
1											
1											
Total no. of bands											
2											
2											
2											
2											
2											
Total no. of bands											
3											
3											
3											
3											
3											
Total no. of bands											
4											
4											
4											
4											
4											
Total no. of bands											

$$\text{Visual obstruction} = 100\% \times \frac{\text{Segment total}}{\text{No. of obs.}}$$

Segment total	No. of observations	Vis. obst.

Notes:

Average visual obstruction: [ ]

Chapter 12

Tree density

It is important to quantify the density and size of trees in savannas and grazed woodlands in order to understand the structural diversity of the plant community. Structural diversity at a site can provide protection from elements and cover for wildlife. Increased density of trees in savannas and grazed woodlands could indicate a trend toward an important community change.

The method described here is extracted from the *USFS Forest Inventory and Analysis (FIA) National Core Field Guide Volume I: Field Data Collection Procedure for Phase 2 Plots,* Version 1.7 (USDA Forest Service 2003). The FIA protocol includes a large number of additional requirements (e.g., assigning a unique record number to each tree) and indicators not needed for our monitoring objectives. For more information on the FIA protocol, please see http://www.srs.fs.usda.gov/fia/data_acquisition/field_guide/p2manual.htm.

Materials

- The same transect(s) used for Line-point and Gap intercept
- Extending range pole
- Steel pins for anchoring tape
- Additional tape (for defining subplots)
- Diameter or DBH tape
- Clipboard, Tree Density and Size Data Forms and pencil(s)

Standard methods (rule set)

1. Define measurement area for trees and saplings (>2.5 cm [1 in] in DBH [Diameter at Breast Height] or DRC [Diameter at Root Collar]).

Rules

1.1 Establish four subplots, one with its center located at the center of the spoke and the remaining three located at 36.6 m (120 ft) on each of the three transects (Fig. 12.1).

1.2 Subplots should have a 7.3 m (24 ft) radius (see subplots in Fig 12.1).

1.3 Other subplot sizes may also be used. If using a different subplot size be sure to record the size and adjust indicator calculations accordingly.

2. Determine for which species DRC will be used instead of DBH.

Rules

2.1 DRC is normally used on multi-stemmed species.

2.2 A list of species that the USFS classifies as multi-stemmed can be found in Appendix 4 of the FIA protocol (USDA Forest Service 2003).

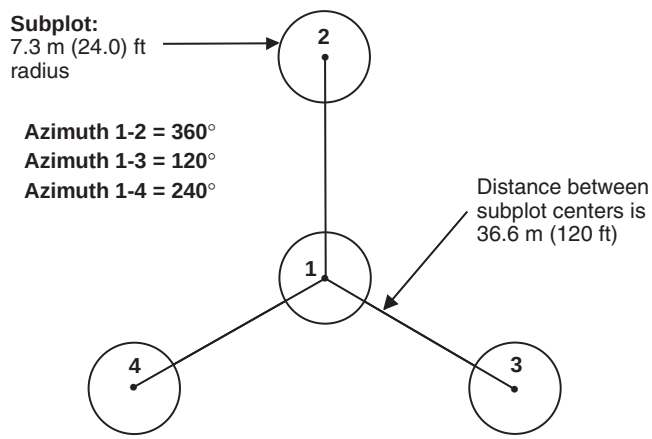


Figure 12.1. USFS Forest Inventory and Analysis plot diagram (modified from USDA Forest Service 2003).

3. Record the species or common name for each tree that falls within each subplot.

Rules

3.1 Include only those individuals with at least 50 percent of the plant base inside the plot.

3.2 Use the same codes or names used for the Line-point intercept method.

3.3 Record the species code in the "Species" column of the Tree Density and Size Data Form.

Figure 12.2. Savanna/woodland ecosystem showing relatively low tree density.

4. Record the DBH or DRC in the appropriate column.

Rules

4.1 Measure DBH at 1.4 m (4.5 ft) using a diameter tape (Fig. 12.3).

4.2 If a diameter tape is not available, measure with a standard tape measure and convert to diameter with the following formula ($\pi \approx 3.14$):

diameter = circumference $\div \pi$

4.3 Measure DRC as illustrated in Fig. 12.4. For multi-stemmed individuals,

DRC for the tree = SQRT (SUM [DRC^2]).

Figure 12.3. Measuring DBH.

5. Record each tree's height.

Rules

5.1 Measure the maximum height of the tree as the distance from the bottom of the trunk to the highest point of the canopy.

5.2 If the tree is too tall to measure with a meter/yard stick, use an extendable range pole (Fig. 12.5), visually estimate the height, or use a clinometer and trigonometry.

5.3. Record tree height in the "Height" column on the data form.

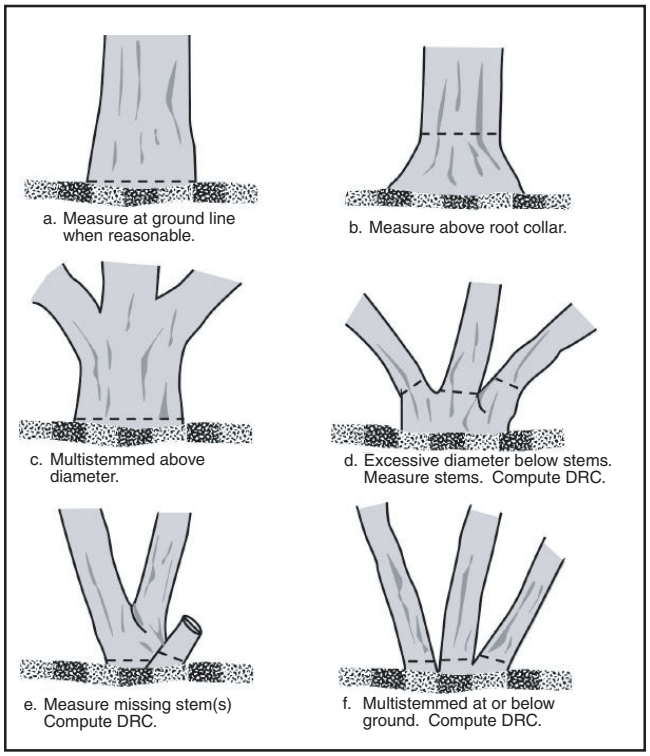


Figure 12.4. How to measure DRC (modified from USDA Forest Service 2003).

Figure 12.5. Measuring tree height with an extendable range pole.

Tree density calculations

1. Calculate the plot area in acres.

Rules

1.1 Plot area = (4 x π x plot radius x plot radius) ÷ conversion factor (π ≈3.14).

1.2 The metric conversion factor is 10,000 (converts square meters to hectares).

1.3 The English conversion factor is 107,639 (converts square feet to hectares).

2. Sum the number of trees and saplings.

Rules

2.1 Count all trees detected on all four subplots (trees have a DBH or DRC ⩾12.7 cm or 5 in).

2.2 Count all saplings detected on all four subplots (saplings have a DBH or DRC ⩾2.5 cm or 1 in and ⩽12.7 cm or 5 in).

3. Calculate densities.

Rules

3.1 Tree density = (total no. of trees) ÷ (plot area).

3.2 Sapling density = (total no. of saplings) ÷ (plot area).

Example

Tree Density and Size Data Form

Monitoring plot: 3 **Date:** 22 July 2003 **Line length:** 36.6 **(m or ft?)** circle one

Observer: Mark Second **Recorder:** Tara Third

Subplot radius 7.3 **(m or ft?)** circle one **Diameter units: (cm or in?)** circle one **Height units: (m or ft?)** circle one

Subplot 1 (plot center)				Subplot 2 (Line 1)				Subplot 3 (Line 2)				Subplot 4 (Line 3)			
Species	DBH	DRC	Ht.	Species	DBH	DRC	Ht.	Species	DBH	DRC	Ht.	Species	DBH	DRC	Ht.
POFR	40		6.5					POFR	52		11.5	POFR	4		3
												FRVE	35		10

Total plot area (all subplots) = (4 x 3.14 x 7.3 m x 7.3 m) ÷ 10,000 = 0.07 hectares
(plot radius; plot radius)

Total plot area (all subplots) = (4 x 3.14 x ____ ft x ____ ft) ÷ 107,639 = ____ hectares
(plot radius; plot radius)

3 = Total number of TREES (DBH ≥ 12.7 cm [5 in])

1 = Total number of SAPLINGS (2.5 cm [1 in] < DBH < 12.7 cm [5 in])

$$\text{Tree density} = \frac{\text{No. of trees}}{\text{Plot area}} = \frac{3}{0.07} = 42.9$$

$$\text{Sapling density} = \frac{\text{No. of saplings}}{\text{Plot area}} = \frac{1}{0.07} = 14.3$$

Tree Density and Size Data Form

Monitoring plot: _____ **Date:** _____ **Line length:** _____ **(m or ft?)** circle one

Observer: _____ **Recorder:** _____

Subplot radius _____ **(m or ft?)** circle one **Diameter units: (cm or in?)** circle one **Height units: (m or ft?)** circle one

Subplot 1 (plot center)				Subplot 2 (Line 1)				Subplot 3 (Line 2)				Subplot 4 (Line 3)			
Species	DBH	DRC	Ht.	Species	DBH	DRC	Ht.	Species	DBH	DRC	Ht.	Species	DBH	DRC	Ht.

Total plot area (all subplots) = (4 x 3.14 x [ ] m x [ ] m) ÷ 10,000 = [ ] hectares
plot radius plot radius

Total plot area (all subplots) = (4 x 3.14 x [ ] ft x [ ] ft) ÷ 107,639 = [ ] hectares
plot radius plot radius

[ ] = Total number of TREES (DBH ≥ 12.7 cm [5 in])

[ ] = Total number of SAPLINGS (2.5 cm [1 in] < DBH < 12.7 cm [5 in])

$$\text{Tree density} = \frac{\text{No. of trees}}{\text{Plot area}} = \frac{[\ ]}{[\ ]} = [\ ]$$

$$\text{Sapling density} = \frac{\text{No. of saplings}}{\text{Plot area}} = \frac{[\ ]}{[\ ]} = [\ ]$$

Chapter 13

Riparian channel vegetation survey

The Riparian channel vegetation survey provides a general assessment of plant cover and composition along both sides of the channel. It is appropriate for systems and reaches with the potential to support a continuous band of riparian vegetation on the banks.

This approach is based on the "greenline" method developed by Alma Winward (2000), except that Winward's greenline method is based on identifying the plant community at each point along the channel. Winward's method is superior to the method presented here and is recommended if the expertise is available to identify plant communities.

Winward's definition of the greenline is critical: "the first line of perennial vegetation that forms a lineal grouping of community types on or near the water's edge." Winward adds, "Most often the greenline is located at or near the bank-full stage (Fig. 13.1). Or, as flows recede and the vegetation continues to develop summer growth, it may be located part way out on a gravel or sandbar (Fig. 13.2). At times when banks are freshly eroding or when a stream has become entrenched, the greenline may be located several feet above bank-full stage (Fig. 13.3). In these situations, the vegetation is seldom represented by hydrophilic species and, in fact, may be composed of non-riparian species…" (Winward 2000).

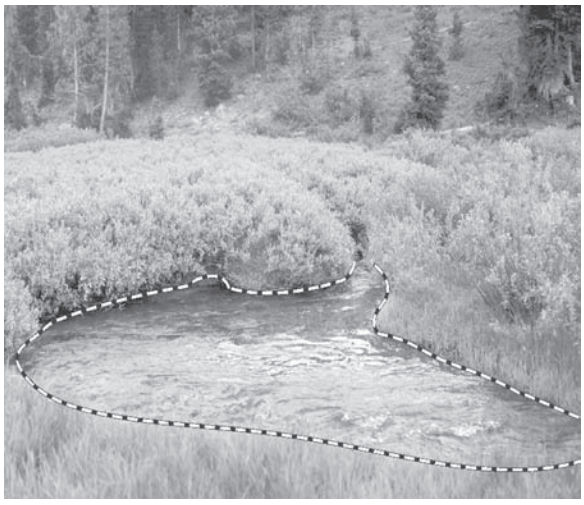


Figure 13.1. Location of the greenline at or near bank-full stage (Winward 2000).

Figure 13.2. Location of the greenline (Winward 2000).

Figure 13.3. Location of the greenline on an eroded bank. Following the definition of greenline, "the first line of perennial vegetation that forms a lineal grouping of community types on or near the water's edge," the eroded non-riparian portion of the stream bank serves as the current greenline (Winward 2000).

Materials

- "L" tool or dual-ended laser pointer (see Appendix A for construction and suppliers)
- 50 or 100 m tape (150 or 300 ft)
- Meter (or yard) stick
- Extending range pole
- Clipboard, Riparian Channel Vegetation Survey Data Forms and pencil(s)

Standard Methods (rule set)

Note: Due to the difficulty in defining the greenline, and the physical impossibility of defining a permanent transect, on-site trainings are particularly important for this method. Where possible, this method should be repeated by the same person each time it is completed.

1. Determine pace length.

Rules

1.1 In order to increase the repeatability of this method, observers should try to calibrate their pace 1 m or 3 ft.

1.2 Determine pace length by repeatedly walking along a measuring tape and counting the number of paces required for a particular distance (e.g., 100 m or 100 yd) (Fig. 13.4).

1.3 Divide distance by pace number to determine pace length (e.g., 100 m ÷ 125 paces = 0.8 m [80 cm] per pace).

2. Measure the channel vegetation.

Rules

2.1 Begin in the channel at the point the Line-point or Gap intercept tape crosses the channel.

2.2 Indicate the direction of the "walk" (upstream or downstream) and record the side of the channel (e.g., NE, NW, SE or SW) in the blank next to "Stream side" on the Riparian Channel Vegetation Survey Data Form.

2.3 Select a stream side and direction and begin the survey, keeping in mind the standard pace length. Place the "L" tool at the first pace ("Pt." on the data form) along the edge of the greenline with the "scope" end pointing away from the center of the channel (Fig. 13.5).

2.4 For the point defined by the center of the L-tool scope, record the uppermost top layer species intercept under "Top layer" on the data form.

2.5 Look up and down the scope, if necessary, to ensure that all species are recorded. Record additional species intercepts in the appropriate "Lower layers" column.

2.6 Record the appropriate soil surface code in the last column of the data form.

2.7 If desired, record the height of the tallest plant intercepted in the "Ht." column.

Figure 13.4. Checking pace length.

Figure 13.5. Conducting the Riparian channel vegetation survey.

3. Repeat the measurement for all four sides of the channel.

Rules

3.1 Return to the start point for each of the four "walks," two upstream and two downstream on each side of the channel, and repeat steps 2.2 through 2.7.

3.2 The stopping points on one bank may not coincide with those on the other bank due to differences in the lengths of meanders on each side of the channel.

Riparian channel vegetation survey indicator calculations

See the Line-point intercept section in Quick Start for foliar cover, basal cover and bare ground. Instructions are provided here for calculating three additional indicators.

Site-specific indicators based on functional groups can be extremely valuable in riparian areas. Winward (2000) includes specific suggestions for developing indicators of greenline successional status and greenline bank stability, based on community types that have been defined for the U.S. Intermountain Region.

1. Calculate percent stabilizing species cover.

Rules

1.1. Acquire or develop a list of bank stabilizing species. Winward (2000) includes lists for the U.S. Intermountain region.

1.2. Count the total number of sample points at which a stabilizing species was recorded.

1.3. Multiply the number of stabilizing species sample points (from rule 1.2) by 2* and record your "% stabilizing spp. cover" in the blank provided on the data form.

2. Calculate stabilizing species as a percent of total species cover.**

Rules

2.1 Acquire or develop a list of bank stabilizing species (see Winward 2000).

2.2 Count the total number of times that a stabilizing species was intercepted ("Top layer" and "Lower layers" columns). Where more than one stabilizing species is intercepted at a point, all are counted. Record this on the data form as the numerator or "Total no. of stabilizing spp intercepts."

2.3 Count the total number of plant intercepts, to include species and litter intercepts ("Top layer" and "Lower layers" columns). Record this on the data form as the denominator or "Total no. of plant intercepts."

2.4 Divide the total number of stabilizing species intercepts by the total number of plant intercepts. Multiply this value by 100 and record in the blank provided.

3. Calculate percent woody species cover.

Rules

3.1 Acquire or develop a list of woody species.

3.2 Count the total number of sample points at which a woody species was recorded and record in the blank provided on the data form.

3.3 Multiply the number of samples points with woody species (from 3.2) by 2* and record your "% woody spp cover" on the data form.

---

*For 50 points per line. Multiply by 1 for 100 points per line. Multiply by 4 for 25 points per line.

**Note that this is total *species* cover, not total cover. Total cover would require that multiple plant intercepts of the same species be recorded.

Example

Riparian Channel Vegetation Survey Data Form

Page 1 of 1 Date: 15 September 2002 **Shaded cells for calculations**

Plot: North X Upstream or ____ Downstream Stream side: NE

Observer: Cathy Berger Recorder: Tom Marshall Pace length: 100 (cm or in?) circle one

Pt.	Top layer	Ht.	Lower layers Code 1	Code 2	Code 3	Soil surface	Pt.	Top layer	Ht.	Lower layers Code 1	Code 2	Code 3	Soil surface
1	FEID	40				FEID	26	ARTRT	85	L			S
2	NONE					S	27	ARTRT	155	L			ARTRT
3	NONE					R	28	ARTRT	200				S
4	NONE					R	29	COSE	105				S
5	NONE					R	30	COSE	190	ARTRT	L		S
6	POPR	10				S	31	ARTRT	170				S
7	NONE					S	32	COSE	145	FEID			S
8	NONE					R	33	ROWO	90				ROWO
9	ARTRT	180				S	34	FEID	10				S
10	NONE					R	35	FEID	5	L			S
11	ARTRT	155	L			S	36	FEID	5	L			S
12	ARTRT	220	L			ARTRT	37	COSE	120	FEID			S
13	NONE					R	38	COSE	130				S
14	NONE					R	39	NONE					S
15	NONE					R	40	COSE	210				S
16	NONE					R	41	COSE	190				COSE
17	ARTRT	205				S	42	ARTRT	160	L			S
18	NONE					R	43	ARTRT	180	L			S
19	NONE					R	44	COSE	220				S
20	ARTRT	220				S	45	ROWO	100				S
21	ARTRT	190	L			S	46	ARTRT	200				ARTRT
22	ARTRT	160	L			S	47	ARTRT	90				S
23	ARTRT	210	FEID			ARTRT	48	ARTRT	150				S
24	ARTRT	240	FEID	L		S	49	POFR	700	ARTRT	L		S
25	ARTRT	220	FEID			ARTRT	50	POFR	550	ARTRT			S

Top layer codes: Species code, common name, or NONE (no cover)

Lower layers: Species code, common name, L (herbaceous litter), WL (woody litter, >5mm [1/4 in] diameter)

% foliar cover = 36 top layer pts (1st col) x 2 = 72 %

% bare ground* = 3 pts (w/ NONE over S) x 2 = 6 %

% basal cover = 8 plant base pts (last col) x 2 = 16 %

Unknown species codes:

AF# = annual forb
PF# = perennial forb
AG# = annual grass
PG# = perennial grass
SH# = shrub
TR# = tree

Soil surface codes (do not use litter):

Species code (for basal intercept)
R = rock fragment (>5mm [1/4 in] diameter)
BR = bedrock
M = moss
LC = visible biotic crust on soil
S = soil, without any other soil surface code
EL = embedded litter
D = duff

% stabilizing spp cover = 8 pts with stabilizing spp x 2 = 16 %

$$\frac{\text{Total no. of stabilizing spp intercepts}}{\text{Total no. of intercepts}} \times 100\% = \frac{8}{44} \times 100 = 18.2\ \%$$

% woody spp cover = 31 pts with woody spp x 2 = 62 %

*Bare ground occurs ONLY when Top layer= NONE, Lower layers are empty (no L), and Soil surface = S

Riparian Channel Vegetation Survey Data Form

Page ____ of ____ **Date: _____** **Shaded cells for calculations**

Plot: _____ **____ Upstream or ____ Downstream** **Stream side: _____**

Observer: _____ **Recorder: _____** **Pace length: _____ (cm or in?)** circle one

Pt.	Top layer	Ht.	Lower layers Code 1	Lower layers Code 2	Lower layers Code 3	Soil surface	Pt.	Top layer	Ht.	Lower layers Code 1	Lower layers Code 2	Lower layers Code 3	Soil surface
1							26						
2							27						
3							28						
4							29						
5							30						
6							31						
7							32						
8							33						
9							34						
10							35						
11							36						
12							37						
13							38						
14							39						
15							40						
16							41						
17							42						
18							43						
19							44						
20							45						
21							46						
22							47						
23							48						
24							49						
25							50						

Top layer codes: Species code, common name, or NONE (no cover)

Lower layers: Species code, common name, L (herbaceous litter), WL (woody litter, >5mm [$^1/_4$ in] diameter)

% foliar cover = ____ top layer pts (1st col) x 2 = ____%

% bare ground* = ____ pts (w/ NONE over S) x 2 = ____%

% basal cover = ____ plant base pts (last col) x 2 = ____%

Unknown species codes:

AF# = annual forb
PF# = perennial forb
AG# = annual grass
PG# = perennial grass
SH# = shrub
TR# = tree

Soil surface codes (do not use litter):

Species code (for basal intercept)
R = rock fragment (>5mm [$^1/_4$ in] diameter)
BR = bedrock
M = moss
LC = visible biotic crust on soil
S = soil, without any other soil surface code
EL = embedded litter
D = duff

% stabilizing spp cover = _____ pts with stabilizing spp x 2 = _____%

$$\frac{\text{Total no. of stabilizing spp intercepts}}{\text{Total no. of intercepts}} \times 100\% = \frac{\boxed{}}{\boxed{}} \times 100 = _____\%$$

% woody spp cover = _____ pts with woody spp x 2 = _____%

*Bare ground occurs ONLY when Top layer= NONE, Lower layers are empty (no L), and Soil surface = S

Chapter 14

Riparian channel and gully profile

The Riparian channel and gully profile provides a description of channel shape. This method can also be used to record the shape of the soil surface (e.g., covered by rills and gullies) in uplands.

Caution!

- Stream currents can be dangerous.
- Use this method only when and where it can be safely applied.

Materials

- Two 1.5 m (5 ft) rebar stakes
- 100 m (300 ft) roll of nylon string
- Hacksaw
- Hand sledge
- String line level
- Meter stick
- 100 m (300 ft) tape
- Clipboard, Riparian Channel Profile Data Forms and pencil(s)

Standard Methods (rule set)

1. Determine the location for the profile.

Rules

1.1 Measure the profile where the Line-point or Gap intercept crosses the channel.

1.2 Determine where the edge of the greenline is on each side of the channel.

2. Erect rebar, string and tape.

Rules

2.1 Using the hacksaw, make a notch on both pieces of rebar about 3 cm from the end.

2.2 Pound one rebar in on one side of the channel at least 2 m (6 ft 7 in) in from the edge of the greenline, leaving 25-50 cm (10-20 in) exposed (Fig. 14.1). Install with the notch end up.

2.3 Tie the nylon string at the notch and pull it tight across the channel.

2.4 Determine how high the other rebar should be in order for the line to be level on the opposite side of the channel, and then pound in the other rebar.

2.5 Pull the string tight and tie off at the notch on the second rebar.

2.6 Install the line level and fine-tune the depth of either rebar until the line is perfectly level (Fig. 14.2).

2.7 Stretch the tape between the pieces of rebar with the 0 end on the left as you are looking upstream.

Figure 14.1. Installing rebar 2 m from edge of greenline.

Figure 14.2. Level the string across the channel.

3. Record the channel profile.

Rules

3.1 Beginning at the rebar at the 0 m end of the measuring tape, measure the distance from the soil surface to the string, using a meter stick (Fig. 14.3).

3.2 Record the position along the tape under "Tape distance" and the channel depth measurement under "Channel depth" on the data form.

3.3 Repeat these measurements at 50 cm (1 or 2 ft) intervals.

3.4 Make the final measurement at the rebar on the opposite end of the channel.

3.5 For riparian systems only (not gullies), record the location of the greenline (bank-full) on each side of the channel.

Figure 14.3. Record the channel depth every 50 cm (1 to 2 ft) for the length of the tape crossing the channel.

Riparian channel profile and soil surface contour indicator calculations

Note: Due to the difficulty in defining channel width, the same person should calculate these indicators each time. Save the raw data so the indicators can be recalculated in the future. These indicators can be used to monitor relative changes. Interpretation requires a trained professional who is familiar with the area. Please see Chapter 17 for more information.

1. Graph the channel profile.

Rules

1.1 Mark a line at the top of the graph to represent the string. Make sure it is parallel to the "x" (horizontal) axis, and set it to "0".

1.2 Graph heights relative to the "y" (vertical) axis, creating a graph that looks like the shape of the channel.

1.3 Always draw the graph as if you are looking at the profile from downstream of it.

1.4 Graph each measurement as a negative number against the distance along the measuring tape.

1.5 If measurements are not evenly spaced or a measurement is missing and you are using a computer, be sure that the "x" axis is correct. In Microsoft® Excel, you must use the "scatter" (not the "line") graph option.

2. Calculate the bank angle.

Rules

2.1 On the graph, mark the base and top of the bank on the side of the channel marked by the 0 end of the tape.

2.2 Measure the horizontal distance between these two points.

2.3 Measure the vertical distance between these two points.

2.4 Divide the vertical distance by the horizontal distance.

2.5 To express the angle in percent, multiply the result of Rule 2.4 by 100.

2.6 To express the angle in degrees, use a calculator to calculate the arctangent of the result of Rule 2.4. Excel and some calculators report the result in radians. To convert from radians to degrees, multiply by 57.3. In Excel, the formula is:

=DEGREES(ATAN(result of Rule 2.4)).

2.7 Record this as the "bank angle (0-end)" in the blank provided on the data form. Include appropriate units (percent or degrees).

2.8 Repeat 2.1 through 2.7 for the other bank on the non-zero end of the tape and record as the "bank angle (non-0 end)." Ensure you subtract the base from the top at the non-0 end.

3. Calculate the width:depth ratio.

Rules

3.1 The *width* is the horizontal (parallel to the "x" axis) distance between the points used for the bank angle at the top of each bank.

3.2 The *depth* is the greatest vertical distance from a straight line drawn between these two points to the bottom of the channel. The straight line between the two points will not necessarily be horizontal.

3.3 Divide the width by the depth and record as the "width:depth ratio" in the blank provided on the data form.

Sinuosity

The level of sinuosity is an excellent indicator of stream status, particularly in relatively low gradient systems. Sinuosity is most easily quantified using aerial photography. A simple index of sinuosity is the ratio of distance along the streambed to the straight-line distance between two points.

Example

Riparian Channel Profile Data Form

Date: 5 October 2002

Shaded cells are for calculations

Monitoring plot: North **Line:** 1

Observer: Ken Fields **Recorder:** Ken Fields

Side of channel where line starts (N, S, E, W): E

Tape distance always starts at "0" with a reading from where the string is tied to the rebar.
The last reading should be where the string is tied to the rebar on the opposite side of the channel.

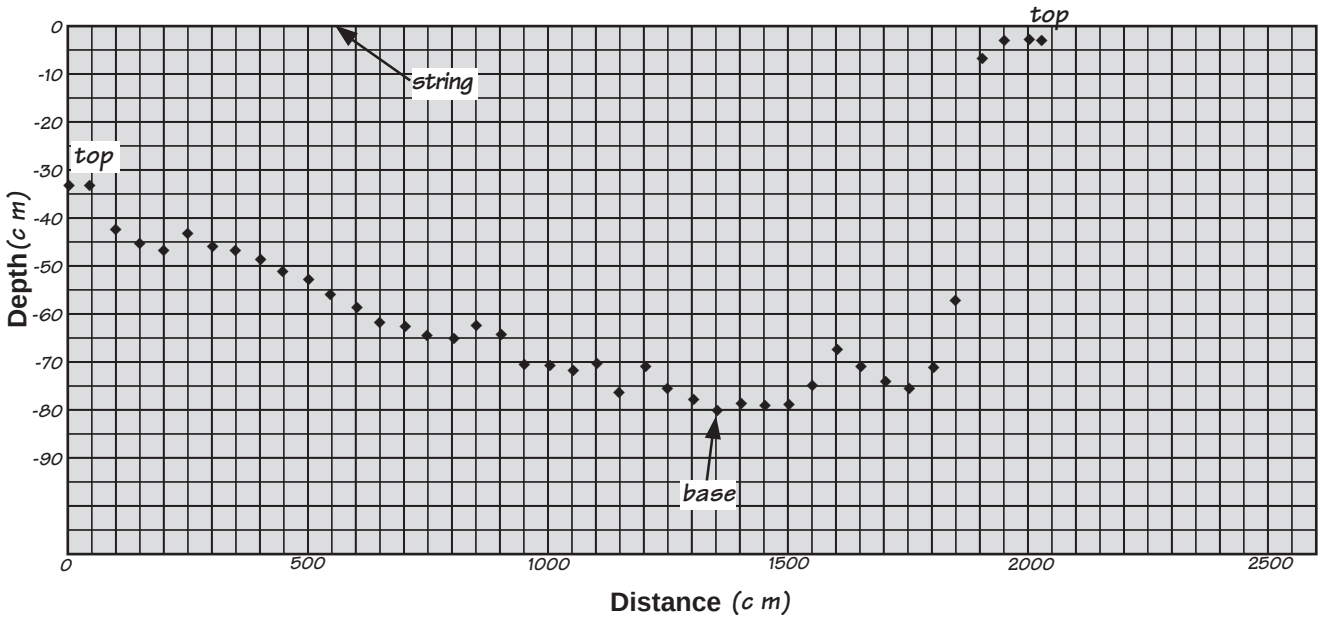
Tape distance	Channel depth (cm)	Tape distance	Channel depth (cm)	Tape distance	Channel depth (cm)	Tape distance	Channel depth (cm)
0	33.0	600	58.5	1200	71.5	1800	71.0
50	33.0	650	62.0	1250	75.5	1850	57.5
100	42.5	700	62.5	1300	77.5	1900	7.0
150	45.5	750	64.5	1350	80.0	1950	3.5
200	46.5	800	65.0	1400	78.5	2000	3.0
250	43.5	850	62.5	1450	79.0	2022	3.0
300	46.0	900	64.5	1500	78.5		
350	47.0	950	70.5	1550	75.0		
400	48.5	1000	70.5	1600	67.5		
450	51.0	1050	72.0	1650	71.0		
500	52.5	1100	70.0	1700	74.0		
550	56.0	1150	76.5	1750	75.5		

Bank angle (0 end) = $\frac{\text{vertical distance}}{\text{horizontal distance}}$ x 100% = $\frac{47}{1300}$ x 100% = 3.6 %

Bank angle (non-0 end) = $\frac{\text{vertical distance}}{\text{horizontal distance}}$ x 100% = $\frac{77}{650}$ x 100% = 11.8 %

Width:depth ratio = $\frac{\text{width}}{\text{depth}}$ = $\frac{1950}{77}$ = 25.3

Remember for this end:
2000 - 1350 = 650



Riparian Channel Profile Data Form

Date: _____

Shaded cells are for calculations

Monitoring plot: _____ **Line:** _____

Observer: _____ **Recorder:** _____

Side of channel where line starts (N, S, E, W): _____

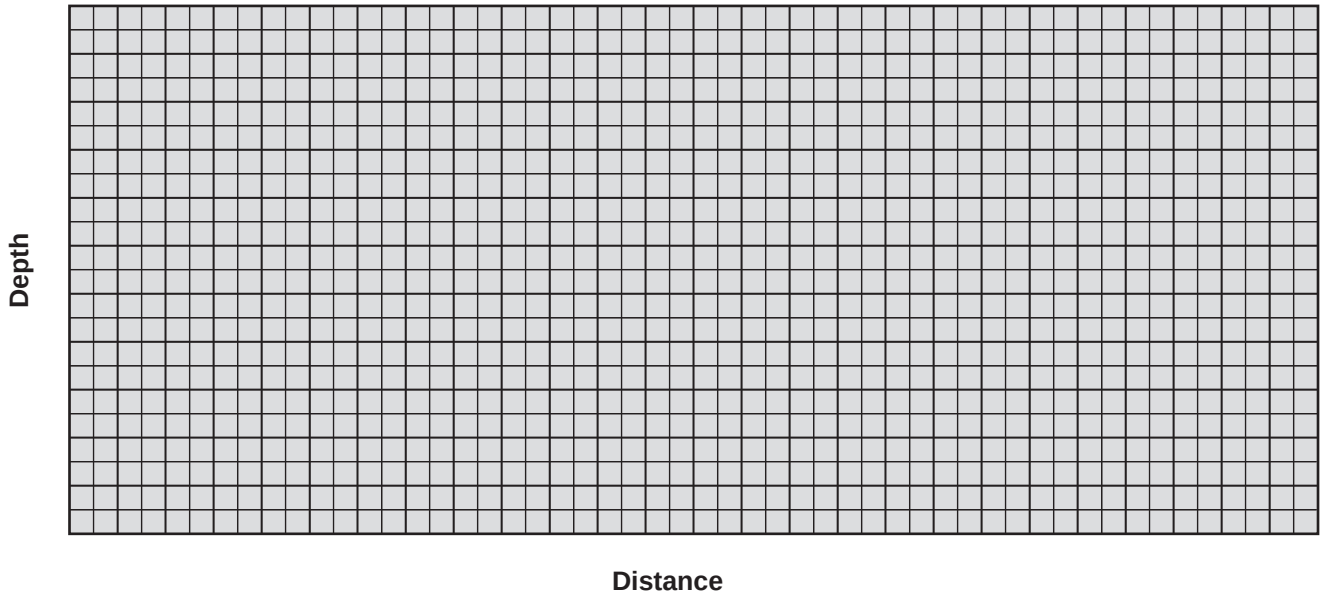
Tape distance always starts at "0" with a reading from where the string is tied to the rebar.
The last reading should be where the string is tied to the rebar on the opposite side of the channel.

Tape distance	Channel depth (cm)	Tape distance	Channel depth (cm)	Tape distance	Channel depth (cm)	Tape distance	Channel depth (cm)

$$\text{Bank angle (0 end)} = \frac{\text{vertical distance}}{\text{horizontal distance}} \times 100\% = \frac{\boxed{}}{\boxed{}} \times 100\% = _____\ \%$$

$$\text{Bank angle (non-0 end)} = \frac{\text{vertical distance}}{\text{horizontal distance}} \times 100\% = \frac{\boxed{}}{\boxed{}} \times 100\% = _____\ \%$$

$$\text{Width:depth ratio} = \frac{\text{width}}{\text{depth}} = \frac{\boxed{}}{\boxed{}} = _____$$



Chapter 15

Density, frequency and Line-point intercept alternative methods

This chapter includes a brief discussion of density and frequency methods, and alternative Line-point intercept methods. Density and frequency are generally used for individual species of interest, although it is possible to use them for all species encountered in an area. For more information on density and frequency, see Elzinga et al. 2001.

Density

Plant density is simply the number of individuals per unit area. It is particularly useful for monitoring vegetation where cover varies widely during the season (e.g., annuals). It is not appropriate where individuals are difficult to distinguish (e.g., many rhizomatous grasses).

Method. Count the number of individuals of the species of interest that have at least 50 percent of their base in a subplot (quadrat) or other plot of defined size. The subplots should be large enough so that most of them include more than one individual of each species that is being monitored. Multiple noncontiguous subplots are randomly or systematically located in the plot.

Calculations. Add the number of individuals found in each subplot. Divide this sum by the area of subplots to generate the average density (number per square meter or square feet). To convert to the number per hectare, multiply the density by 10,000 (if working with square meters). To convert the density in number per square feet to the number per hectare, multiply by 107,639.

Frequency

Plant frequency is the proportion of subplots out of all subplots of a specified size that contain a particular species. It is a rapid and useful indicator of the spatial distribution of different species, and is appropriate for the same types of species as density (above). Two methods for collecting frequency data are the rapid method and the intensive method. The rapid method generates data for just one species. The intensive method produces data for many species. Data collected with the intensive method (below) can generate information about fine-scale associations among species.

Rapid method. Define and use only one subplot size. The subplot should be small enough to ensure that the species of interest does not occur in all subplots. This is because if the species occurs in all subplots, frequency will always be 1.0. Randomly or systematically locate and establish subplots. Count the number of subplots in which at least one individual of the target species is located. A species must have at least 50 percent of its base in a subplot to be considered present.

Intensive method. Define and use only one subplot size. Subplot size should be selected based on the species of greatest interest. Randomly or systematically establish subplots. Make a comprehensive species list. For each subplot, record whether or not each species occurs in that subplot. A species is recorded for a subplot if at least 50 percent of at least one plant base falls within the subplot.

To increase speed, use a species list with tally marks or dot boxes. A dot box consists of four dots in a square connected by four lines with an "X" in the middle. Each dot and each line represents a plot in which the species occurs, for a total of 10 individuals per complete dot box.

Calculations. Divide the number of subplots in which the species occurs by the number of subplots searched. This is frequency.

Line-point intercept alternatives

Line-point intercept can be used to generate more indicators than virtually any other monitoring method. Adding height measurements (Option B in Table 15.1) generates additional information on vegetation structure. The height of first (top layer) intercept is recorded under 'Ht'. If litter or woody litter is the tallest element (i.e., taller than the plant at that point), record this in the notes. An alternative method (used by the USDA National Resources Inventory) is to record the tallest element within a 15 cm radius of the point. If species information is required, the species of this element (or WL for woody litter) should be recorded in a separate column. Options D through H take less time, but generate fewer indicators.

Figure 15.1. Line-point intercept with height alternative.

Typical applications. Line-point intercept (Table 15.1: A-E) should be used where precise, repeatable measurements are required. Options D and E can reduce time where changes in species composition (e.g., grass to shrub, or annuals to perennials) are not important. Option D is ideal where the primary objective is to document changes in erosion resistance.

Step-point intercept methods (Table 15.1: F-H) require less time because no tape is required. They can be relatively accurate *provided that a pin is used in place of the toe of your boot.* Using the toe can significantly overestimate cover because plants are pushed over by the foot, which artificially increases measured cover data.

Quadrat-point intercept. Where quadrats (or subplots) are being used along a line (e.g., to monitor frequency or density), points on the four corners of the frame can sometimes be used to replace four points along the line, provided that the points are sufficiently far apart. The minimum distance varies with plant community. To determine whether or not this method is appropriate, randomly select six transects and compare means and variability for both methods. For example, a 50 m transect with 100 points with a point every 50 cm would be compared with a 50 m transect with 25 frames (four points each), one frame located every 2 m.

Table 15.1. Alternative Line-point intercept methods comparison. See also quadrat-point intercept below.

		Modifications from Standard (Alternative A = Quick Start)				------Indicators------			
Alternative		**Method**	**Form**	**Time**	**Accuracy & Repeatability**	**Foliar/ Basal**	**Comp-osition**	**Structure**	**Ht.**
		----------Line-point intercept----------							
A	Standard (Quick-Start)	None	None	Mod. to High	High	Yes/Yes	Yes	Yes	No
B	Standard + height	Add height of highest intercept at least every 10th point	Add height column	High	High	Yes/Yes	Yes	Yes	Yes
C	Standard + dead	Only record each species once, but if you intercept a dead plant part for a given species, place a check in the "Dead" column	Change "Height" in Option B to "Dead"	Mod. to High	High	Yes/Yes	Yes	Yes	No
D	Total, foliar, basal cover only	Record first intercept + any plant basal hits	Delete lower layers	Mod. to Low	High	Yes/Yes	No	No	No
E	Total cover only	Record only first intercept (foliar, litter, rock, etc...)	Delete lower layers and soil surface	Low	High	Yes/No	No	No	No
		----------Step-point Intercept with Pin----------							
F	Standard (Quick-Start "Semi-quantitative alternative"	Pace transect, drop pin 15 cm (6 in) in front of toe	None	Mod.	Mod. to Low	Yes/Yes	Yes	Yes	No
G	Total, foliar, basal cover (species not recorded)	See D and F	See D	Low	Mod. to Low	Yes/Yes	No	No	No
H	Total cover (species not recorded)	See E and F	See E	Very Low	Mod. to Low	Yes/No	No	No	No

Line-point Intercept with Height Data Form

Page ____ of ____ **Shaded cells for calculations**

Plot: _____ Line No.: _____ Observer: _____ Recorder: _____

Direction: _____ Date: _____ Intercept (point) spacing interval = _____ cm (_____ in)

Pt.	Top layer	Ht.	Lower layers			Soil surface	Pt.	Top layer	Ht.	Lower layers			Soil surface
			Code 1	Code 2	Code 3					Code 1	Code 2	Code 3	
1							26						
2							27						
3							28						
4							29						
5							30						
6							31						
7							32						
8							33						
9							34						
10							35						
11							36						
12							37						
13							38						
14							39						
15							40						
16							41						
17							42						
18							43						
19							44						
20							45						
21							46						
22							47						
23							48						
24							49						
25							50						

% foliar cover = ____ top layer pts (1st col) x 2 = ____%

% bare ground* = ____ pts (w/ NONE over S) x 2 = ____%

% basal cover = ____ plant base pts (last col) x 2 = ____%

Top layer codes: Species code, common name, or NONE (no cover)

Lower layers: Species code, common name, L (herbaceous litter), WL (woody litter, >5mm [$^1/_4$ in] diameter)

Unknown species codes:

AF# = annual forb
PF# = perennial forb
AG# = annual grass
PG# = perennial grass
SH# = shrub
TR# = tree

Soil surface codes (do not use litter):

Species code (for basal intercept)
R = rock fragment (>5mm [$^1/_4$ in] diameter)
BR = bedrock
M = moss
LC = visible biotic crust on soil
S = soil, without any other soil surface code
EL = embedded litter
D = duff

*Bare ground occurs ONLY when Top layer = NONE, Lower layers are empty (no L), and Soil surface = S

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 (Σ) 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.

Interpretation

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).

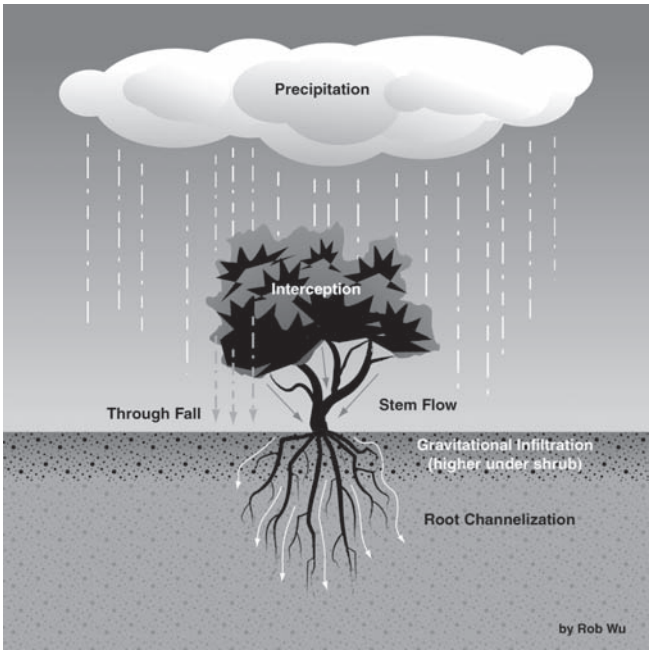


Figure 17.2. Effect of vegetation structure on infiltration (figure modified from Martinez-Meza and Whitford 1996).

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.

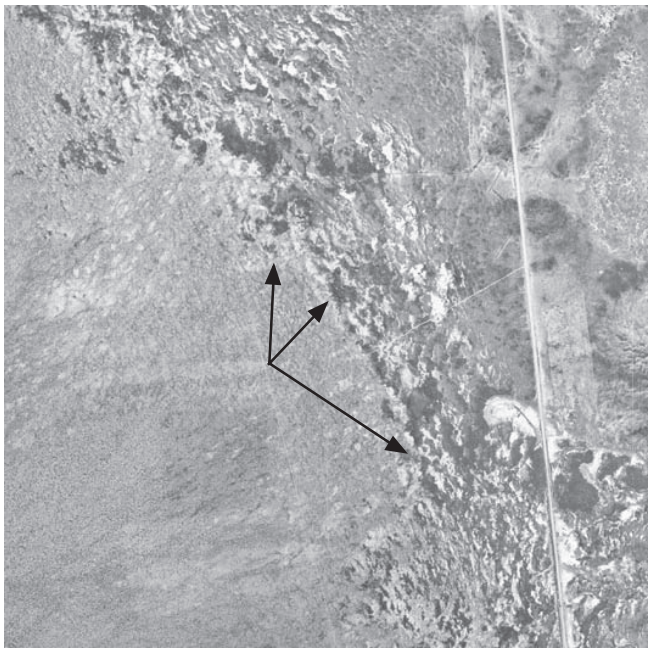


Figure 17.5. Banded vegetation on the Jornada Experimental Range, New Mexico.

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

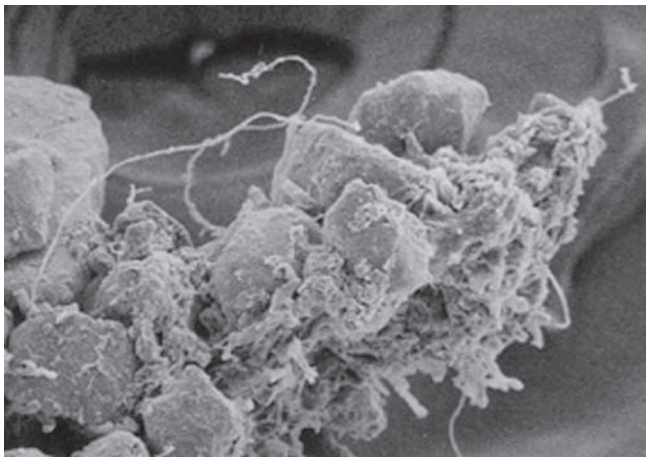


Figure 17.6. Fungal hyphae entanglement of soil particles.

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

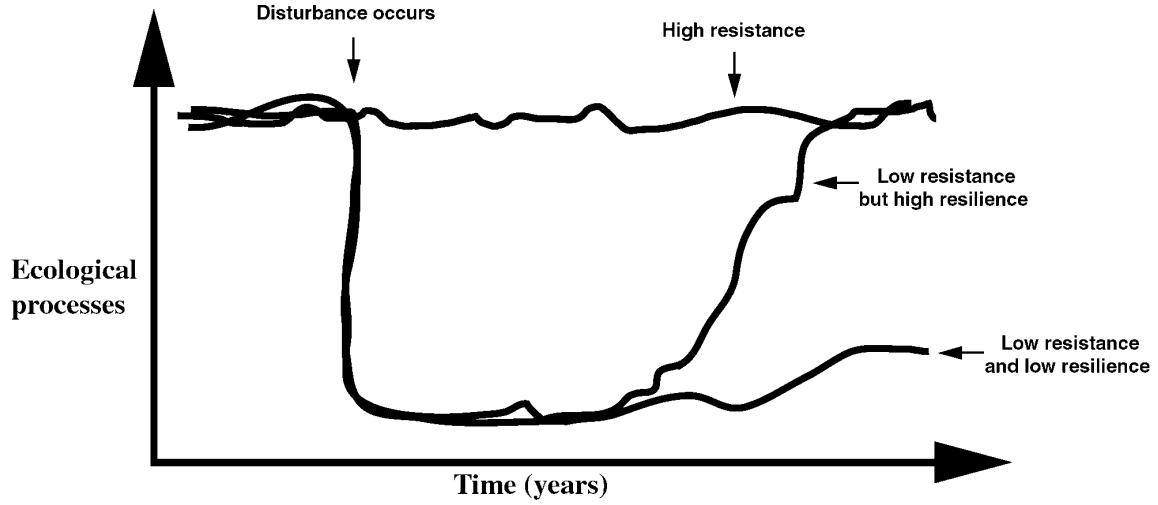


Figure 17.10. Resistance is the ability of a system to resist a disturbance over time. Resilience is the ability of a system to rebound after a disturbance (adapted from Seybold et al. 1999).

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

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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
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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.

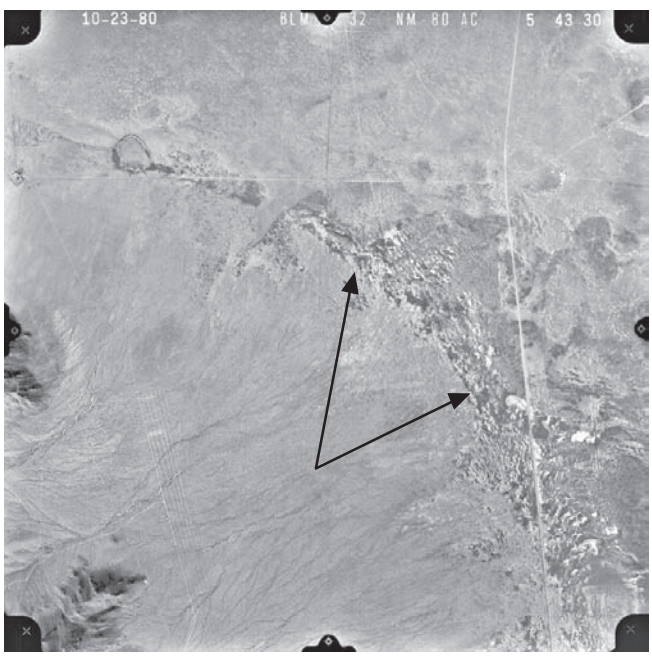

Figure 17.13. Large gaps between banded vegetation patches shown in an aerial photo.

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
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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.

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Blackburn and Pierson 1994
Herrick 1999
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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.

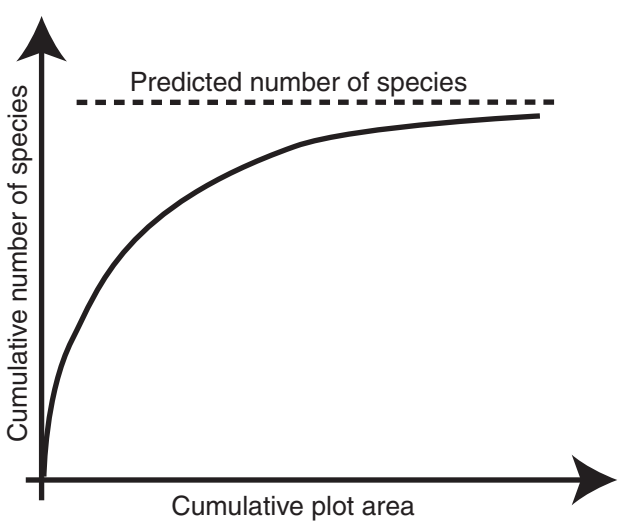


Figure 17.14. Species area curve.

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).

Section IV: Special topics

Riparian (Ch. 18)

Photo by Bob Gibbens

Livestock production (Ch. 19)

Photo by Doug Burkett

Wildlife habitat (Ch. 20)

Photo by Jayne Belnap

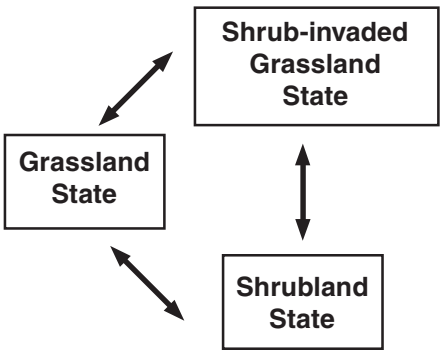
Vehicles/Recreation (Ch. 21)

Photo by Patrick Shaver

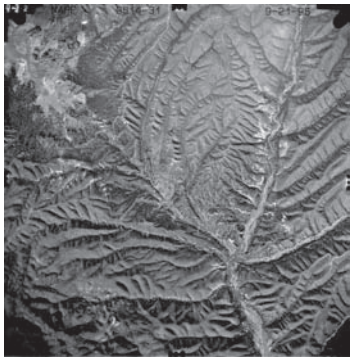
Fire (Ch. 22)

Photo by Mike Pellant

Invasive species (Ch. 23)



State and transition models (p. Ch. 24)



Remote sensing (Ch. 25)

Soil carbon (Ch. 26)

The monitoring methods included in the previous chapters of this manual were selected because they generate indicators relevant to the three key attributes: soil and site stability, hydrologic function and biotic integrity. These attributes represent the foundation for nearly every land management objective, including livestock production, wildlife habitat, recreation and watershed protection. The first six chapters, and the ninth chapter, of this section provide additional guidance on how to adapt these protocols to address more specific management and monitoring objectives.

Each of these chapters is organized into four sections: an introduction, a summary table, methods notes and additional resources. Notes are included only for methods that require modifications or for which there are additional indicators that are not described in the methods chapters (Section II, Chs. 7 through 15). The additional resources portion describes printed and online resources. When possible, local experts (NRCS, USFS, Extension, etc.) should be consulted, particularly for projects involving multiple objectives in complex systems.

Each chapter addresses three strategies. The first and simplest strategy is to calculate additional indicators from the core measurements described in Quick Start (Vol. I). Many of the measurements included in this manual were selected in part because they can be used to easily generate a large number of indicators. For example, Line-point intercept was selected instead of vegetation frequency or density because it can be used to generate cover and composition indicators, as well as information on soil surface properties such as rock and lichen cover. Unlike Daubenmire quadrats, Line-point intercept data can easily generate vegetation structure indicators. Line-point intercept also can quantify ground cover in plant interspaces.

The second strategy involves making relatively simple modifications or additions to the core measurements, such as adding height to the Line-point intercept measurements.

The third and most expensive strategy is to incorporate supplementary measurements.

Each of these strategies increases monitoring costs. The first six chapters, and the ninth chapter of Section IV, include tables defining the relative priority of each measurement for typical applications. These tables can be used, together with the time estimates in Quick Start, to compare the relative costs and benefits of each measurement for the particular management or monitoring objective. Because each situation is unique, these rankings should be used only as a rough guide for selecting measurements.

The lists of additional resources are by no means complete. There are hundreds of monitoring guides available now and many more are becoming available on the Internet. Most are specific to particular uses or values, and most can be adapted to and integrated with the flexible monitoring system described here.

Please note that there is potential for overlap among the special topics. The first (Riparian) is a type of land. The next three (Livestock production, Wildlife habitat and Off-road vehicles) are most commonly thought of as land uses or values. The fifth (Fire) is often applied as a management tool but it, like the sixth (Invasive species), can also be viewed as a threat. It is increasingly common to find that all six topics need to be addressed simultaneously. For example, fire is used to control invasive species in riparian zones that are simultaneously managed for livestock, wildlife, recreation and carbon sequestration. The advantage of using an integrated system is that the data are relevant to all six topics. While the time allocated to different measurements may vary depending on the relative importance of each topic, the basic structure should remain constant.

Chapters 24 and 25 provide a brief introduction to state and transition models, and remote sensing. Both of these tools can be extremely useful in monitoring program design and data interpretation.

Chapter 18

Riparian

Important indicators in most riparian systems are plant community composition and structure. These can be monitored using a combination of one or more of the following methods: Line-point intercept, Riparian channel vegetation survey, Belt transect and Tree density. Additional long-term monitoring methods can provide more complete information on relationships between changes in vegetation and channel morphology.

Figure 18.1. Riparian vegetation along Rio Peñasco, New Mexico

Table 18.1. Guidelines for applying monitoring methods to riparian systems.

Quick Start measurements (Vol. I)	Modifications	Additional indicators	Typical priority
Photo points	Include channel photos	n/a	High
Line-point intercept (perpendicular to channel)*	Include height	Yes	High
Gap intercept	None	No	Moderate
Soil stability test*	None	No	Moderate
Belt transect*	None	No	Moderate
Supplementary measurements (Vol. II)			
Compaction test*	None	No	Low
Single-ring infiltrometer*	None	No	Low
Plant production	None	No	Low
Plant species richness*	None	No	Low
Vegetation structure	None	No	Moderate
Tree density*	None	No	Moderate
Riparian channel vegetation survey	None	No	High
Riparian channel and gully profile	None	No	High

* Please see notes below.

Riparian notes

Line-point intercept. The Line-point intercept method can be used to effectively monitor changes in cover and composition across the width of the riparian zone. Install transects perpendicular to the channel with at least three transects per area of interest. Set transect ends at least 5 m (15 ft) outside the maximum potential riparian zone. Transects should be extended further in areas where the riparian area is expected to expand. For extremely wide riparian areas, reduce the frequency of measurements along the transect. Adding height measurements at each point provides useful information on vegetation structure. Use the Line-point Intercept with Height Data Form in Chapter 15 to record height measurements.

In addition to the standard indicators, calculate the proportion of the transect covered by woody riparian species, and average plant height. Standard deviation of height measurements and the average number of species recorded at each point are useful indicators of structural diversity. Changes in the width of riparian zones can be monitored by noting where riparian vegetation begins and ends along the transect. Line-point intercept data also can be used for this purpose, but will often underestimate riparian zone width.

Soil stability test. The Soil stability test can be a useful indicator of changes in soil structural development, but results are often difficult to interpret in riparian systems. Interpretation of data is limited by the fact that soil texture often varies widely within a riparian zone. Texture also may change during the year as flood events deposit new material. Sediment deposition may result in a negative change in average soil stability following a flood. However, sediment deposition by floods is often a positive indicator of riparian zone recovery, despite its initially low stability.

Belt transect and Tree density. Either of these methods can be used to monitor woody plant density by size class. Belt transects are more appropriate for monitoring recruitment of new individuals, while the Tree density method is more applicable for areas with a few highly dispersed individuals. The Belt transect can be applied either along the greenline (edge of the channel) or on the Line-point intercept transect that crosses the channel.

Compaction and Infiltration. High rates of recreational or grazing use, especially on moist or wet soil, can cause degradation of soil structure, including compaction. Where compaction appears to have resulted in reduced infiltration, both the infiltrometer and the penetrometer may be used. Infiltration measurements are usually low priority because they are relatively time consuming (high cost-benefit ratio). Compaction test measurements are relatively rapid, but the data are difficult to interpret unless the measurements are made in soil with the same moisture content each year. This is more likely to be possible in arid ecosystems when measurements can often be made following a period with no precipitation.

Plant species richness. Plant species richness can be a valuable indicator of riparian recovery and degradation. It is useful when biodiversity is a management objective. The method generally has a low priority because a minimum estimate of richness can be calculated from the Line-point intercept and Riparian channel vegetation survey. The method is also quite time consuming, adding significantly to costs in most cases.

Additional resources

A large number of riparian monitoring systems have been developed for perennial streams. Many systems focus on specific stream characteristics believed to be important for fish habitats, including water temperature and chemistry. One of the most widely applied riparian vegetation methods is described in Winward (2000). This method, like the Riparian channel vegetation survey, depends on identifying the greenline. Researchers are continuing to develop appropriate methods for intermittent streams, washes and arroyos where the greenline is often difficult to identify. Using aerial photography and videography to monitor (Prichard et al. 1996) is becoming increasingly popular, particularly where dense vegetation and accessibility make ground measurements difficult or impossible.

Chapter 19

Livestock production

Long-term sustainability of livestock production in upland areas depends on the three key ecosystem attributes: soil and site stability, hydrologic function and biotic integrity. The Quick Start measurements should be adequate for monitoring these attributes, except where there is a specific problem such as compaction, or a concern such as biodiversity (species richness). Where the flexibility exists to make short-term changes in stocking rates or grazing patterns (e.g., by moving water, salt blocks or supplemental feed), conduct short-term monitoring (Quick Start).

Photo by Bob Gibbens

Figure 19.1. Herding cattle in the Chihuahuan Desert.

Table 19.1. Guidelines for applying monitoring methods to systems where livestock production is the primary use.

Quick Start measurements (Vol. I)	Modifications	Additional indicators	Typical priority
Photo points	None	n/a	High
Line-point intercept	None	Yes	High
Gap intercept	None	No	High
Soil stability test	None	No	High
Belt transect	None	No	High
Supplementary measurements (Vol. II)			
Compaction test	None	No	Low
Single-ring infiltrometer	None	No	Low
Plant production*	None	No	High
Plant species richness	None	No	Low
Vegetation structure	None	No	Low
Tree density	None	No	Low
Riparian channel vegetation survey	None	No	Low**
Riparian channel and gully profile	None	No	Low

* Please see notes below.
** Except in riparian zones, where priority is high.

Livestock production notes

Plant production. Annual forage production is sometimes considered to be one of the most important indicators for livestock management. This is generally calculated as part of total plant production. It can be used to plan annual stocking rates. It is also a long-term indicator of changes in land status. Plant production is one of the most difficult and costly indicators to accurately monitor, especially in arid and semi-arid ecosystems. It can also be difficult to interpret, particularly in areas with highly variable precipitation.

An aboveground standing biomass of forage species is a useful short-term indicator, which can be used to determine how many animals a pasture will support for a particular period of time. It can be calculated from the plant production data collected by simply setting utilization to 0 and the growth adjustment factor to 1.0 (Rules 9 and 10 in Chapter 9). Residual (standing) biomass, like residual cover, is also an excellent short-term indicator for determining when to remove livestock from a pasture.

Additional resources

Most monitoring systems used by federal agencies in the United States were designed to monitor livestock grazing impacts on plant communities and, to a lesser extent, production. They often include a mixture of short-term indicators (such as stubble height and estimated utilization) and long-term indicators (such as similarity to a hypothesized historic plant community). The Natural Resources Conservation Service (NRCS) and Bureau of Land Management (BLM) both currently rely on the NRCS *National Range and Pasture Handbook* (USDA-NRCS 1997) for monitoring guidance. However, there is significant variability at both the state and local level. The United States Forest Service (USFS) has relied on the Parker Three Step method for monitoring in most regions, although other methods are increasingly used. The basic approach is described in Parker (1951). The local office should be consulted to find out exactly how the method was and is being applied in each forest. In addition to federal handbooks, most state extension services have developed and published rangeland monitoring guides. Again, these generally focus on effects of livestock grazing and include a mix of short- and long-term indicators. Contact your local extension office or land-grant university for current versions.

Chapter 20

Wildlife habitat

Important characteristics for wildlife management are vegetation composition and structure. These can be monitored using augmented versions of the Line-point intercept and Belt transect methods, as well as adding a cover pole or cover board measurement (Vegetation structure).

Every species has unique habitat requirements. These requirements may be poorly understood and they can change during the year. Therefore, please read the Wildlife habitat notes section below to determine which combination of methods best suits your needs.

Photo by Doug Burkett

Figure 20.1. Mule deer habitat.

Table 20.1. Guidelines for applying monitoring methods when wildlife habitat is the primary management objective.

Quick Start measurements (Vol. I)	Modifications	Additional indicators	Typical priority
Photo points	None	n/a	High
Line-point intercept*	Include height	Yes	High
Gap intercept*	May include height requirement	Yes	Moderate
Soil stability test*	None	No	Low
Belt transect*	None	No	High
Supplementary measurements (Vol. II)			
Compaction test	None	No	Low
Single-ring infiltrometer	None	No	Low
Plant production*	None	No	Moderate
Plant species richness*	None	No	Low
Vegetation structure*	None	No	High
Tree density	None	No	High
Riparian channel vegetation survey	None	No	Low**
Riparian channel and gully profile	None	No	Low

* Please see notes below.
** Except in riparian zones, where priority is high.

Wildlife habitat notes

Line-point intercept. Line-point intercept can be used to assess plant composition. In savannas and other systems with widely scattered trees, it should be supplemented with the Belt transect and/or Tree density methods.

Where vertical vegetation structure is of interest, height estimates should be included for at least every fifth point. Use the Line-point Intercept with Height Data Form in Chapter 15. Line-point intercept (with height) should be combined with Canopy Gap intercept to best understand vegetation structure.

In addition to the standard indicators, calculate the proportion of the line covered by woody species and average height. The standard deviation of the height measurements and the average number of species recorded at each point are useful indicators of structural diversity. The distribution of species along a transect can be used, together with Gap intercept from the same transect, to characterize individual vegetation patches.

Gap intercept. Canopy Gap intercept is generally more useful than Basal Gap intercept for addressing horizontal vegetation structure with respect to wildlife. Canopy Gap intercept should be combined with Line-point intercept (with height) to best understand vegetation structure. Basal Gap intercept may be used as a surrogate in systems where canopy cover is extremely dynamic. The standard Gap intercept indicators can be used to estimate the proportion of area in which an animal would be exposed to aerial predators or to direct sunlight. The standard indicator classes (25-50 cm, 51-100 cm, etc.) were selected based on erosion criteria. The proportion of land in even larger gaps (e.g., > 500 cm, approximately 15 ft) can be used to examine the extent to which vegetation is clumped or dispersed.

The Gap intercept method can be modified to examine gaps between tall clumps of vegetation by establishing a minimum height or by recording two separate gap types (greater than *x* cm and less than *x* cm tall) for canopy intercepts. The indicator calculations and data forms are identical to the standard technique.

Soil stability test. While not directly related to habitat for most wildlife species, soil stability is essential to the sustainability of the system. It is also an important indicator of the integrity of soil processes, including the activity of soil-dwelling animals responsible for root and plant litter decomposition.

Belt transect. Belt transects can be used to assess plant species composition in communities containing widely scattered trees. Additional size classes can be included for species measured with the Belt transect to better estimate vertical vegetation structure (but see the Vegetation structure method discussed below).

Plant production. Please see discussion in "Livestock production notes" in Chapter 19.

Plant species richness. Please see "Riparian" discussion in Chapter 18.

Vegetation structure (cover pole). Cover poles and boards are among the most widely used tools for characterizing habitat structure. The proportion of the pole that is obscured by vegetation in each height increment when viewed from a specified distance reflects the proportion of an animal that would be obstructed from view at that distance.

Additional resources

We found few generic resources for wildlife habitat monitoring, although there are literally hundreds of protocols available for individual species. A wide range of literature does exist linking vegetation structure to wildlife habitat, bird diversity, visual obstruction and production (e.g., Robel 1970, Robel et al. 1970, and Harrell and Fuhlendorf 2002).

If a particular species or group of species is of concern, try contacting a local wildlife biologist or searching the Internet. Keywords that may assist in Internet searches include: foliage height diversity (FHD), vegetation structure, vertical structural diversity, wildlife habitat structure, cover pole, cover board and Robel Pole. Krebs (1998) lists a number of techniques for measuring animal populations directly. *Measuring and Monitoring Plant and Animal Populations* (Elzinga et al. 2001) also has information on animal population monitoring, although the primary focus is on vegetation monitoring. *Research and Management Techniques for Wildlife and Habits* (1994) is another resource for wildlife habitat methods.

Chapter 21

Off-road vehicle use and other recreational land uses

Areas impacted by off-road vehicles and other recreational land uses are often characterized by linear surface disturbances. While these disturbances can cover a relatively small portion of the landscape, their effects on ecosystem function can be significant, especially in steeply sloping terrain and riparian zones. Recent research (Herrick et al. unpublished data) has shown that even a single pass of a relatively small vehicle can compact some soils, significantly reducing water infiltration and soil stability for extended periods of time.

Photo by Jayne Belnap

Figure 21.1. Off-road vehicle trails north of Salt Lake City.

Table 21.1. Guidelines for applying monitoring methods to off-road vehicle use and other recreational land uses.

Quick Start measurements (Vol. I)	Modifications	Additional indicators	Typical priority
Photo points	None	n/a	High
Line-point intercept*	Add "track" as final column	No	High
Gap intercept*	Add "track" as 3rd gap type	Yes	High
Soil stability test	Stratify by on/off track	Yes	High
Belt transect*	None	No	High
Supplementary measurements (Vol. II)			
Compaction test	Stratify by on/off track	No	High
Single-ring infiltrometer	Stratify by on/off track	No	Moderate
Plant production	None	No	Low
Plant species richness*	None	No	Low
Vegetation structure	None	No	Low
Tree density	None	No	Low
Riparian channel vegetation survey	None	No	Low**
Riparian channel and gully profile	None	No	Low

* Please see notes below.
** Except in riparian zones, where priority is high

In order to make a sufficient number of measurements in tracked areas, it may be necessary to pre-stratify soil measurements into areas that both do and do not appear to be in tracks. Randomly select locations for an equal number of soil measurements (Soil stability test, Compaction test and/or infiltration) in tracked and non-tracked areas. If this approach is used, it is essential that track intercepts be recorded on the Line-point Intercept or Gap Intercept Data Form so that a weighted average can be calculated for each soil indicator.

Recreation notes

Line-point intercept. Where vehicle tracks are relatively distinct, the proportion of area they cover can be quantified by recording the number of Line-point intercept points that fall on them. Use the Line-point Intercept with Height Data Form and change the "Height" column to "Track" (or add another column). The track cover estimate is likely to be less precise than other cover estimates, such as bare ground, because of the difficulty in defining what constitutes a track. Observer ability varies, and tracks tend to be more apparent early and late in the day. On some soils it may be possible to define a minimum depth required for tracks to be recorded.

Gap intercept. The Gap intercept method can also be used to quantify the proportion of the area covered by tracks. This is particularly useful in areas where tracks cross the transects relatively infrequently (e.g., less than five percent of the transect). On the Gap Intercept Data Form simply use the last few columns of the "Basal Gap intercept" side of the page and record where each track or contiguous set of tracks begins and ends along the transect.

Belt transect. Belt transect measurements and other strategies to monitor invasive species (see "Invasive species," Ch. 23) should be given high priority due to the potential for vehicles to transport invasive species relatively large distances. It is important to train field workers to identify all species that could potentially invade a site, based on soil and climate requirements, whether or not the species is already present in the area.

Plant species richness. Please see the discussion in "Riparian notes" in Chapter 18.

Additional resources

David Cole of the USFS Rocky Mountain Forest and Range Experiment Station has written a number of publications on monitoring recreational impacts. They are available on the USFS websites (http://fsinfo.fs.fed.us/cgi-bin/gw/chameleon, http://www.srs.fs.fed.us/pubs/index.jsp or http://leopold.wilderness.net/pubs.cfm). Most of these focus on the effects of hikers, campers and mountain bikers. Richard Knight of Colorado State University and others have also published extensively on monitoring recreational impacts. However, there are surprisingly few protocols available for monitoring off-road vehicle effects.

Chapter 22

Fire

There are two general types of fire monitoring: fire risk and fire recovery. Fire risk monitoring is a relatively well-developed science based on estimates of fuel availability, vertical and horizontal continuity of fuel, moisture content and weather conditions. Fire risk monitoring is not addressed here.

Fire recovery monitoring is generally initiated following fire. Where possible (e.g., prescribed burns), pre-fire baseline data should be collected at the same time of year that monitoring will be continued following fire. It is more important to monitor at the same time of year before and after than to take measurements immediately following the fire.

Photo by Pat Shaver

Figure 22.1. Prescribed fire in an old world bluestem, sideoats grama, little bluestem and blueberry juniper grassland community.

Table 22.1. Guidelines for applying monitoring methods to post-fire recovery.

Quick Start measurements (Vol. I)	Modifications	Additional indicators	Typical priority
Photo points	None	n/a	High
Line-point intercept*	None	Yes	High
Gap intercept*	May include coarse woody debris and/or embedded litter	No	High
Soil stability test*	Classify as "hydrophobic"	No	High
Belt transect*	None	No	High
Supplementary measurements (Vol. II)			
Compaction test*	None	No	Low
Single-ring infiltrometer	None	No	Low
Plant production*	None	No	Low
Plant species richness*	None	No	Low
Vegetation structure*	None	No	Moderate
Tree density*	None	No	Low-High
Riparian channel vegetation survey	None	No	Low**
Riparian channel and gully profile	None	No	Low

* Please see notes below.
** Except in riparian zones, where priority is high.

Fire

The most common post-fire and fire recovery concerns are runoff, erosion and regeneration of the plant community. Runoff and erosion are expensive to measure directly. The Quick Start methods and indicators reflect changes in plant communities and in the risk of runoff and erosion. Consequently, the basic measurements often can be applied to post-fire recovery monitoring with relatively little modification.

The method modifications described here are based on experience from northern New Mexico in grasslands invaded by piñon pine, juniper, oak and/or ponderosa pine. Additional modifications may be useful in other ecosystems.

Fire notes

Line-point intercept. The Line-point intercept can be applied with little modification. For savannas and woodlands with significant coarse woody debris, it may be useful to split the woody litter class (WL on the Line-point Intercept Data Form) into multiple size classes. Where short-term mortality estimates are required, the height column from the Line-point Intercept with Height Data Form (Ch. 15) can be changed to "Dead?" and used as a checkbox. However, mortality may be more precisely quantified using the Belt transect method, especially for woody species. Differentiating between dead and live herbaceous plants is normally not recommended because of the high level of uncertainty associated with these assessments. In addition, plant mortality is usually more accurately reflected in increased bare ground and reduced plant cover the following year.

Gap intercept. Gap intercept is one of the more useful measurements for monitoring post-fire recovery. It distinguishes between recovery occurring uniformly across a site, and recovery concentrated in dense vegetation patches. Some organizations have modified the Gap intercept method to include embedded litter because of its role in helping to slow runoff. Embedded litter is assumed to have a similar effect on runoff as a plant base does. While this may be true for systems in which litter is firmly anchored to the soil by fungal mats, it is probably not appropriate in all cases. Coarse woody debris can also act like a plant base where it is in direct contact with the soil surface.

Soil stability test. Prescribed burns rarely cause short-term changes in soil stability. Stability can begin to decline over time, however, if plant recovery is slow. This is due to reduced root, fungal and litter inputs necessary for soil aggregate formation.

Intense fires where a large amount of fuel is burned at the soil surface can actually increase soil stability by making it hydrophobic. Unfortunately, because these surfaces repel water, they ultimately increase erosion downslope because they increase surface runoff. Other factors can contribute to hydrophobicity, including high fungal concentrations. Hydrophobicity can be easily quantified by recording the number of soil stability samples that float when they are placed in water.

Belt transect and Tree density. The Belt transect and Tree density methods can be used to quantify mortality and recruitment by simply recording live and dead individuals, and new seedlings, in different columns. The Belt transect method is also useful for monitoring the invasive plant populations after they have become established (see "Invasive species," Chapter 23).

Compaction. Fire does not cause compaction. However, fire-fighting activities often do, especially when vehicles are driven off road. In addition to the burned area itself, firebreaks and access points for fire crews should be considered for inclusion in post-fire recovery monitoring. Where time permits, infiltration may also be measured.

Plant production. Please see the discussion in "Livestock production notes" (Chapter 19).

Plant species richness. Please see the discussion in "Riparian notes" (Chapter 18).

Vegetation structure. Vegetation structure indicators can be used as a relative indicator of the presence of "ladder fuels" in savannas. Taller herbaceous plant material and low branches facilitate the movement of ground fires into tree canopies.

Additional resources

In the past, fire recovery monitoring was traditionally limited to photographs and occasional quadrat or transect measurements. Funding was rarely available for repeated measurements, or to develop and test protocols. Increased interest in response to large burned areas has sparked the development of a large number of monitoring systems, many of which are becoming available on the Internet. Many of the systems consist of separate methods for each monitoring objective (runoff, erosion, wildlife, vegetation, etc.). Where possible, the methods should be combined in order to limit costs associated with redundant measurements.

Chapter 23

Invasive species

Invasive species may be the most important, ecologically sensitive and profitable single factor to monitor in many areas. The amount of money that can be saved through early detection of a new population can often exceed the current value of the land. Unfortunately, establishment can be difficult to detect remotely, and it is impossible to search every acre every year. The following protocol can be used to reduce monitoring costs while increasing the probability of early detection. It is based on rapid assessment of nonpermanent plots in areas with a high risk of invasion.

The methods included in this manual can be used to address two objectives related to invasive species:

(1) To monitor changes in invasive species after they have become established (Belt transect for low cover and Line-point intercept for high cover).

Photo by Mike Pellant

Figure 23.1. Cheatgrass grassland with sagebrush.

(2) To monitor changes in the susceptibility of a site to invasion (Line-point intercept and Gap intercept) where there is a high risk of seed dispersal, or it is known that invasive species already exist in the seed bank.

The "Invasive Species Detection Protocol" at the end of this chapter is designed to detect invasive species in the early stages of establishment on a site.

Table 23.1. Guidelines for applying methods to invasive species monitoring.

Quick Start measurements (Vol. I)	Modifications	Additional indicators	Typical priority
Photo points	None	No	Moderate
Line-point intercept*	Possibly add disturbed soil as soil surface class	No	Moderate
Gap intercept*	None	No	Moderate
Soil stability test	None	No	Low
Belt transect*	Increase search area	No	High
Supplementary measurements (Vol. II)			
Compaction test	None	No	Low
Single-ring infiltrometer	None	No	Low
Plant production*	None	No	Moderate
Plant species richness*	None	No	Low
Vegetation structure	None	No	Low
Tree density	None	No	Low
Riparian channel vegetation survey	None	No	Low
Riparian channel and gully profile	None	No	Low

* Please see notes below.

Invasive species notes

Line-point intercept. The Line-point intercept method can be used to quantify invasive species cover changes where the species is a significant component of the plant community (generally greater than five percent cover). Line-point intercept cover and composition indicators also often reflect the resistance of a site to invasive species establishment.

The plant community can affect resistance directly by competing with the invasive species. It can affect resistance indirectly through its effects on herbivore populations and soil microbial communities. It can also indirectly affect resistance to invasion through its effect on the timing, frequency and intensity of disturbances, which then modify conditions for establishment of both invasive and non-invasive species. Relevant indicators are site specific and may include percent bare ground or percent cover of a particular functional group.

Gap intercept. The proportion of the land covered by large gaps in foliar or basal cover directly affects invasive plant establishment through its effect on competition and soil stability. It can indirectly affect invasive plant establishment through its effects on small herbivore activity and larger scale disturbances such as fire. No new indicators are required, but the gap sizes of interest may vary depending on species.

Belt transect. The Belt transect is one of the most rapid methods for monitoring invasive species that cover too little area to be reliably detected with the Line-point intercept method (generally less than five percent cover). It can also be used to quantitatively monitor the appearance of small seedlings where it is known that the species already exists in the seedbank, or where there is a high risk of introduction.

Plant production. Please see the discussion in Chapter 19, "Livestock production notes."

Plant species richness. Please see the discussion in Chapter 18, "Riparian notes."

Invasive Species Detection Protocol

(1) ***Use existing information to stratify the landscape into areas that have an inherently high invasion risk for each species, based on soil and climate***. Ecological Site Descriptions (Chapter 2) can be extremely helpful and often list potentially invasive species. Aerial photographs and other remote sensing tools can be extremely useful in developing risk-based landscape stratification.

(2) ***Within high risk monitoring units, identify areas most susceptible to invasion***. This analysis should be based on risk of dispersal (the risk that seeds will be brought to the site) and risk of successful establishment (the probability seeds will land in an area favorable for establishment). For example, trails are highly susceptible to invasion. Trails have an increased risk of invasion because of the high probability of dispersal from distant plant populations. Trails are also at risk because trail margins are often disturbed, reducing competition against invasives.

(3) ***Identify additional high-risk areas each year.*** For example, the establishment of a new campground, road or mineral survey operation can increase the risk of invasive species establishment. Again, aerial photographs and other remote sensing tools can be invaluable in this process.

(4) ***Randomly select areas for ground-based surveys based on risk analyses in 1 through 3 above.***

(5) ***Visit each area and complete a rapid assessment that includes the following:***
- Estimate and record presence, number and size of invasive species.
- Predict the probability that population size will increase for all invasive species encountered, based on site characteristics, climate and disturbance regime.
- Evaluate future invasion risk, including the need to return to the area within a specified period of time.
- Record GPS locations of invasive plants and populations.

(6) ***Revise risk analysis (steps 1 through 3) based on field observations***.

Chapter 24

State and transition models: an introduction

State and transition (S&T) models (Figs. 24.1 and 24.2) illustrate possible changes in plant communities and soil properties and their interactions. They can be used, together with assessments of the current status, to help decide *where* to monitor based on where change is most likely to occur. They can also be used to help decide *what* to monitor, because they often provide information on soil and vegetation changes that are likely to precede a change in state. States are distinguished by transitions, which may be relatively irreversible, reflecting a significant increase in energy required to shift back to the previous state.

Individual S&T models are usually developed for each ecological site. Ecological sites are defined as land that has a similar potential to support a particular range of plant communities based on soils and climate. Land included in each ecological site is expected to respond similarly to different types of disturbance, climate and management.

State and transition models generally include at least two states, and one or more plant community within each state. Plant communities within a state are similar in their species compositions. Plant communities within a state are generally functionally similar in their capacity to limit soil loss, cycle water and produce vegetative biomass. Changes among plant communities within states are considered to be reversible through simple changes in grazing management (in grazed ecosystems) or fluctuating climatic conditions. The S&T diagrams (Fig. 24.1) show possible transitions between states. The diagrams also illustrate the factors that increase the probability that changes will occur. Transitions between states are reversible only through generally costly, intensive practices such as shrub removal or soil modification.

The NRCS, BLM, The Nature Conservancy and other organizations are currently developing state and transition models, and similar types of models. Many are available from NRCS. Please contact your local NRCS field office or refer to the NRCS website for state and transition models pertaining to your ecological sites. All indicators described in this manual can be used to help quantitatively define states and the probability that transitions will occur. For more information on the development of these models, see Bestelmeyer et al. (2003) and Stringham et al. (2001).

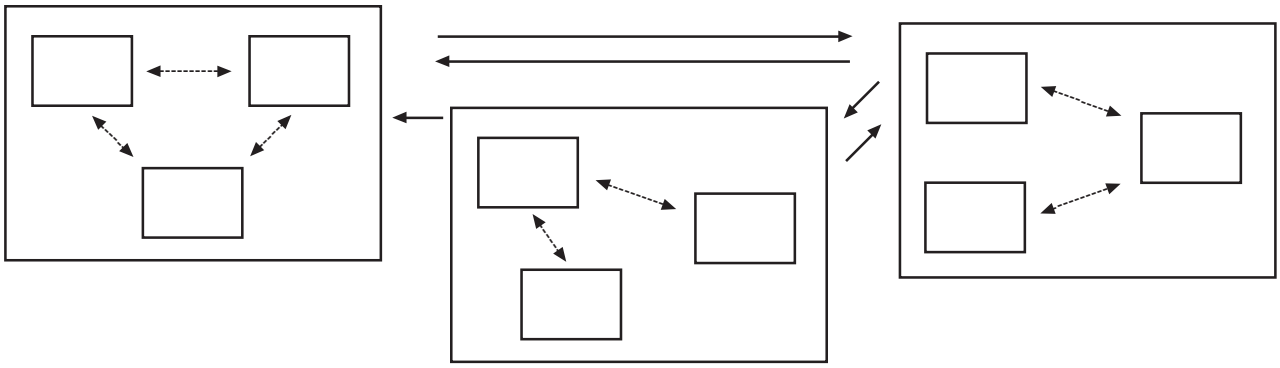


Figure 24.1. Typical state and transition model structure (based on Bestelmeyer et al. 2003 and Stringham et al. 2003). Large boxes are states defined by relatively irreversible transitions. Small boxes within states represent plant communities. Transitions (dashed lines) are relatively reversible. Single-state systems are possible where no thresholds have been identified.

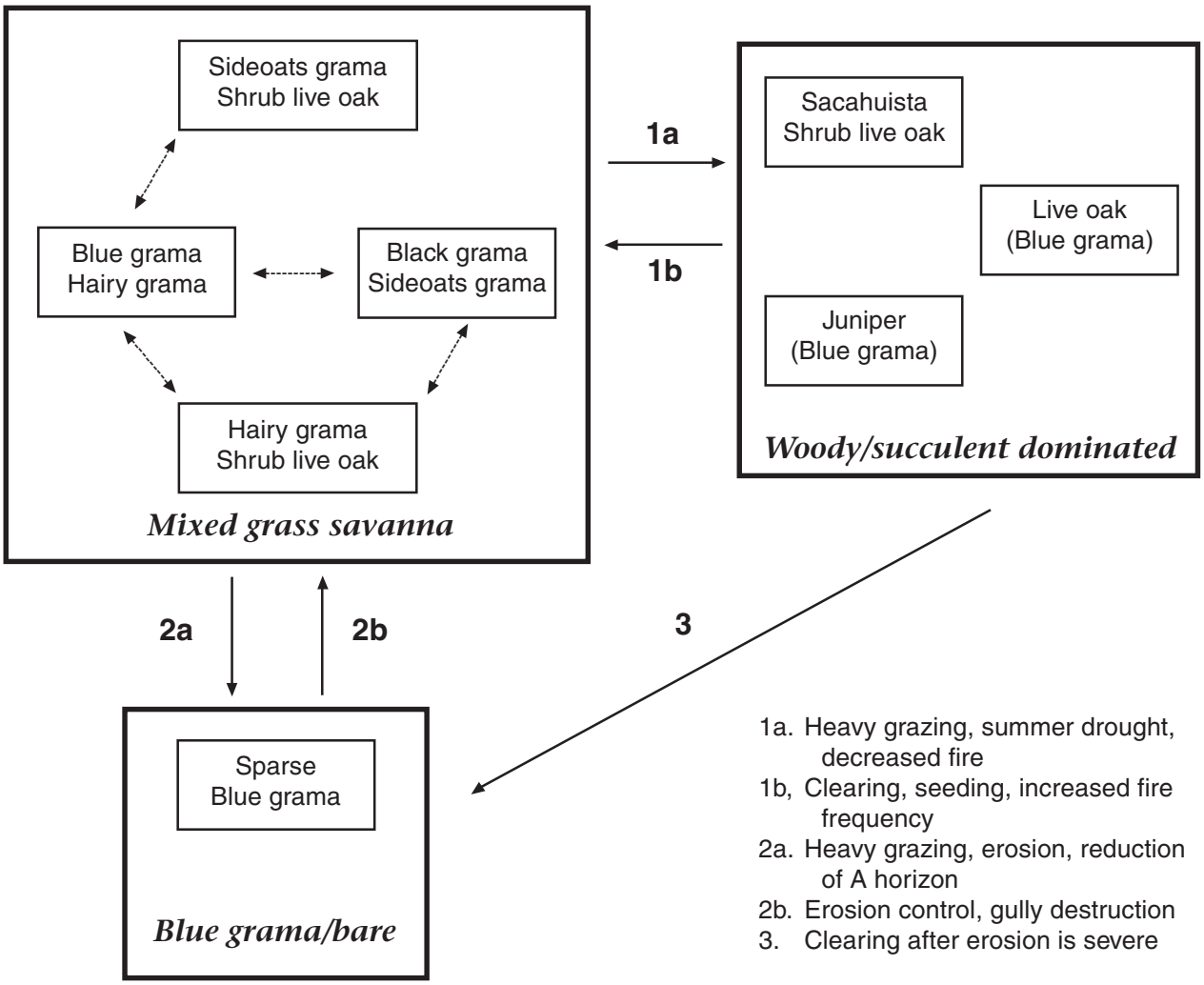


Figure 24.2. State and transition conceptual model for the "Breaks" ecological site in west-central New Mexico (Major Land Resource Area 36, Land Resource Unit WP-3). General structure follows Bestelmeyer et al. (2003) and Stringham et al. (2001, 2003). See description on following page.

Description for state and transition model for an ecological site ("Breaks") in west-central New Mexico (MLRA WP-3) (Fig. 24.2).

Overview

The Breaks sites intergrade with Hills sites and often contain Loamy sites occurring as narrow to broad drainageways. The historic plant communities of the Breaks sites are dominated by black grama (*Bouteloua eriopoda*) and sideoats grama (*Bouteloua curtipendula*) and/or blue grama (*Bouteloua gracilis*) among others, depending on soil types and aspect. Under heavy grazing pressure, especially on steeper slopes and on soils with strong argillic (clay-rich) horizons, erosion may lead to a persistent loss of vegetation. A decline in fire frequencies, or perhaps regional increases in the relative amount of winter rainfall or grazing, may lead to significant increases in the abundance of woody plants and succulents including sacahuista (*Nolina microcarpa*), shrub liveoak (*Quercus* spp.), and one-seed juniper (*Juniperus monosperma*). The established woody plants may compete with grasses and lead to persistent reductions in grass abundance. No systematic studies of communities, states or transitions have been performed in the Breaks site.

Catalog of states, community pathways, and transitions

Mixed-grass savanna: The expression of the community depends upon aspect and soil. On south-facing slopes, black grama tends to dominate and there may be some sideoats grama among other grasses. On north-facing slopes, sideoats grama dominates, with blue grama and hairy grama (*Bouteloua hirsuta*) as subordinates; black grama occurs in smaller amounts. In some cases (especially west of Silver City), sacahuista (*Nolina microcarpa*) may be dense enough to be considered a secondary dominant. Live oak, sacahuista, and juniper exist in low densities giving the site a savanna aspect. Grazing and drought-induced mortality may lead to reductions in black and sideoats grama and dominance by hairy grama, blue grama, or annuals.

Diagnosis: Sacahuista, oak and juniper are present and scattered; most of the ground surface is grassy, with few large bare areas.

Transition to woody/succulent-dominated state (1a): It is unclear why succulents or trees increase in abundance, although it is likely that the subsequent decline in grasses is due to competition for water and nutrients. The formation of bare ground patches due to grazing, decreases in fire frequency, and increases in winter precipitation, either independently or in concert, may be responsible for the transition.

Key indicators of approach to transition: Increases in bare ground, decreases in litter cover and grass cover, increased frequency of oak seedlings and small sacahuista (threshold may have been crossed), decreased fire frequency.

Transition to blue grama/bare state (2a): Heavy grazing, especially in drought conditions on steeper slopes and on soils with shallow, strong argillic horizons (e.g., Lonti gravelly loam) may result in grass loss and subsequent erosion of the organic matter-rich A horizon.

Key indicators of approach to transition: Increases in bare ground, decreases in litter cover and grass cover, surface soil loss, water flow patterns, rills, pedestalling of plants and stones.

Woody/succulent-dominated: Grass cover is often highly reduced and shrubs, trees, or succulents become dominant. Bare ground is extensive, and scattered, small blue grama or hairy grama plants represent the dominant grass cover. West of Silver City, sacahuista tends to dominate in this state, and liveoak may or may not be a secondary dominant. In other cases, juniper or oak may dominate.

Diagnosis: Oak, sacahuista, and/or juniper are the dominant perennial species and the bare ground areas between them are interconnected. Grass clumps are small and scattered. Evidence of erosion (rills, water flow patterns, pedestalling) is common.

Transition to woody/succulent-dominated state (1b): Thinning of woody or succulent species may release grasses from competitive suppression and grasses may colonize patches where trees or sacahuista were present. If erosion in interspaces has not been severe, recolonization may take place there over several years.

Transition to blue grama/bare state (3): Tree and succulent removal, especially on slopes, may accelerate erosion if grasses do not respond to the treatment and the soil is exposed to raindrop impact and erosion.

Blue grama/bare: This state is characterized by extreme erosion and tends to occur on steeper slopes. Bare ground cover is extreme, gullies may be present, and few small perennial plants, usually blue grama, are present. Trees and succulents are not especially abundant.

Diagnosis: Bare ground is interconnected, and trees and succulents are not especially abundant. Evidence of erosion is common, the mollic A horizon is very shallow (a few cm) or missing.

Transition to mixed grass savanna state (2b): The placement of structures (e.g., terraces) to retard erosion and that accumulate soil, in addition to the destruction of gullies, may be used to initiate the eventual recovery of perennial grass dominance.

Information sources and theoretical background: Communities, states, and transitions are based upon information in the Ecological Site Description and observations by Gene Adkins, NRCS and Brandon Bestelmeyer, USDA-ARS Jornada Experimental Range.

Chapter 25

Remote sensing

Remote sensing includes any data that are collected remotely, including aerial photographs, satellite imagery and digital elevation models generated from aircraft or satellites.

Remote sensing can increase the quality and cost-effectiveness of monitoring programs in a number of different ways. It can be used to stratify the landscape into relatively homogeneous units, to extrapolate ground-based measurements and, in some cases, to quantify properties and processes in the absence of ground-based measurements using previously established relationships.

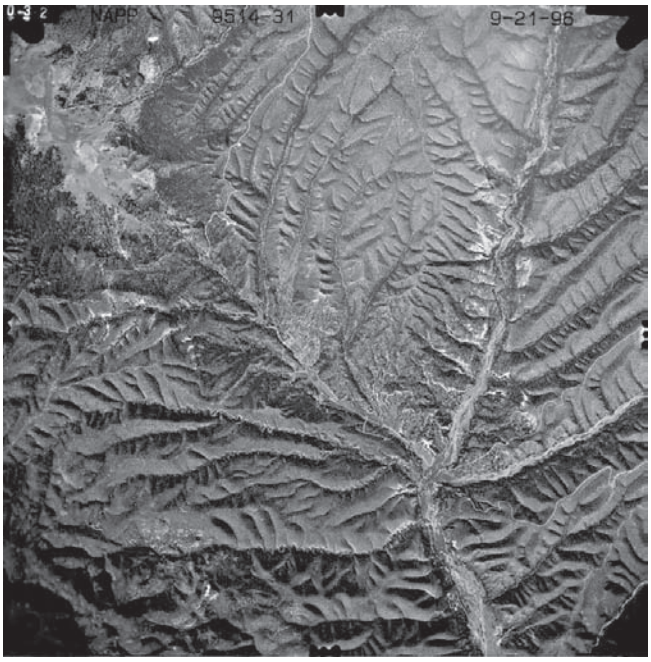


Figure 25.1. Example of a color IR aerial photo of Mimbres Watershed.

Increasing monitoring cost-effectiveness with remote sensing

Incorporating remote sensing imagery into the monitoring design process at an early stage can dramatically increase cost-effectiveness and reliability. It helps to focus monitoring on representative areas with a high potential for change, while avoiding areas that have already crossed a threshold. Although imagery used for this step should be as recent as possible, the actual date is not as critical for the monitoring design step as when used as monitoring data. Additionally, variability in image quality is much less critical than when the imagery is being used directly for monitoring.

Options for incorporating remote sensing into monitoring programs are summarized in Table 25.1. Option 1 can be done with or without GIS knowledge. Options 2 and 3 (Table 25.1) require training or extensive experience in remote sensing and GIS. Option 3 is difficult, but not impossible, to apply to larger areas. It can be more easily applied to relatively small areas (farms, ranches or conservation areas). All three options often can be applied together.

Option 1. It is appropriate to use remote sensing imagery for monitoring unit stratification and extrapolation where the imagery lends itself to visual classification of geomorphic and vegetation units. During stratification, use remote sensing imagery (e.g., aerial photographs), together with other available spatial data, to stratify the landscape into relatively similar landscape units (Figs. 2.1 through 2.4 in Ch. 2). Where possible, further subdivide landscape units based on current vegetation, management and the status of the three ecological attributes (soil and site stability, hydrologic function and biotic integrity).

The next step in stratification is to combine these spatial data with state and transition models (Bestelmeyer et al. 2003; Briske et al. 2003; Stringham et al. 2001, 2003) and information on current and potential drivers (Brown and Havstad 2004). All of this information can be used to identify landscape units with a relatively high potential for degradation or recovery.

Extrapolation using remotely sensed data requires an adequate number of plots to represent the landscape. Develop a good relationship between these ground-based measurements and remote-sensing indicators. If this is not feasible, it is possible to extrapolate using remotely sensed imagery if extensive, long-term knowledge of the landscape, its ecological communities, and their interactions and drivers exists.

Table 25.1. Comparison of options for integrating remote sensing into ground-based monitoring programs. For a comparison of different types of imagery, see Muchoney and Unnasch 2001.

Option	Application	Imagery type and scale	Knowledge	Cost
1	Monitoring unit stratification for increased sampling efficiency	Air photos (any time in last ten years)	Ability to visually classify geomorphic and vegetation units	Low
2	Coarse-scale extrapolation based on repeated, ground-truthed imagery	Landsat, MODIS and other multispectral imagery that is regulary generated and archived	Ability to process and classify multispectral data	Med.
3	Fine-scale extrapolation based on repeated, ground-truthed imagery	QuickBird, IKONOS, air photos and other single band and multispectral imagery	Ability to process and classify multispectral data	High

Option 2. The ability to make coarse-scale extrapolations based on repeated, ground-truthed imagery depends on the scale of the imagery and the scale of the vegetation heterogeneity and dynamics. Imagery and ground-based data must be collected in the same time frame (either within the same month or within the same season). Expertise in image classification is required for this option.

Option 3. Fine-scale extrapolation based on repeated, ground-truthed imagery has the same requirements as described in Option 2, but to a higher degree. Fine-scale extrapolation requires the highest level of GIS expertise, field sampling, and image quality. Imagery must be at a fine enough resolution to detect the same community level changes as the ground-based measurements. Defining the relationship(s) between the field-based indicators and remote-sensing indicators can be challenging. It can even, at times, be impossible (see "Monitoring with remote sensing alone" below).

Monitoring with remote sensing alone

A fourth option for incorporating remote sensing into monitoring programs is to use predefined relationships between remote sensing indicators and ground-based measurements. This option is problematic because of the high spatial and temporal variability in soil and vegetation relationships. Confounding this factor is the relatively low vegetation cover typical for rangelands. In addition, vegetation reflectance and temperature change rapidly and unpredictably in response to highly variable soil moisture. All of these caveats make monitoring solely via remote sensing in arid and semi-arid communities challenging.

New techniques that take advantage of greater computing power, higher resolution images and integration of information using different types of images are currently being developed at the Jornada Experimental Range and elsewhere (Rango et al. 2003). While these techniques are likely to be more sensitive and reliable, it is unlikely that we will ever be able to design comprehensive monitoring programs based exclusively on remote sensing. Periodic ground-truthing is likely to be required for most applications.

Conclusions

By using remote sensing imagery primarily to improve monitoring program design, we exploit the strengths of remote sensing technologies. Using remote sensing imagery only for stratification allows us to avoid the pitfalls of over-

reliance on relatively abstract indicators, many of which require new ground-based calibration data for each new set of imagery. By combining remote sensing with qualitative assessments and state and transition models, we can target both management and monitoring to those parts of the landscape with the highest probability of change. Where it is possible to obtain repeated, concurrent ground-based and remote-sensing data, imagery can be used to generate a more precise extrapolation than is possible with the initial stratification alone. However, the ability to make such extrapolations is tightly linked to the type of vegetation community and the resolution of the imagery.

Parts of this Chapter were adapted from Herrick et al. (2003).

Chapter 26

Soil carbon

Soil carbon can be a useful and accessible long-term indicator of change in the functioning of an ecosystem. Soil carbon is directly related to soil organic matter content, a key indicator of soil quality. Soil organic matter is important for maintaining soil structure. Soils with good soil structure generally have lower erosion rates, higher water infiltration rates and higher water-holding capacities. Soil organic matter also serves as an important nutrient reservoir.

Typically, increasing soil carbon has positive effects on soil and ecosystem health. But simply increasing soil carbon may not always be the land management goal. For instance, replacement of grasslands by woody-dominated plant communities may increase total carbon sequestration at the landscape level, but reduce soil quality near the soil surface in plant interspaces. This reduction in soil quality associated with woody plant invasion is particularly common in arid ecosystems.

Carbon sequestration

In addition to being a good indicator of soil quality, sequestering (storing for long periods) carbon in the soil keeps it out of the atmosphere, where it occurs as carbon dioxide and contributes to the greenhouse effect and global warming. The United States has adopted a market-based approach to provide incentives for reducing greenhouse gases in the atmosphere. Efforts are currently underway to establish standard systems for "trading" carbon released into the atmosphere (e.g., from fossil fuel combustion) for additional carbon stored in the soil as soil organic matter. From a practical perspective, this means that carbon producers (e.g., power plant operators) can purchase credits in a market. Those credits may be supplied by a variety of sources, including increased soil carbon sequestration. However, formal trading procedures are not currently in place and the details are still uncertain.

Figure 26.1 Soil organic matter and soil carbon are usually higher near the soil surface.

In most cases, meeting land management objectives will require tracking changes in soil carbon over time. There are three options for carbon monitoring: measurement, modeling, and monitoring changes in vegetation cover, composition and production.

Soil carbon measurement is currently too expensive in most arid and semi-arid ecosystems. This is due to a combination of high sampling and analysis costs and the large number of samples required to detect a change.

Soil carbon models predict changes in soil carbon based on soil properties, current vegetation and climate. However, most available carbon models focus on agricultural, forest and grassland ecosystems, and do not reliably predict soil carbon dynamics in diverse arid and semi-arid ecosystems. Given their drawbacks, carbon measurement and modeling are not yet recommended as viable monitoring options. However, the accuracy of both measurement and modeling is improving. Cost-effective rangeland carbon monitoring systems integrating the two approaches should be available within the next decade.

A third, more practical, option for the present time is to simply monitor changes in vegetation cover and composition (Line-point intercept method) and production (Plant production method). These indicators cannot currently predict

Table 26.1. Guidelines for applying monitoring methods to soil carbon monitoring.

Quick Start measurements (Vol. I)	Modifications	Additional indicators	Typical priority
Photo points*	None	n/a	Moderate
Line-point intercept*	None	Yes	High
Gap intercept*	None	No	Moderate
Soil stability test*	None	No	Moderate
Belt transect*	None	No	Moderate
Supplementary measurements (Vol. II)			
Compaction test	None	No	Low
Single-ring infiltrometer	None	No	Low
Plant production	None	No	High
Plant species richness	None	No	Low
Vegetation structure	None	No	Low
Tree density*	None	No	Moderate
Riparian channel vegetation survey	None	No	Low
Riparian channel and gully profile	None	No	Low

* Please see notes below.

soil carbon changes, but they are associated with changes in carbon inputs. In general (but not always), soil carbon increases with cover and production. In systems in which a significant portion of the production is consumed by livestock or wildlife, utilization records ("Short-term monitoring" in Quick Start) should also be carefully maintained.

Carbon notes

Photo points. Soil profile photos showing near-surface carbon accumulation where accumulation rates are high can supplement vegetation photos. They can help substantiate changes recorded in the quantitative soil and vegetation data. They are also useful communication tools.

Line-point intercept. Line-point intercept data are used in models to estimate carbon inputs. Both cover and species composition are required for carbon models.

Gap intercept. Gap intercept may be used as an index of soil erosion risk. The highest concentration of soil organic carbon is usually in the top ten centimeters (4 in), which is also the layer that is most susceptible to soil erosion.

Soil stability test. Soil stability is closely related to the creation of new soil organic matter, and may be a good early warning indicator of changes in total soil organic carbon. However, the relationship between soil stability and soil organic carbon is highly variable. It should only be used as a general indicator to compare among management systems. When testing for soil stability as an indicator of soil carbon, be sure to test soil from different depths. In many arid soils, the stability of the top few millimeters of the soil surface is stabilized by cyanobacteria. Changes in cyanobacterial biomass are not necessarily related to changes in root production, which is the primary source of soil organic matter in most rangeland ecosystems.

Belt transect and Tree density. Changes in both the density and cover of shrubs and trees have the potential to significantly modify soil carbon sequestration. Either of these two methods, Belt transect or Tree density, can be used to detect

changes in woody species when cover is below that which can be monitored using Line-point intercept methods (generally five percent).

Additional resources

Guidelines for soil carbon monitoring are currently in the process of being established. Because this field is so dynamic, the best approach to locating the most current and relevant resources is an Internet search, focusing on those resources that include evaluations of the cost, accuracy and precision of the proposed methods. A recent Council on Agricultural Science and Technology report (CAST 2004) provides a good overview of many of the issues associated with soil carbon sequestration. For information on CENTURY, one of the models currently being applied in the United States, see www.nrel.colostate.edu/projects/century5/reference/html/Century/desc-intro.htm (accessed June 23, 2008).

Appendix A: Monitoring tools

Measuring tapes, stakes and flags are available through most hardware stores and natural resource supply catalogs. Manufacturers of, and instructions to build, less widely available tools are listed below. Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture. The tools are not patented. None of the authors receive any compensation from manufacturers.

Caution. Fabrication of these tools, like any shop fabrication project, can result in injury. If you are not comfortable with the required procedures and standard safety protocols, *find someone who is*.

Table A.1. List of specialized tools used in methods described in the manual.

Tools	Manufacturers (as of June, 2004)
Soil stability kit*	Synergy Resource Solutions
Impact penetrometer*	Darbyshire Machine Synergy Resource Solutions
Single-ring infiltrometer*	Synergy Resource Solutions
Cover pole*	Synergy Resource Solutions
Riparian channel vegetation survey pole*	Synergy Resource Solutions
Laser pointer for Line-point intercept	Synergy Resource Solutions

* Instructions for constructing these tools included below.

Manufacturer contact information:

Darbyshire Machine, Inc.
P.O. Box 4410, Anthony, NM 88021
1-800-291-6818 —darby@darbyshire.com
www.darbyshire.com

Synergy Resource Solutions, Inc.
5393 Hamm Rd., Belgrade, MT 59714
406-388-9378 —Synergy@countgrass.com
www.countgrass.com

Soil stability kit (Quick Start)

Materials needed for construction of stability kits:

- Schedule 40 PVC pipe with a $^3/_4$ in inside diameter
- PVC pipe cutter and hacksaw
- Tape measure and pencil
- A section of metal window screen (mesh size approx. 1.5 mm [$^1/_{16}$ in])
- A bottle of water-resistant contact cement
- A plastic trash bag
- 2 plastic "parts" boxes (21 x 11.5 x 3.5 cm outside dimensions [8 $^1/_2$ x 4 $^{15}/_{32}$ x 1 $^5/_{16}$ in]) with 18 cells, approximately 3 x 3 x 3 cm each (1 $^1/_4$ x 1$^1/_4$ x 1 $^1/_4$ in each)
- One small tube of silicone sealant
- A small piece of sheet metal, handle of an old spoon, or pocket knife

1. Stability basket construction.

1.1 Cut pieces of PVC pipe into 3 cm (1 $^1/_4$ in) lengths.

1.2 Make a 2 cm deep, cross-sectional cut, 5 mm from one end (Fig. A.1).

1.3 Make the second cut perpendicular to the first, ending at the end of the cross-sectional cut in step 1.2 (Fig. A.2). This forms the basket handle.

1.4 Remove burrs from all cuts.

1.5 Lay out a section of window screen on top of a plastic trash bag. Make sure the screen is flat and has no creases.

1.6 Apply contact cement to the bottom of the cut PVC and quickly place on top of the screen (Fig. A.3). Apply glue only in areas with adequate ventilation.

1.7 Allow contact cement to dry overnight.

1.8 After 24 hours, remove the plastic trash bag from the screen. Cut out each basket from the screen (Fig. A.4).

2. Plastic box preparation.

2.1 If the plastic box has removable parts, be sure to glue them into place.

2.2 Use silicone caulk or sealant to seal all corners inside the box.

3. Stability shovel construction.

3.1 Using tin snips, cut out the shape of the stability shovel from a piece of thin sheet metal, tin can, aluminum weighing tin or similar material with a thickness of 1 mm ($^1/_{32}$ in) or less (Fig. A.5).

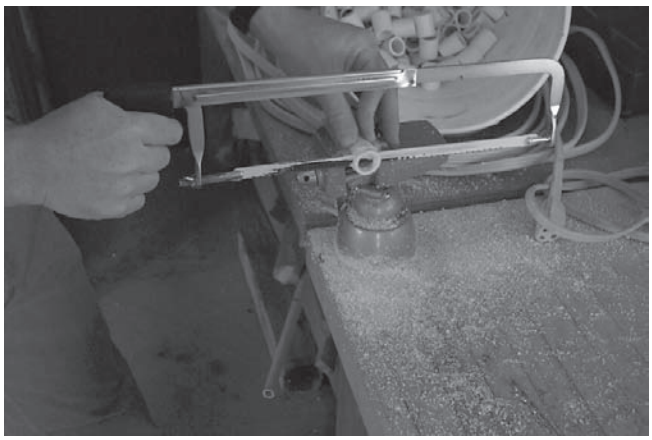


Figure A.1. First cut on PVC.

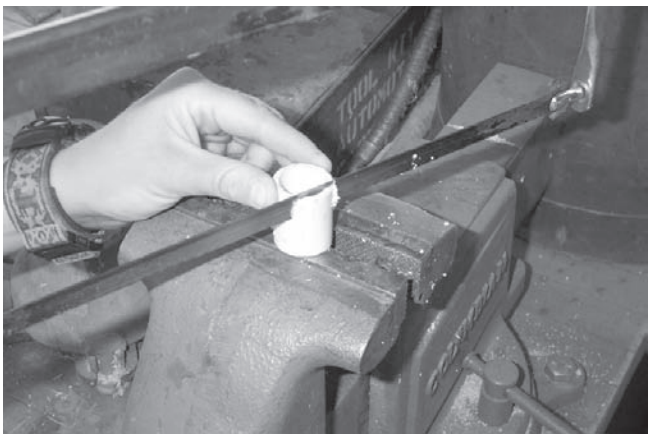


Figure A.2. Second cut on PVC.

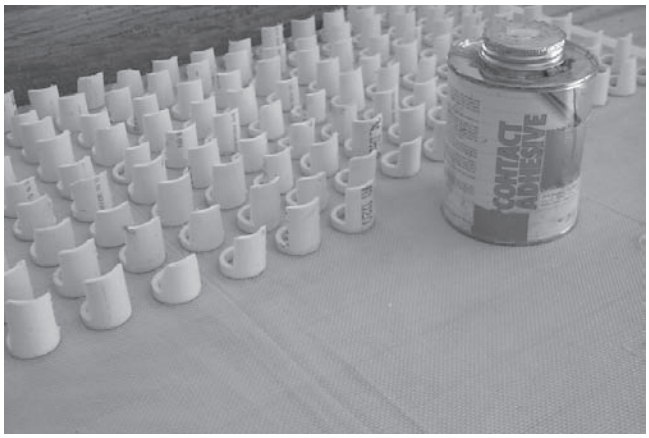


Figure A.3. Baskets glued to screen.

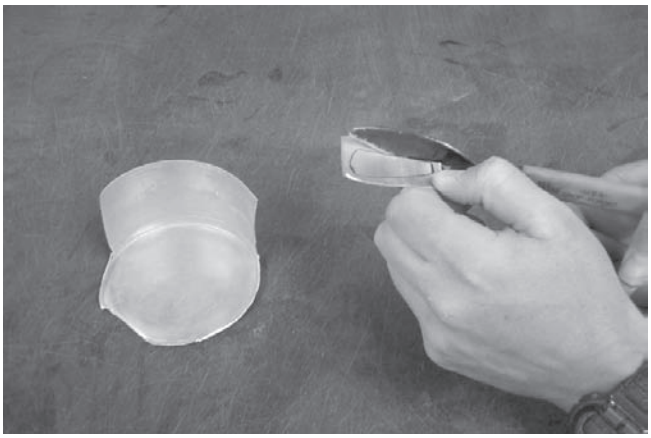


Figure A.5. Cutting shovels with tin snips.

Figure A.4. Cutting out baskets from screen.

Impact penetrometer (Chapter 7)

Materials needed for construction of impact penetrometers:

- 0.625 in (15.9 mm) diameter steel rod 60.0 in (152.40 cm) long
- Removable steel cone, hardened and smoothed to a shiny finish (see Fig. A.6 for dimensions)
- 2.0 kg sliding steel hammer, 15.75 in (40 cm) long with internal diameter of 0.688 in (17.5 mm) and external diameter of 2.0 in (5.1 cm)
- 0.5 in (12.7 mm) thick steel striker plate with 1.25 in (3.18 cm) external diameter
- Adjustable steel collar

Note:
Most machine shops should be able to construct the impact penetrometer from Figure A.6 and the instructions below.

1. Steel penetrometer rod construction.

1.1 The 60 in (152.4 cm) steel rod is 0.625 in (15.9 mm) in diameter and is constructed of 2 pieces (Fig. A.6).

1.2 Etch the lower rod at 5 cm (1 $^{31}/_{32}$ in) increments, starting from the top of the cone and ending at 50 cm (19 $^{11}/_{16}$ in).

1.3 Thread the bottom of the upper rod (male) to join with the striker plate (female).

1.4 The striker plate extends 0.39 in (1 cm) out of the rod.

1.5 The upper rod contains the sliding steel hammer and adjustable steel collar.

2. Removable steel cone construction.

2.1 The removable steel cone is 0.015 in (0.38 mm) in radius at its point and 0.8 in (20.3 mm) in diameter at its base.

2.2 See Figure A.6 for cone angle specifications.

2.3 The base of the cone contains a threaded end (male) that connects to the lower, etched rod.

2.4 The cone is one seamless, hardened unit, and the cone is smoothed to a shiny finish (Fig. A.6).

3. 2.0 kg (4.51 lbs) sliding steel hammer construction.

3.1 The sliding steel hammer should be exactly 2.0 kg (4.51 lbs).

3.2 Stamp the exact weight on the hammer.

3.3 The steel hammer should be approximately 15.75 in (40.0 cm) in length, and must slide over the upper rod (Fig. A.6).

JORNADA IMPACT PENETROMETER

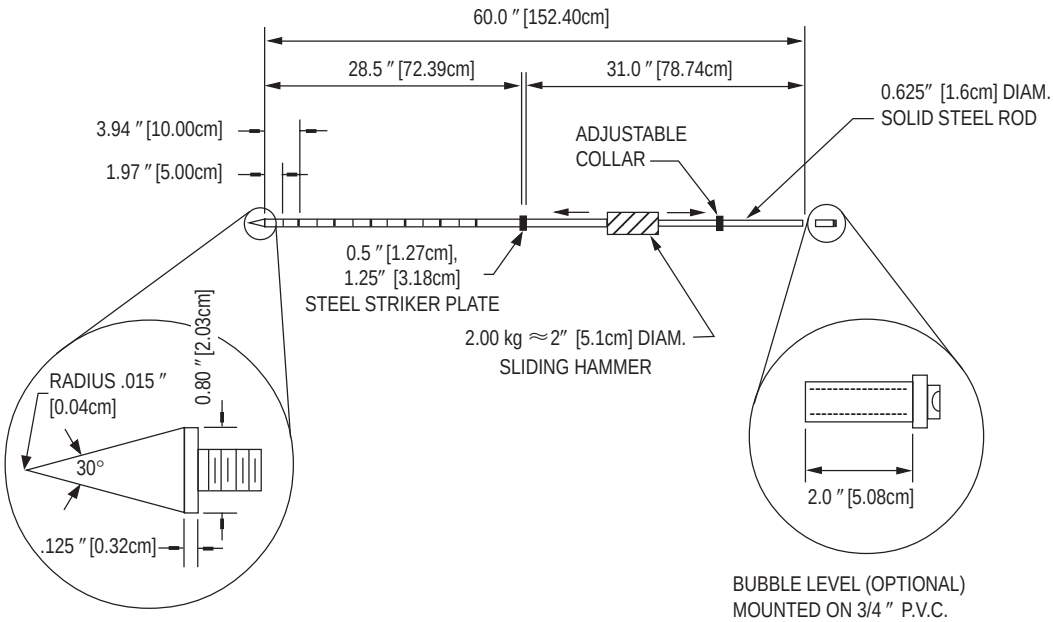


Figure A.6. Impact penetrometer design (Herrick and Jones 2002). All dimensions are in inches [cm]. Use steel for all parts except for the bubble level mount. Weld the striker plate to the center of a single rod, or to the bottom half of a two-piece rod. Thread the top half. Cut the cone, from steel, on a lathe and then harden. Shorten the penetrometer for transport by threading the bottom end of the top section of the shaft into the striker plate. Always wear protective clothing when using the penetrometer (ear plugs and heavy leather gloves).

Single-ring infiltrometer (Chapter 8)

Materials needed for construction of six infiltrometers:

- At least 72 cm (28 $^{11}/_{32}$ in) of 12.5 cm (5 in) diameter thin-walled (max 1.5 mm [$^{1}/_{16}$ in] thick) metal cylinders (irrigation pipe is ideal; stovepipe is OK provided that seams [if any] are sealed).
- 1 hacksaw
- 1 grinder or metal file
- Bath towels
- Two 20-oz plastic pop bottles
- Flexible plastic grocery bags
- One five-gallon bucket of water
- One 15 cm (6 in) ruler
- One stopwatch
- At least six (ideally 18) wide-mouthed, smooth-sided, 32-oz plastic soda bottles
- 18 to 20 gauge steel wire
- A drill and $^{29}/_{64}$ in or $^{7}/_{16}$ in bit
- At least six (ideally 18) plastic serological pipette tubes (10 ml in $^{1}/_{10}$)
- Silicone caulking
- Six 0.5 in (1 $^{5}/_{16}$ cm) rubber stoppers with a hole in the center that is slightly smaller than the diameter of the pipettes.
- Six thin rubber bands, large enough to stretch around the bottle
- Black felt-tip permanent marker

1. Infiltrometer ring construction.

1.1 Cut 12.5 cm (4 $^{15}/_{16}$ in) diameter irrigation pipe (or stove pipe) into 12 cm (4 $^{23}/_{32}$ in) lengths and remove burrs.

1.2 Sharpen the end that will be inserted into the soil to a 45° angle, using a grinder or metal file.

1.3 Drill 2 small holes, 5 mm (0.2 in) apart and 1 cm (0.4 in) below the top edge of the ring, at three equally spaced locations around the ring (Fig. A.7).

1.4 Thread wire through the rings so that a triangle is formed inside the ring (Fig. A.8).

1.5 Pull the wire tight.

1.6 Using a permanent marker, draw an insertion depth line around the outside of the ring, 3 cm above the bottom.

1.7 Repeat steps 1.1 through 1.6 until six (ideally 18) rings are constructed.

2. Infiltration bottle construction.

2.1 Remove the label from the 32 oz, wide-mouthed, smooth-sided soda bottle.

2.2 Drill a hole in the bottom center of the bottle that is slightly larger than the small end of the rubber stopper. The hole should be 12 mm in diameter. A $^{29}/_{64}$ in drill bit works best. A $^{7}/_{16}$ in drill bit will work, but requires widening the hole.

2.3 Position a rubber stopper in hole (Fig. A.9).

2.4 Slide a plastic pipette into the rubber stopper so the end is almost to the cap. Lubricate pipette with silicone grease.

2.5 Cut off the end of the pipette if it protrudes more than 10 cm (3.9 in) outside the bottom of the bottle.

2.6 Apply three 10 cm (3.9 in) beads of silicone caulking at equally spaced intervals around the bottle. Start at the top of the bottle and go to about its mid-section (Fig. A.10).

2.7 Using a marker, draw a line down the smooth portion of the bottle (Fig. A.11).

2.8 Slide the rubber band around the bottle.

2.9 Repeat steps 2.1 through 2.8 until six (ideally 18) bottles are constructed.

3. Accessories

3.1 Cut up bath towels into five 25 x 50 cm (10 x 20 in) pieces.

3.2 Cut the tops off of the two 20 oz plastic soda bottles. Draw a line indicating the 375 ml water level, using a permanent marker.

3.3 Cut the flexible plastic grocery bags into two 30 x 30 cm (12 x 12 in) sheets.

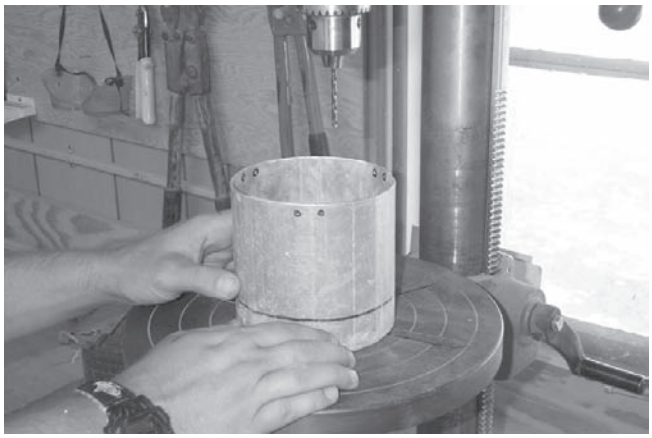


Figure A.7. Drill three equally spaced pairs of holes 1 cm from the top of the ring. Each hole should be 5 mm from its pair.

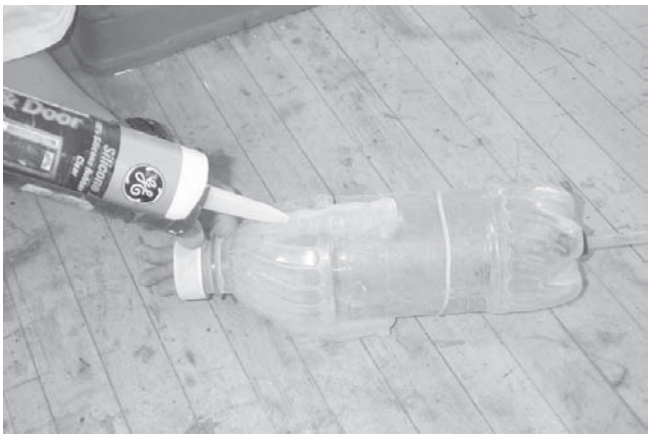


Figure A.10. Apply three 10 cm silicone beads from top of bottle to mid-section.

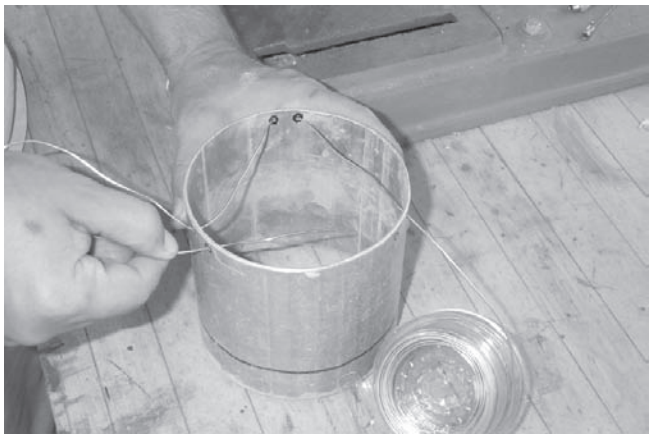


Figure A.8. Thread wire through holes and tighten.

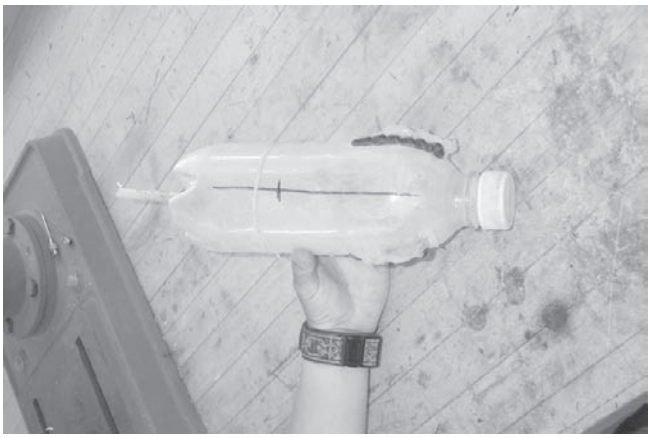


Figure A.11. Draw line along smooth length of bottle.

Figure A.9. Drill hole in bottom of wide-mouthed, 32 oz soda bottle and insert stopper.

Cover pole (Chapter 11: Vegetation structure)

Materials needed for cover pole:

- 2 m (78 $^{3}/_{4}$ in) of 1-in (2.5-cm) diameter PVC pipe
- One male-threaded PVC coupling
- One female-threaded PVC coupling
- PVC pipe cleaner, primer and glue
- One aluminum $^{3}/_{4}$ in (1.9 cm) wide tent stake
- One 1 in (2.5 cm) diameter PVC tube cap
- Masking tape
- Enamel paint (white, fluorescent orange, black)
- Spar-urethane glossy varnish
- Epoxy
- Drill with $^{1}/_{4}$ in (6 mm) drill bit
- Hacksaw

Materials needed for sight pole:

- 1.1 m (43 $^{5}/_{16}$ in) of $^{1}/_{2}$ in (1.3 cm) PVC pipe
- Two $^{1}/_{2}$ in (1.3 cm) PVC tube caps

1. Cover pole construction:

1.1 Cut the 1 in (2.5 cm) diameter pipe into two 1 m (39 $^{3}/_{8}$ in) lengths.

1.2 Attach male coupling to pipe, using the cleaner, primer and glue.

1.3 Repeat process with other pipe half and female coupling (Fig. A.12).

1.4 Connect two halves at coupling.

1.5 Measure and trim the connected pipe back to a 2 m (78 $^{3}/_{4}$ in) length.

1.6 Drill one hole each at 1 in and at 2 in (2.5 and 5 cm) above the bottom of the pipe. Each hole should be $^{1}/_{4}$ in (6.4 mm) in diameter.

1.7 Cover all holes, except for the one at the 2 in (5 cm) level, using the masking tape.

1.8 Drill two $^{1}/_{4}$ in holes into the tent spike in the area that will be between the end of pipe and the 2 in hole.

1.9 Insert tent spike into the bottom of the pipe so that at least 3 in of the spike protrudes below the end of the pipe (in areas with very loose topsoil increase protruding spike length).

1.10 Using masking tape, seal the bottom of the pipe to hold the spike in place and inject epoxy into one of the open holes until epoxy reaches the 2 in level.

1.11 Let epoxy dry, with spike straight in the pipe (Fig. A.13).

1.12 Using masking tape and paint, paint alternate 10 cm segments white and black with every 5th section painted fluorescent orange (Fig. A.14).

1.13 Once dry, coat with spar-urethane to avoid scratches and UV degradation of paint colors.

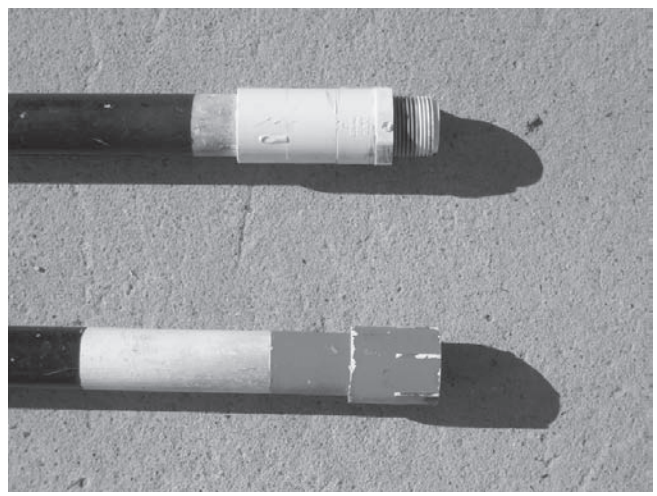


Figure A.12. Male and female couplings for cover pole.

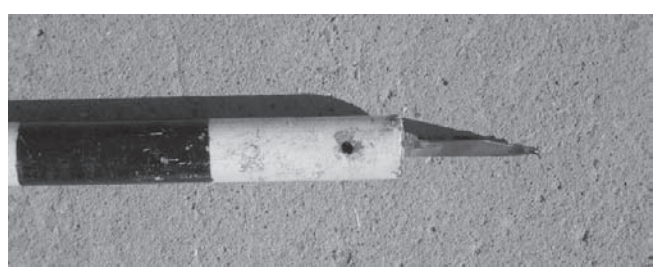


Figure A.13. Spike attached to cover pole.

2. Sight pole construction:

2.1 Using the cleaner, primer and glue, attach one cap to end of pipe.

2.2 Measure 1 m from end of cap and drill $^1/_4$ in hole through pipe.

2.3 Attach cap to other end of pipe without using glue (can be used as storage for Line-point intercept pin flags).

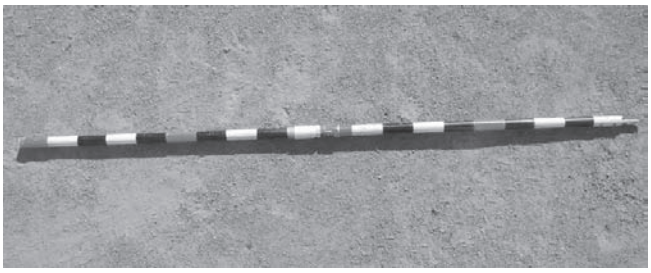


Figure A.14. Completed cover pole.

Riparian vegetation survey pole (Chapter 13)

Materials needed for construction of L-tool for Riparian channel vegetation survey:

- 2 m (78 $^{3}/_{4}$ in) of $^{3}/_{4}$ in (1.9 cm) inside diameter schedule 40 PVC pipe
- One $^{3}/_{4}$ in PVC elbow joint
- One $^{3}/_{4}$ in PVC T-joint
- PVC cement
- One hacksaw
- One meter stick
- One permanent marker

1. L-tool construction.

1.1 Cut four pieces of $^{3}/_{4}$ in diameter PVC pipe, as follows: one 50 cm (11 $^{11}/_{16}$ in) piece, one 100 cm (39 $^{3}/_{8}$ in) piece and two 10 cm (3 $^{15}/_{16}$ in) pieces.

1.2 Connect and glue the 100 cm (39 $^{3}/_{8}$ in) pipe to the 50 cm (11 $^{11}/_{16}$ in) pipe with the elbow joint.

1.3 Connect the T-joint to the end of the 50 cm (11 $^{11}/_{16}$ in) pipe and position it parallel with the 100 cm (39 $^{3}/_{8}$ in) pipe. Glue in place.

1.4 Place a 10 cm (3 $^{15}/_{16}$ in) piece on each open end of the T-joint and glue in place.

1.5 The finished product should look like Figure A.15.

1.6 Mark and label lines every 10 cm (3 $^{15}/_{16}$ in) on the 100 cm (39 $^{3}/_{8}$ in) pipe to determine plant height.

2. Optional laser installation.

2.1 The L-tool works much better with a double-ended laser pointer in place of the "T".

2.2 For sources, see Table A.1.

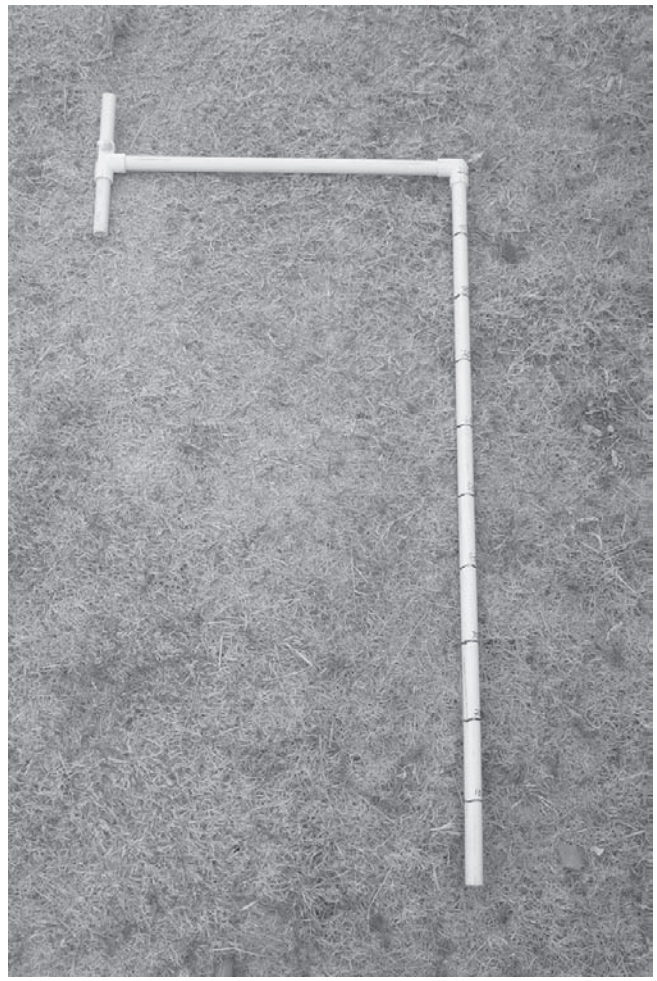


Figure A.15. L-tool design.

Appendix B: Conversion factors

English units are used wherever practical. Metric units are used for linear measurements. The advantage of metric tapes is that a single number (cm) can be used to record distances. Decimal feet tapes may be substituted; the calculations remain the same. Metric tapes are available from Forestry Supplier, Ben Meadows, Gemplers and other catalog suppliers. They are also increasingly available at building supply stores.

feet	X	0.305	=	meters	meters	X	3.281	=	feet
inches	X	2.54	=	centimeters	centimeters	X	0.394	=	inches
inches	X	25.4	=	millimeters	millimeters	X	0.039	=	inches
miles	X	1.609	=	kilometers	kilometers	X	0.621	=	miles
acres	X	0.405	=	hectares	hectares	X	2.471	=	acres
quarts	X	0.946	=	liters	liters	X	1.057	=	quarts
ounces	X	29.57	=	milliliters	milliliters	X	0.034	=	ounces
pounds	X	0.454	=	kilograms	kilograms	X	2.205	=	pounds
ounces	X	28.35	=	grams	grams	X	0.035	=	ounces
lb/acre	X	1.12	=	kg/ha	kg/ha	X	0.891	=	lb/acre
square meters	X	10.764	=	square feet	square feet	X	0.0929	=	square meters

Appendix C: How many measurements?

Introduction

This appendix describes three options for deciding how many measurements to make for selected indicators. Option 1 is the simplest. Option 3 is the best.

Option 1
General recommendations for arid and semi-arid grasslands and shrublands based on a study of eight plant communities in southern New Mexico, USA.

Option 2
Specific results for each of the eight plant communities.

Option 3
Equations for calculating measurement requirements based on available data for your area.

For Options 1 and 2, Type I error = 0.2 and Type II error = 0.2; Power = 0.8; rho = 0.5. The Internet version will allow for modification of these parameters (select "Monitoring and Assessment" from http://usda-ars.nmsu.edu). We will update these recommendations as new information becomes available for different ecological sites.

Table C.1. Information requirements.

	Option		
	1	2	3
Minimum detectable change desired for each indicator	**Yes**	**Yes**	**Yes**
Knowledge of plant community composition and structure	No	**Yes**	**Yes**
Data from your plots	No	No	**Yes**

Definitions

Type I error. Type I error is the probability that you will conclude that a change has occurred when there has been no change.

Type II error. Type II error is the probability that you will conclude that no change has occurred when there really has been a change. Scientists often set Type I error at 0.05 and ignore Type II error, allowing it to exceed 0.5 in many cases. For most monitoring studies, we set Type I = Type II = 0.2 because it is usually just as important to be able to detect real change as it is to avoid falsely concluding that change has occurred. Reducing either type of error requires increasing the number of measurements.

Power. Power is the probability that you will conclude that a change has occurred when there really has been a change. It is equal to 1 minus Type II error.

Rho. Rho is the correlation between sampling unit values in the first time period and sampling unit values in the second time period. Increasing rho reduces the number of replications required. For example, sampling requirements decline by 50 percent if rho is increased from 0.5 to 0.75.

Returning as close as possible to the location of the original transect increases rho. Remember, however, that while it is important to place the transect in approximately the same location each year, it is unnecessary (and generally impossible) to measure exactly the same *points* each year. Note that for comparisons between two independent plots, rho = 0.

Average. Average is the sum divided by the number of values.

Median. Median is the value within a group of numbers at which half the values are larger and half are smaller.

Plot scale. Plot scale is the scale at which we normally collect monitoring data. An individual plot is defined as one hectare (2.5 acres). One hectare (2.5 acres) is the area covered by a spoke plot with three 50 m transects starting 5 m from the center. This scale is appropriate if the key area concept is applied—that is, if you are confident that change detected in an individual plot accurately reflects changes occurring across larger areas.

Landscape scale. Landscape scale is the scale at which statistically based monitoring programs are normally applied. Change is detected using multiple plots located within relatively homogeneous monitoring units (see Volume II, Section I).

Data for Options 1 and 2
The recommendations listed under Options 1 and 2 are based on a study completed in southern New Mexico, USA in 2000. Measurements were completed on three transects in each of three plots in eight plant communities (Fig. C.1; Table C.2). The plant communities represented a relatively degraded and non-degraded state in each of four ecological sites.

Caution
While this is one of the more comprehensive studies of replication requirements for a variety of soil and vegetation measurements, *it is still extremely limited*, particularly for the recommendations at the landscape (monitoring unit) scale. The Option 1 estimates are based on a total of 72 transects and 24 plots. Each Option 2 estimate is based on just nine transects and three plots. Furthermore, these data are specific to southern New Mexico. The estimates will tend to be more accurate in regions where plant communities are similar in structure to the Chihuahuan Desert (e.g., Great Basin and Sonoran Desert), and less so in regions with different plant community structure (e.g., annual grassland and shortgrass prairie). We have included footnotes highlighting specific characteristics of the plots sampled that may explain unusually high values.

See our website for revised recommendations based on more comprehensive data ("Monitoring and Assessment" link at http://usda-ars.nmsu.edu).

Assumptions
The tables printed here are based on the following assumptions:

- Type I error (p-value) = 0.2
- Type II error (1 – power) = 0.2
- Rho (between-date correlation) = 0.5
- The absolute minimum number of replications is 2.

The "rho" assumption is extremely important. Sampling requirements decline by 50 percent if rho is increased to 0.75. The value of 0.5 is conservative. The value will be higher (and therefore sampling requirements lower) in most monitoring programs. Rho = 0.5 was selected based on the results of a different multi-year study in a semi-arid environment where a 30 m transect was shifted left or right at least 1 m (3 ft) within a 6 m (18 ft) band each year.

The absolute minimum number of transects was set to two to ensure that the data can be statistically analyzed. In some cases, our analyses (for Options 1 and 2) generated replication recommendations that were less than two.

These assumptions are for design purposes only. Your ability to detect change depends on site variability. If your site is more variable than the sites used to generate these recommendations, the minimum detectable change will be larger for a given sample size. If your site is less variable, you will be able to detect a smaller change. It is nearly always better to establish more transects than you think you need, as the number can later be reduced without information loss.

When you analyze your data, you can calculate rho, set Type I and II errors at any level, and determine how many transects need to be re-measured in future years using the equations in Option 3.

Instructions: Option 1

Choose Option 1 if you are comfortable using the median sample size recommendations from all eight communities combined. If you are not

comfortable using the median of all eight communities, use Option 2 or 3. Use Tables C.3 and C.4 to determine how many transects and measurements are required at the plot scale. Use Tables C.5 and C.6 to determine how many plots (with the specified number of transects and measurements) are required at the landscape scale. Please see the "Caution" and "Assumptions" sections in the Introduction above.

Plant Community

Sandy loam - Loamy sand

(Sandy Ecological Site)

A. Stoloniferous grasses (*Bouteloua eriopoda* [black grama])

B. Large shrubs (*Prosopis glandulosa* [honey mesquite])

Sandy loam

(Shallow Sandy Ecological Site)

C. Rhizomatous/stoloniferous/bunchgrasses (*B. eriopoda & B. gracilis* [black & blue grama])

D. Rhizomatous/stoloniferous grasses and sub-shrubs (*Gutierrezia sarothrae* [snakeweed])

Very fine sandy loam

(Gyp Upland Ecological Site)

E. Salt desert shrubland (*Atriplex canescens* [fourwing saltbush])

F. Degraded salt desert shrubland (*A. canescens* [fourwing saltbush])

Clay loam

(Clayey Ecological Site)

G. Banded (patchy) stoloniferous grasses (*Pleuraphis mutica* [tobosa])

H. Patchy stoloniferous grasses (*Scleropogon brevifolius* [burrograss])

Figure C.1. Photographs of each plant community used to generate the sampling requirement estimates listed for Options 1 and 2.

Table C.2. Average indicator values for each plant community used for Options 1 and 2.

	Cover (%)			Area in gaps > min. length (%)				Soil stability (class)		Compaction test (penetrometer strikes)		Infiltration (Single-ring)
				Canopy		Basal						
Community*	**Canopy (foliar)**	**Basal**	**Bare ground**	**25 cm**	**50 cm**	**50 cm**	**100 cm**	**Surface**	**Sub-surface**	**0-10 cm**	**0-20 cm**	**(mm/hr)**
A	70	5	22	48	36	74	51	4.6	1.6	11	37	271
B	28	7	57	76	72	91	86	2.1	1.3	6	18	241
C	57	18	24	29	9	27	6	5.2	3.6	12	27	88
D	50	9	27	30	14	33	14	4.1	2.7	15	38	86
E	25	2	29	88	84	94	89	5.8	2.5	5	17	300
F	13	1	40	93	89	95	91	5.8	3.0	14	32	170
G	47	6	43	56	44	63	45	4.8	2.9	22	56	78
H	36	6	43	62	42	62	36	4.3	2.2	19	43	58
Average	**41**	**7**	**36**	**60**	**49**	**67**	**52**	**4.6**	**2.5**	**13**	**34**	**161**

*See Figure C.1 for key. For each community, values are based on 3 plots with 3 50 m transects per plot (vegetation), 18 soil stability and compaction per plot and 9 infiltration measurements per plot.

Table C.3. Typical number of 50 m (~150 ft) transects to detect vegetation change at the **plot*** scale. Sample sizes (number of transects) represent the median number of transects required based on all eight plant communities.

Vegetation indicators (units)	Minimum detectable change (%)	Transects	Minimum detectable change (%)	Transects	Minimum detectable change (%)	Transects
Line-point intercept (50 points/transect)**						
Foliar cover	5	6	10	2	20	2
Basal cover	2	9	5	2	10	2
Bare ground	5	8	10	2	20	2
Canopy Gap intercept**						
% transect in gaps >25 cm	5	6	10	2	20	2
% transect in gaps >50 cm	5	9	10	3	20	2
Basal Gap intercept**						
% transect in gaps >50 cm	5	5	10	2	20	2
% transect in gaps >100 cm	5	6	10	2	20	2

Table C.4. Typical number of measurements to detect soil change at the **plot*** scale. Sample sizes (number of measurements) represent the median number of measurements required based on all eight plant communities.

Indicators (units)	Minimum detectable change	Measure-ments	Minimum detectable change	Measure-ments	Minimum detectable change	Measure-ments
Soil stability test						
Surface stability (classes)	0.5	44	1	12	2	4
Sub-surface stability (classes)	0.5	35	1	9	2	3
Compaction test***						
0-10 cm (strikes)	10%	54	20%	14	50%	3
0-20 cm (strikes)	10%	51	20%	14	50%	3
Infiltration test***						
Rate (mm/hour)	20%	33	30%	15	50%	6

* 1 ha (~2.5 acre) plot.

** Absolute change (e.g., increase from 10 to 15 percent is a 5 percent change).

*** Relative change (e.g., increase from 10 to 15 strikes is a 50 percent change).

See website for revised recommendations based on more comprehensive data ("Monitoring and Assessment" link at http://usda-ars.nmsu.edu).

Table C.5. Typical number of plots with one or three 50 m (~150 ft) transects needed to detect vegetation change at the monitoring unit **(landscape unit)*** scale. Sample sizes (number of transects) represent the median number of transects required based on all eight plant communities.

Indicator (units)	Minimum detectable change (%)	Transects per plot		Minimum detectable change (%)	Transects per plot		Minimum detectable change (%)	Transects per plot	
		1	3		1	3		1	3
Line-point intercept (50 points/transect)**									
Foliar cover	5	8	4	10	3	2	20	2	2
Basal cover	2	12	6	5	3	2	10	2	2
Bare ground	5	11	5	10	4	2	20	2	2
Canopy Gap intercept**									
% transect in gaps >25 cm	5	11	6	10	3	2	20	2	2
% transect in gaps >50 cm	5	11	6	10	3	2	20	2	2
Basal Gap intercept**									
% transect in gaps >50 cm	5	13	8	10	4	3	20	2	2
% transect in gaps >100 cm	5	9	5	10	3	2	20	2	2

Table C.6. Typical number of plots with specified number of measurements needed to detect soil change at the monitoring unit **(landscape unit)*** scale. Sample sizes (number of measurements) represent the median number of measurements required based on all eight plant communities.

Indicator (units)	Minimum detectable change	Measurements per plot		Minimum detectable change	Measurements per plot		Minimum detectable change	Measurements per plot	
		6	18		6	18		6	18
Soil stability test									
Surface stability (classes)	0.5	10	5	1	3	2	2	2	2
Sub-surface stability (classes)	0.5	6	3	1	2	2	2	2	2
Compaction test***									
0-10 cm (strikes)	10%	24	20	20%	7	6	50%	2	2
0-20 cm (strikes)	10%	27	24	20%	7	6	50%	2	2
Infiltration test***									
Rate (mm/hour)	20%	11	7	30%	6	3	50%	2	2

* A monitoring unit is assumed to fall in a single ecological site in a particular state (similar soil, landscape position, and status).

** Absolute change (e.g., increase from 10 to 15 percent is a 5 percent change).

*** Relative change (e.g., increase from 10 to 15 strikes is a 50 percent change).

See website for revised recommendations based on more comprehensive data ("Monitoring and Assessment" link at http://usda-ars.nmsu.edu).

Instructions for Option 2: PLOT scale

Choose this option to determine how many vegetation transects and soil measurements you need to detect change within a plot (plot scale). Complete the Plot Scale Worksheet (see Table C.7) to calculate the recommended number of measurements for your plot-scale monitoring project. The recommendations are based on data from the southern New Mexico study (Tables C.8 through C.13). Before beginning, please see the "Caution" and "Assumptions" sections in the Introduction to this appendix.

Step 1. Using Figure C.1 and Table C.2, select at least three plant communities that appear to be most similar to your own. Record them under "Plant communities" in the worksheet (Table C.7).

We strongly recommend that you select at least three communities, even if your community appears to have very similar characteristics to only one of the eight.

Step 2. Define the minimum change you want to be able to detect at the plot scale for each indicator. Record this value under "Minimum detectable change" in the Plot Scale Worksheet.

Step 3. Copy appropriate values for the number of measurements and transects from Tables C.8 through C.13 for each community to the Plot Scale Worksheet. Make sure to copy the values from the correct rows and columns.

Step 4. Record the median or maximum number of measurements and transects in the last column.

Table C.7. Plot Scale Worksheet. Use this form, together with Tables C.8 through C.13, to determine the appropriate number of transects (vegetation) or measurements (soil) needed to detect change at the **plot** scale. "Absolute %" means that a change from 10 to 15 percent cover would be 5 percent.

Indicators	Minimum detectable change	Plant communities					Median*
Line-point intercept	**Absolute %**	Number of 50 m (150 ft) transects with 50 points/transect					
Bare ground							
Basal cover							
Foliar cover							
Canopy Gap intercept	**Absolute %**	Number of 50 m (150 ft) transects					
Gaps > 25 cm (~0.8 ft)							
Gaps > 50 cm (~1.7 ft)							
Basal Gap intercept	**Absolute %**	Number of 50 m (150 ft) transects					
Gaps > 50 cm (~1.7 ft)							
Gaps > 100 cm (~3.3 ft)							
Soil stability test	**Stability classes**	Number of measurements					
Surface stabliity							
Sub-surface stability							
Compaction test	**% change in strikes**	Number of strikes					
0-10 cm							
0-20 cm							
Infiltration (Single-ring infiltrometer)	**% change in rate**	Number of measurements					
Rate							

* Middle value of those listed at left. For a more conservative estimate, use maximum.

Table C.8. Line-point intercept replication requirements (number of 50 m transects with 50 points per transect) for the **plot** scale. Use median or maximum of at least three communities. See Table C.15 for landscape scale.

	Minimum detectable change (%)*		
Foliar cover	**5**	**10**	**20**
Community	Transects required		
A	**6**	**2**	**2**
B	**5**	**2**	**2**
C	**13**	**4**	**2**
D	**6**	**2**	**2**
E	**4**	**2**	**2**
F	**2**	**2**	**2**
G[1]	**32**	**8**	**2**
H	**16**	**4**	**2**
Median	**6**	**2**	**2**

	Minimum detectable change (%)*		
Basal cover	**2**	**5**	**10**
Community	Transects required		
A	**12**	**2**	**2**
B	**9**	**2**	**2**
C	**10**	**2**	**2**
D	**8**	**2**	**2**
E	**6**	**2**	**2**
F	**3**	**2**	**2**
G	**9**	**2**	**2**
H	**10**	**2**	**2**
Median	**9**	**2**	**2**

	Minimum detectable change (%)*		
Bare ground cover	**5**	**10**	**20**
Community	Transects required		
A	**2**	**2**	**2**
B	**7**	**2**	**2**
C	**13**	**4**	**2**
D	**8**	**2**	**2**
E	**5**	**2**	**2**
F[2]	**28**	**7**	**2**
G[1]	**22**	**6**	**2**
H	**7**	**2**	**2**
Median	**8**	**2**	**2**

* Absolute change (e.g., increase from 10 to 15 percent is a 5 percent change).

[1]High values due to patch structure associated with banded vegetation.

[2]High values due to highly variable lichen cover (not counted as bare ground).

See website for revised recommendations based on more comprehensive data ("Monitoring and Assessment" link at http://usda-ars.nmsu.edu).

Table C.9. Canopy gap replication requirements (number of 50 m transects) for the **plot** scale. Use median or maximum of at least three communities. See Table C.16 for landscape scale.

Canopy Gap intercept % transect in gaps >25 cm	Minimum detectable change (%)*		
	5	10	20
Community	Transects required		
A[1]	23	6	2
B	11	3	2
C	6	2	2
D	4	2	2
E	2	2	2
F	2	2	2
G[2]	24	6	2
H	5	2	2
Median	6	2	2

Canopy Gap intercept % transect in gaps >50 cm	Minimum detectable change (%)*		
	5	10	20
Community	Transects required		
A[1]	22	6	2
B	11	3	2
C	6	2	2
D	5	2	2
E	3	2	2
F	3	2	2
G[2]	37	10	3
H	13	4	2
Median	9	3	2

* Absolute change (e.g., increase from 10 to 15 percent is a 5 percent change).

[1]High values due to presence of unvegetated rodent mounds on some transects.

[2]High values due to patch structure associated with banded vegetation.

See website for revised recommendations based on more comprehensive data ("Monitoring and Assessment" link at http://usda-ars.nmsu.edu).

Table C.10. Basal gap replication requirements (number of 50 m transects) for the **plot** scale. Use median or maximum of at least three communities. See Table C.17 for landscape scale.

Basal Gap intercept % transect in gaps >50 cm	Minimum detectable change (%)*		
	5	10	20
Community	Transects required		
A	5	2	2
B	2	2	2
C	5	2	2
D	14	4	2
E	2	2	2
F	2	2	2
G[1]	26	7	2
H[2]	11	3	2
Median	5	2	2

Basal Gap intercept % transect in gaps >100 cm	Minimum detectable change (%)*		
	5	10	20
Community	Transects required		
A	7	2	2
B	4	2	2
C	4	2	2
D	6	2	2
E	5	2	2
F	3	2	2
G[1]	43	11	3
H[2]	15	4	2
Median	6	2	2

* Absolute change (e.g., increase from 10 to 15 percent is a 5 percent change).

[1]High values due to patch structure associated with banded vegetation.

[2]High values associated with variable decreases in plant patch size. This is typical of degradation in grass communities where reproduction is predominately vegetative.

See website for revised recommendations based on more comprehensive data ("Monitoring and Assessment" link at http://usda-ars.nmsu.edu).

Table C.11. Soil stability test replication requirements for the **plot** scale. Use median or maximum of at least three communities. See Table C.18 for landscape scale.

Surface Soil stability test	**Minimum detectable change (units)**		
	0.5	**1**	**2**
Community	Measurements required		
A	**50**	**13**	**4**
B	**37**	**10**	**3**
C	**35**	**9**	**3**
D	**77**	**20**	**5**
E	**12**	**3**	**2**
F	**13**	**4**	**2**
G	**57**	**15**	**4**
H	**57**	**15**	**4**
Median	**44**	**12**	**4**

Sub-surface Soil stability test	**Minimum detectable change (units)**		
	0.5	**1**	**2**
Community	Measurements required		
A	**24**	**6**	**2**
B	**19**	**5**	**2**
C	**43**	**11**	**3**
D	**36**	**9**	**3**
E	**46**	**12**	**3**
F	**34**	**9**	**3**
G	**44**	**11**	**3**
H	**28**	**7**	**2**
Median	**35**	**9**	**3**

See website for revised recommendations based on more comprehensive data ("Monitoring and Assessment" link at http://usda-ars.nmsu.edu).

Table C.12. Compaction test replication requirements for the **plot** scale. Use median or maximum of at least three communities. See Table C.19 for landscape scale.

Compaction test 0-10 cm (strikes)	Minimum detectable change (%)*		
	10	20	50
Community	Measurements required		
A	60	15	3
B[1]	122	31	5
C	24	6	2
D	32	8	2
E	52	13	3
F	72	18	3
G	56	14	3
H	34	9	2
Median	54	14	3

Compaction test 0-20 cm (strikes)	Minimum detectable change (%)*		
	10	20	50
Community	Measurements required		
A	30	8	2
B	92	23	4
C	88	22	4
D	33	9	2
E	55	14	3
F	49	13	2
G	53	14	3
H	35	9	2
Median	51	14	3

* Relative change (e.g., increase from 10 to 15 strikes is a 50 percent change).

[1]High values due to extreme differences between soil under shrubs and soil in shrub interspaces.

See website for revised recommendations based on more comprehensive data ("Monitoring and Assessment" link at http://usda-ars.nmsu.edu).

Table C.13. Infiltration test replication requirements for the **plot** scale. Use median or maximum of at least three communities. See Table C.20 for landscape scale.

Single-ring infiltration rate	**Minimum detectable change (%)***		
(mm/hour)	**20**	**30**	**50**
Community	Measurements required		
A	**19**	**9**	**3**
B	**35**	**16**	**6**
C	**30**	**14**	**5**
D	**47**	**21**	**8**
E	**15**	**7**	**3**
F	**22**	**10**	**4**
G[1]	**232**	**103**	**38**
H[1]	**115**	**52**	**19**
Median	**33**	**15**	**6**

* Relative change (e.g., increase from 50 to 75 mm/hour is a 50 percent change).

[1]High values due to strong influence of different types of vegetation on infiltration rates, together with variability in soil surface texture in the test plots.

See website for revised recommendations based on more comprehensive data ("Monitoring and Assessment" link at http://usda-ars.nmsu.edu).

Instructions for Option 2: LANDSCAPE scale

Choose this option to determine how many vegetation transects and soil measurements are required to detect change within a monitoring unit (landscape scale). Complete the Landscape Scale Worksheet (Table C.14) to calculate the recommended number of measurements for your landscape-scale monitoring project. The recommendations are based on data from the southern New Mexico study (Tables C.15 through C.20). Before beginning, please see the "Caution" and "Assumptions" sections in the Introduction to this appendix, Appendix C.

Step 1. Using Figure C.1 and Table C.2, select at least three plant communities that appear to be most similar to your own. Record them under "Plant communities" in the worksheet (Table C.14). We strongly recommend that you select at least three communities, even if your community appears to have very similar characteristics to only one of the eight.

Step 2. Define the minimum change you want to be able to detect at the landscape scale for each indicator. Record this value under "Minimum detectable change" in the Landscape Scale Worksheet.

Step 3. Circle the number of transects (1 vs. 3 for vegetation) and measurements (6 vs. 18 for soil) per plot for each method.

Step 4. Copy the appropriate values for the number of measurements and transects from Tables C.15 through C.20 for each community to the Landscape Scale Worksheet. Make sure to copy the values from the correct rows and columns.

Step 5. Record the median or maximum number of plots required in the last column of Table C.14.

Table C.14. Landscape Scale Worksheet. Use this form, together with Tables C.15 through C.20, to determine the appropriate number of transects (vegetation) or measurements (soil) needed to detect change at the **landscape** (monitoring unit) scale. For each method, specify whether plots include 1 or 3 transects and 6 or 18 soil measurements, and use appropriate values from Tables C.15 through C.20.

Indicators	Minimum detectable change	Plant communities					Median*
Line-point intercept: Plots with (1 or 3) 50 m (150 ft), 50 point-transects							
Bare ground (%)							
Basal cover (%)							
Foliar cover (%)							
Canopy Gap intercept: Plots with (1 or 3) 50 m (150 ft) transects							
Gaps > 25 cm (~0.8 ft)							
Gaps > 50 cm (~1.7 ft)							
Basal Gap intercept: Plots with (1 or 3) 50 m (150 ft) transects							
Gaps > 50 cm (~1.7 ft)							
Gaps > 100 cm (~3.3 ft)							
Soil stability test (stability class): Plots with (6 or 18) measurements							
Surface stabliity							
Sub-surface stability							
Compaction test (% change in average strikes): Plots with (6 or 18) measurements							
0-10 cm							
0-20 cm							
Infiltration test (% change in average rate): Plots with (6 or 18) measurements							
Rate							

* Middle value of those listed at left. For a more conservative estimate, use maximum.

Table C.15. Line-point intercept replication requirements (50 m transects with 50 points per transect) for the **landscape** (monitoring unit) scale. Use median or maximum of at least three communities. See Table C.8 for plot scale.

Foliar cover	1 transect/plot			3 transects/plot		
	Minimum detectable change (%)*					
	5	10	20	5	10	20
Community	Number of plots required					
A	6	2	2	2	2	2
B	5	2	2	2	2	2
C	15	4	2	7	2	2
D	6	2	2	2	2	2
E	9	3	2	7	2	2
F	2	2	2	2	2	2
G[1]	32	8	2	11	3	2
H	16	4	2	6	2	2
Median	8	3	2	4	2	2

Basal cover	1 transect/plot			3 transects/plot		
	Minimum detectable change (%)*					
	2	5	10	2	5	10
Community	Number of plots required					
A	13	3	2	6	2	2
B	19	3	2	13	3	2
C	17	3	2	11	2	2
D	19	3	2	14	3	2
E	9	2	2	5	2	2
F	3	2	2	2	2	2
G	9	2	2	3	2	2
H	10	2	2	4	2	2
Median	12	3	2	6	2	2

Bare ground cover	1 transect/plot			3 transects/plot		
	Minimum detectable change (%)*					
	5	10	20	5	10	20
Community	Number of plots required					
A	2	2	2	2	2	2
B	7	2	2	3	2	2
C	14	4	2	6	2	2
D	13	4	2	7	2	2
E	5	2	2	2	2	2
F[2]	46	12	3	28	7	2
G[1]	22	6	2	8	2	2
H	9	3	2	4	2	2
Median	11	4	2	5	2	2

* Absolute change (e.g., increase from 10 to 15 percent is a 5 percent change).

[1]High values due to patch structure associated with banded vegetation.

[2]High values due to highly variable lichen cover (not counted as bare ground).

See website for revised recommendations based on more comprehensive data ("Monitoring and Assessment" link at http://usda-ars.nmsu.edu).

Table C.16. Canopy Gap intercept replication requirements (50 m transects) for the **landscape** (monitoring unit) scale. Use median or maximum of at least three communities. See Table C.9 for plot scale.

% transect in canopy gaps > 25 cm	1 transect/plot			3 transects/plot		
	Minimum detectable change (%)*					
	5	10	20	5	10	20
Community	Number of plots required					
A[1]	23	6	2	8	2	2
B	11	3	2	4	2	2
C	11	3	2	7	2	2
D	11	3	2	9	3	2
E	2	2	2	2	2	2
F	2	2	2	2	2	2
G[2]	24	6	2	8	2	2
H	6	2	2	3	2	2
Median	11	3	2	6	2	2

% transect in canopy gaps > 50 cm	1 transect/plot			3 transects/plot		
	Minimum detectable change (%)*					
	5	10	20	5	10	20
Community	Number of plots required					
A[1]	22	6	2	8	2	2
B	12	3	2	5	2	2
C	10	3	2	6	2	2
D	8	2	2	5	2	2
E	3	2	2	2	2	2
F	5	2	2	4	2	2
G[2]	37	10	3	13	4	2
H	19	5	2	11	3	2
Median	11	3	2	6	2	2

* Absolute change (e.g., increase from 10 to 15 percent is a 5 percent change).

[1]High values due to presence of unvegetated rodent mounds on some transects.

[2]High values due to patch structure associated with banded vegetation.

See website for revised recommendations based on more comprehensive data ("Monitoring and Assessment" link at http://usda-ars.nmsu.edu).

Table C.17. Basal Gap intercept replication requirements (50 m transects) for the **landscape** (monitoring unit) scale. Use median or maximum of at least three communities. See Table C.10 for plot scale.

% transect in basal gaps > 50 cm	1 transect/plot			3 transects/plot		
	Minimum detectable change (%)*					
	5	10	20	5	10	20
Community	Number of plots required					
A	5	2	2	2	2	2
B	2	2	2	2	2	2
C	16	4	2	13	4	2
D	21	6	2	12	3	2
E	3	2	2	2	2	2
F	4	2	2	3	2	2
G[1]	26	7	2	9	3	2
H	19	5	2	12	3	2
Median	11	3	2	6	2	2

% transect in basal gaps > 100 cm	1 transect/plot			3 transects/plot		
	Minimum detectable change (%)*					
	5	10	20	5	10	20
Community	Number of plots required					
A	7	2	2	3	2	2
B	4	2	2	2	2	2
C	4	2	2	2	2	2
D	8	2	2	5	2	2
E	11	3	2	8	2	2
F	14	4	2	12	3	2
G[1]	45	12	3	17	5	2
H	21	6	2	12	3	2
Median	10	3	2	7	2	2

* Absolute change (e.g., increase from 10 to 15 percent is a 5 percent change).

[1]High values due to patch structure associated with banded vegetation.

See website for revised recommendations based on more comprehensive data ("Monitoring and Assessment" link at http://usda-ars.nmsu.edu).

Table C.18. Soil stability test replication requirements for the **landscape** (monitoring unit) scale. Use median or maximum of at least three communities. See Table C.11 for plot scale.

Surface Soil stability test	6 measurements/plot			18 measurements/plot		
	Minimum detectable change (units)					
	0.5	1	2	0.5	1	2
Community	Number of plots required					
A	**21**	**6**	**2**	**16**	**4**	**2**
B	**10**	**3**	**2**	**6**	**2**	**2**
C	**6**	**2**	**2**	**2**	**2**	**2**
D	**16**	**4**	**2**	**8**	**2**	**2**
E	**2**	**2**	**2**	**2**	**2**	**2**
F	**3**	**2**	**2**	**2**	**2**	**2**
G	**10**	**3**	**2**	**4**	**2**	**2**
H	**11**	**3**	**2**	**5**	**2**	**2**
Median	**10**	**3**	**2**	**5**	**2**	**2**

Sub-surface Soil stability test	6 measurements/plot			18 measurements/plot		
	Minimum detectable change (units)					
	0.5	1	2	0.5	1	2
Community	Number of plots required					
A	**6**	**2**	**2**	**3**	**2**	**2**
B	**5**	**2**	**2**	**3**	**2**	**2**
C	**9**	**3**	**2**	**4**	**2**	**2**
D	**6**	**2**	**2**	**2**	**2**	**2**
E	**10**	**3**	**2**	**4**	**2**	**2**
F	**6**	**2**	**2**	**2**	**2**	**2**
G	**8**	**2**	**2**	**3**	**2**	**2**
H	**6**	**2**	**2**	**3**	**2**	**2**
Median	**6**	**2**	**2**	**3**	**2**	**2**

See website for revised recommendations based on more comprehensive data ("Monitoring and Assessment" link at http://usda-ars.nmsu.edu).

Table C.19. Compaction test replication requirements for the **landscape** (monitoring unit) scale. Use median or maximum of at least three communities. See Table C.12 for plot scale.

Compaction test 0-10 cm (strikes)	6 measurements/plot			18 measurements/plot		
	Minimum detectable change (%)*					
	10	20	50	10	20	50
Community	Number of plots required					
A[1]	**171**	**43**	**7**	**164**	**41**	**7**
B[2]	**144**	**36**	**6**	**131**	**33**	**6**
C	**21**	**6**	**2**	**18**	**5**	**2**
D	**13**	**4**	**2**	**10**	**3**	**2**
E	**11**	**3**	**2**	**5**	**2**	**2**
F	**16**	**4**	**2**	**8**	**2**	**2**
G	**47**	**12**	**2**	**41**	**11**	**2**
H	**26**	**7**	**2**	**22**	**6**	**2**
Median	**24**	**7**	**2**	**20**	**6**	**2**

Compaction test 0-20 cm (strikes)	6 measurements/plot			18 measurements/plot		
	Minimum detectable change (%)*					
	10	20	50	10	20	50
Community	Number of plots required					
A	**22**	**6**	**2**	**19**	**5**	**2**
B[2]	**149**	**38**	**6**	**139**	**35**	**6**
C	**40**	**10**	**2**	**30**	**8**	**2**
D	**32**	**8**	**2**	**28**	**7**	**2**
E	**17**	**5**	**2**	**11**	**3**	**2**
F	**12**	**3**	**2**	**6**	**2**	**2**
G	**39**	**10**	**2**	**33**	**9**	**2**
H	**19**	**5**	**2**	**15**	**4**	**2**
Median	**27**	**7**	**2**	**24**	**6**	**2**

* Relative change (e.g., increase from 10 to 15 striked is a 50 percent change).

[1]High levels due to variable density of rodent mounds at landscape scale.

[2]High levels due to variable development of mesquite coppice dunes at the landscape scale.

See website for revised recommendations based on more comprehensive data ("Monitoring and Assessment" link at http://usda-ars.nmsu.edu).

Table C.20. Infiltration test replication requirements for the **landscape** (monitoring unit) scale. Use median or maximum of at least three communities. See Table C.13 for plot scale.

Single-ring infiltration rate (mm/hour)	6 measurements/plot			18 measurements/plot		
	Minimum detectable change (%)*					
	20	30	50	20	30	50
Community	Number of plots required					
A	**5**	**2**	**2**	**3**	**2**	**2**
B	**6**	**3**	**2**	**2**	**2**	**2**
C	**13**	**6**	**3**	**10**	**5**	**2**
D	**12**	**6**	**2**	**7**	**3**	**2**
E	**3**	**2**	**2**	**2**	**2**	**2**
F	**10**	**5**	**2**	**7**	**4**	**2**
G[1]	**59**	**27**	**10**	**34**	**15**	**6**
H	**20**	**9**	**4**	**7**	**3**	**2**
Median	**11**	**6**	**2**	**7**	**3**	**2**

* Relative change (e.g., increase from 50 to 75 mm/hour is a 50 percent change).

[1]High values due to strong influence of different types of vegetation on infiltration rates, together with variability in soil surface texture among the test plots.

See website for revised recommendations based on more comprehensive data ("Monitoring and Assessment" link at http://usda-ars.nmsu.edu).

Instructions for Option 3: Calculations based on available data

In Option 3 you conduct your own research to determine how many transects and measurements are needed to detect change. This option requires data from a pilot study within the monitoring unit of interest. Sometimes data from a previous monitoring study or research project can be used. Use one of the equations provided below to determine the necessary number of vegetation transects or soil measurements required at the plot scale, or for the number of plots at the landscape scale.

A pilot study is a small-scale version of your monitoring program. Conducting a pilot study allows you to more accurately estimate the population mean(s), the standard deviation(s) and the degree of correlation between years. These values are used in Equations 1 and 2.

Equation 1. Equation 1 is used to determine requirements for detecting differences between two means from permanent plots, using a paired *t*-test. This is similar to the equations used to generate the recommendations listed in Options 1 and 2. It is the test used to detect change over time.

If you wish to detect change at the plot scale, use a plot's transect data (or soil measurement data) from a single sampling period to generate the population mean and standard deviation.

If you wish to detect change at the landscape (monitoring unit) scale use data from all of the plots within the landscape unit (or monitoring unit) from a single sampling period to generate the population mean and standard deviation. At the landscape scale, the number of replications is equal to the number of plots, not the number of transects or soil measurements.

Equation 2. Equation 2 is used to determine requirements for detecting differences between a single mean and a threshold value, using a one-sample *t*-test. It is assumed that the means will be compared using a paired *t*-test.

If you wish to detect a difference between a plot's mean and a threshold value (at the plot scale), use data from the plot's transects (or soil measurements) to generate the population mean and standard deviation.

If you wish to detect a difference between a landscape unit's (monitoring unit's) mean and a threshold value (landscape scale), use data from all of the plots within the landscape unit (or monitoring unit) to generate the population mean and standard deviation.

For more detailed information, please see Elzinga et al. (2001) or Bonham (1989).

Option 3, Equation 1: determining the necessary sample size for detecting a difference between two means with permanent sampling units that will be evaluated with a paired t-test.

When paired sampling units are being compared, or when data from permanent plots or transects are being compared between two time periods, then sample size determination requires a different procedure than if samples are independent of one another. The equation for determining the number of samples necessary to detect some true difference between two sample means generated at different times from the same monitoring plot or transect is:

$$n = \frac{(s_{diff})^2(Z_\alpha + Z_\beta)^2}{(MDC)^2} \qquad \text{(Equation 1)}$$

Where:

s_{diff} = Standard deviation of the differences between paired samples (see equation and examples below).

Z_α = Z-coefficient for the false-change (Type I) error rate from Table C.21a below.

Z_β = Z-coefficient for the missed-change (Type II) error rate from Table C.21b below.

MDC = Minimum detectable change size. This needs to be specified in absolute terms. For example, if you wanted to detect a 20 percent change in the sample mean from one year to the next and your first year sample mean = 10 plants/plot or transect, then MDC = (0.20 x 10) = 2 plants/plot or transect. Similarly, a change from 10 to 15 percent bare ground is a 5 percent change.

Table C.21a. Table of standard normal deviates for Z_α.

False-change (Type I) error rate (α)	Z_α
0.40	0.84
0.20	1.28
0.10	1.64
0.05	1.96
0.01	2.58

Table C.21b. Table of standard normal deviates for Z_β.

Missed-change (Type II) error rate (β)	Power	Z_β
0.40	0.60	0.25
0.20	0.80	0.84
0.10	0.90	1.28
0.05	0.95	1.64
0.01	0.99	2.33

How many measurements?

If the objective is to track changes over time with permanent sampling plots and only a single year of data is available, then you will not have a standard deviation of differences between paired samples. If you have an estimate of the likely degree of correlation between the two years of data, and you assume that the among-sampling units standard deviation is going to be the same in the second time period, then you can use the equation below to estimate the standard deviation of differences.

$$s_{diff}=(s_1)(\sqrt{(2(1-corr_{diff}))})$$

Where:

s_{diff} = Estimated standard deviation of the differences between paired samples.

s_1 = Sample standard deviation among sampling units at the first time period.

$corr_{diff}$ = Correlation coefficient, or rho, between sampling unit values in the first time period and sampling unit values in the second time period (this is the square root of r^2 (=r) from a regression and is the "rho" discussed in the introduction above).

Example 1:

Management objective:

Achieve at least a 20 percent higher density of Species F at Site Y in areas excluded from grazing as compared to grazed areas in 1999 (landscape scale).

Sampling objective:

I want to be able to detect a 20 percent difference in mean plant density in areas excluded from grazing versus adjacent paired grazed areas. I want to be 90 percent certain (power = 0.9) of detecting that difference, if it occurs. I am willing to accept a 10 percent chance ($\alpha = 0.1$) that I will make a false-change error (concluding that a difference exists when it really does not).

Results from pilot sampling:

Five paired plots (a total of 10 plots) were sampled where one member of the pair was excluded from grazing (with a small exclosure) and the other member of the pair was open to grazing.

Table C.22. Summary statistics for the differences between the two sets of plots.

Plot number	Number of plants/plot		Difference between grazed and ungrazed
	Grazed	Ungrazed	
1	2	3	1
2	5	8	3
3	4	9	5
4	7	12	5
5	3	7	4
	$\bar{x}$=4.20 s=1.92	$\bar{x}$=7.80 s=3.27	$\bar{x}_{diff}$=3.60 s_{diff}=1.67

Given:
The sampling objective specified a desired minimum detectable difference (i.e., equivalent to the *MDC*) of 20 percent. Taking the larger of the two mean values (ungrazed from Table C.22) and multiplying by 20 percent leads to: (7.80 x 0.20) = ***MDC* = 1.56** plants/plot. The larger mean is used because the result generates a more conservative test.

The appropriate **standard deviation** to use is **1.67** (from Table C.22), the standard deviation of the differences between the pairs of plots.

The acceptable **False-change error rate (α)** is 0.10. Therefore the appropriate Z_α from Table C.21a is **1.64**.

The desired **Power** is 90 percent (0.90), so the **Missed-change error rate** (β) **= 0.10**. The appropriate Z_β coefficient from Table C.21b is **1.28**.

Calculate the estimated necessary sample size using the equation provided below:

$$n = \frac{(s_{diff})^2(Z_\alpha+Z_\beta)^2}{(MDC)^2} \qquad n = \frac{(1.67)^2(1.64+1.28)^2}{(1.56)^2} = 9.8$$

Round up 9.8 to 10 plots.

Thus, the final estimated sample size needed to be 90 percent certain of detecting a true difference of 1.56 plants/plot between the grazed and ungrazed plots with a false-change error rate of 0.10 = **10 plots.**

Example 2:
Management objective:
Increase the density of species F at site Q by 20 percent between 1999 and 2002 (landscape scale).

Sampling objective:
I want to be able to detect a 20 percent difference in mean plant density of species F at site Q between 1999 and 2002. I want to be 90 percent certain of detecting that change, if it occurs. I am willing to accept a 10 percent chance that I will make a false-change error (conclude that a difference exists when it really does not).

The procedure for determining the necessary sample size for this example would be very similar to the previous example. Replace "grazed" and "ungrazed" in Table C.22 with "1999" and "2002" and the rest of the calculations would be the same. Because the sample size determination procedure needs the standard deviation of the difference between two samples, you will not have the necessary standard deviation term to plug into the equation until you have two years of data. However, the standard deviation of the difference can be *estimated* in the first year. You will need an estimate of the correlation coefficient between sampling unit values in the first time period and the sampling unit values in the second time period (see the s_{diff} equation above).

Correction for sampling finite populations
The above formula assumes that the population is very large compared to the proportion of the population that is sampled. If you are sampling more than five percent of the entire population area, you should apply a correction to the sample size estimate. This correction incorporates the finite population correction factor (FPC). This will reduce the sample size. The formula for correcting the sample size estimate is as follows:

$$n' = \frac{n}{(1 + (n / N))}$$

Where:

n' = The new sample size based upon inclusion of the finite population correction factor.

n = The original sample size estimate from the equation: $n = \frac{(s_{diff})^2(Z_\alpha+Z_\beta)^2}{(MDC)^2}$

N = The total number of possible plot locations in the population. To calculate N, determine the total area of the population and divide by the size of each individual sampling unit (plot).

Example:
If the pilot data described above was gathered using a 1 m x 10 m (10 m^2) plot and the total population being sampled was located within a 10 m x 50 m macroplot (500 m^2), then N = 500 m^2 ÷ 10 m^2 = 50. The corrected sample size would then be:

$$n' = \frac{n}{(1 + (n / N))} \qquad n' = \frac{10}{(1 + (10 / 50))} = 8.3$$

Round 8.3 to 8.

The new, FPC-corrected estimated sample size needed to be 90 percent confident of detecting a true difference of 1.56 plants/plot between the grazed and ungrazed plots with a false-change error rate of 0.10 = **8 plots**.

Note on the statistical analysis for two sample tests from finite populations
If you have sampled more than five percent of an entire population, you should apply the finite population correction factor to the results of the statistical test. This procedure involves dividing the test statistic by the square root of (1-n/N). For example, if your *t*-statistic from a particular test turned out to be 1.782 and you sampled n=8 plots out of a total N=50 possible plots, then your correction procedure would look like the following:

$$t' = \frac{t}{\sqrt{1 - (n / N)}} \qquad t' = \frac{1.782}{\sqrt{1 - (8 / 50)}} = 1.944$$

Where:

t = The *t*-statistic from a *t*-test.

t' = The corrected *t*-statistic using the FPC.

n = The number of plots or units sampled.

N = The total number of possible plot locations in the population. To calculate N, determine the total area of the population and divide by the size of each individual sampling unit.

You would then need to look up the *p*-value of t' = 1.944 in a *t*-table for the appropriate degrees of freedom to obtain the correct *p*-value for this statistical test.

Option 3, Equation 2: Determining the necessary sample size for detecting a difference between a single mean and a threshold value that will be evaluated with a one-sample t-test.

Here is the equation for determining sample size when a single mean value is going to be compared with some threshold value:

$$n = \frac{(s)^2(Z_\alpha + Z_\beta)^2}{(MDC)^2} \qquad \text{(Equation 2)}$$

Where:

s = Standard deviation of the sample.

Z_α = Z-coefficient for the false-change (Type I) error rate from Table C.21a.

Z_β = Z-coefficient for the missed-change (Type II) error rate from Table C.21b.

MDC = Minimum detectable change from the threshold. This needs to be specified in absolute terms rather than as a relative percentage. For example, if you wanted to detect a 20 percent difference from a threshold density of 30 plants/plot then *MDC* = (0.20 x 30) = 6 plants/plot. Similarly, a change from 10 to 15 percent bare ground is a five percent change.

Example 1:
Management objective:
Maintain a population of species Y in population Z with a density of at least 25 plants/plot for the next 10 years.

Sampling objective:
I want to be able to detect a 20 percent difference in mean plant density from a threshold density of 25 plants/plot. I want to be 90 percent certain of detecting this difference, if it occurs. I am willing to accept a 10 percent chance that I will make a false-change error (conclude that the mean is different from the threshold when it really is not).

Results from pilot sampling:
Mean ($\bar{X}$) = **31** plants/plot
Standard deviation (s) = 7 plants.

Given:
The acceptable **False-change error rate (α) = 0.10**, so the appropriate Z_α from Table C.21a = **1.64**.

The desired **Power** is 90 percent (0.90) so the **Missed-change error rate (β) = 0.10** and the appropriate Z_β coefficient from Table C.21b = **1.28**.

The **Minimum Detectable Change (*MDC*)** is 20 percent of the threshold value or (0.20 x 25)= **5** plants/plot.

Calculate the estimated necessary sample size using the equation provided above:

$$n = \frac{(s)^2(Z_\alpha+Z_\beta)^2}{(MDC)^2} \qquad n = \frac{(7)^2(1.64+1.28)^2}{(5)^2} = 16.7$$

Round up 16.7 to 17 plots.

Final estimated sample size needed to be 90 percent confident of detecting a difference of five plants from the threshold density of 25 plants with a false-change error rate of 0.10 = **17 plots.**

Correction for sampling finite populations
The above formula assumes that the population is very large compared to the proportion of the population that is sampled. If you are sampling more than five percent of the entire population area, you should apply a correction to the sample size estimate. This correction incorporates the finite population correction (FPC) factor. This will reduce the sample size. The formula for correcting the sample size estimate is as follows:

$$n' = \frac{n}{(1 + (n / N))}$$

Where:

n' = The new sample size based upon inclusion of the finite population correction factor.

n = The sample size from the equation: $n = \frac{(s)^2(Z_\alpha+Z_\beta)^2}{(MDC)^2}$

N = The total number of possible plot locations in the population. To calculate N, determine the total area of the population and divide by the size of each individual sampling unit.

Example 2:
If the pilot data described above was gathered using a 1 m x 10 m (10 m^2) plot and the total population being sampled was located within a 20 m x 50 m macroplot (1000 m^2) then N = 1000 m^2/10 m^2 = 100. The corrected sample size would then be:

$$n' = \frac{n}{(1 + (n / N))} \qquad n' = \frac{17}{(1 + (17 / 100))} = 14.5$$

Round up 14.5 to 15.

The new, FPC-corrected estimated sample size needed to be 90 percent certain of detecting a difference of five plants from the threshold density with a false-change error rate of 0.10 = **15 plots**.

Note on the statistical analysis for two sample tests from finite populations
If you have sampled more than five percent of an entire population, you should apply the finite population correction factor to the results of the statistical test. This procedure involves dividing the test statistic by the square root of the finite population factor (1-n/N). For example, if your t-statistic from a particular test turned out to be 1.645 and you sampled n=26 plots out of a total N=100 possible plots, then your correction procedure would look like the following:

$$t' = \frac{t}{\sqrt{1 - (n / N)}} \qquad t' = \frac{1.645}{\sqrt{1 - (26 / 100)}} = 1.912$$

Where:

t = The *t*-statistic from a *t*-test.
t' = The corrected *t*-statistic using the FPC.
n = The number of plots (or units) sampled.
N = The total number of possible plot locations in the population. To calculate N, determine the total area of the population and divide by the size of each individual sampling unit.

You would then need to look up the *p*-value of $t' = 1.912$ in a *t*-table at the appropriate degrees of freedom to obtain the correct *p*-value for this statistical test.

Appendix D: Soil Quality Information Sheets

Additional information on soil indictors is available in a series of information sheets about soil quality and rangelands. Rangeland Soil Quality Information Sheets (USDA-NRCS 2001) address soil properties that change in response to management and climate. Refer to these sheets for a description of soil properties that can serve as indicators, factors affecting them and general management strategies to improve them.

Available on line at: http://soils.usda.gov/sqi/management/gl_mgmt.html (accessed June 23, 2008).

Rangeland Soil Quality Information Sheets (accessed June 23, 2008)

1. Rangeland Soil Quality — Introduction
   (http://soils.usda.gov/sqi/management/files/RSQIS1.pdf)

2. Rangeland Soil Quality — Indicators for Assessment and Monitoring
   (http://soils.usda.gov/sqi/management/files/RSQIS2.pdf)

3. Rangeland Soil Quality — Aggregate Stability
   (http://soils.usda.gov/sqi/management/files/RSQIS3.pdf)

4. Rangeland Soil Quality — Compaction
   (http://soils.usda.gov/sqi/management/files/RSQIS4.pdf)

5. Rangeland Soil Quality — Infiltration
   (http://soils.usda.gov/sqi/management/files/RSQIS5.pdf)

6. Rangeland Soil Quality — Organic Matter
   (http://soils.usda.gov/sqi/management/files/RSQIS6.pdf)

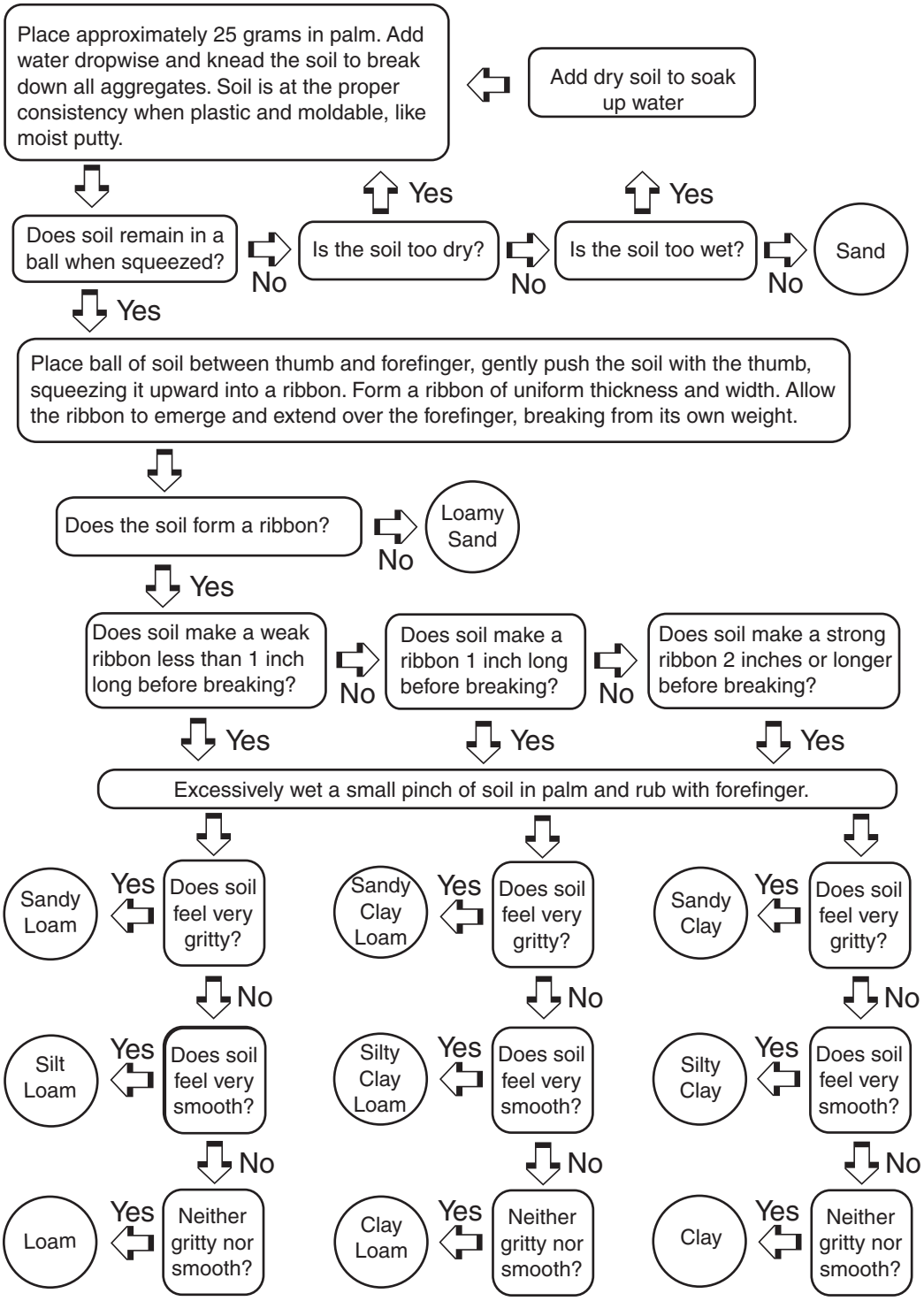
7. Rangeland Soil Quality — Physical and Biological Soil Crusts
   (http://soils.usda.gov/sqi/management/files/RSQIS7.pdf)

8. Rangeland Soil Quality — Soil Biota
   (http://soils.usda.gov/sqi/management/files/RSQIS8.pdf)

9. Rangeland Soil Quality — Water Erosion
   (http://soils.usda.gov/sqi/management/files/RSQIS9.pdf)

10. Rangeland Soil Quality — Wind Erosion
    (http://soils.usda.gov/sqi/management/files/RSQIS10.pdf)

Appendix E: Soil texture chart



Glossary

An asterisk (*) indicates a term used in this manual. Other terms commonly used in rangeland monitoring are also included for reference.

Abundance The total number of individuals of a species in an area, population or community (SRM 1999).

Accuracy* The closeness of a measured or computed value to its true value (Elzinga et al. 2001). See also **precision***.

Active fraction The highly dynamic or labile portion of **soil organic matter*** that is readily available to soil organisms. May also include the living biomass. Particulate organic matter (POM) and light fraction (LF) are measurable indicators of the active fraction. POM particles are larger than other SOM and can be separated from soil by sieving. LF particles are lighter than other SOM and can be separated from soil by centrifugation.

Annual plant A plant that completes its life cycle and dies in one year or less. See also **biennial plant** and **perennial plant** (SRM 1999).

Annual production* (syn. **primary production**) The conversion of solar energy to chemical energy through the process of photosynthesis. It is represented by the total quantity of organic material produced within a year (SRM 1999). See **total annual production***.

ARS* Agricultural Research Service.

Aspect* The direction a slope faces.

Assessment* The process of estimating or judging the value or functional status of ecological processes (e.g., **rangeland health***).

Attribute* One of the three components—soil and site stability, hydrologic function, and integrity of the biotic community—that collectively define **rangeland health***.

Azimuth* Compass direction; from 0 to 360°.

Bank-full* The bank-full stage corresponds to the water level (stream discharge) just below the point that water enters the floodplain. It is the most effective stage for maintaining the shape of stream channels. The following features can be used to identify bank-full: top of the point bar, significant changes in vegetation, topographic slope break, change in size, staining or color of substrate, and change in the nature and amount of debris deposits. Definition and examples derived from Dunne and Leopold (1978), Rosgen (1996) and Prichard et al. (1998a). Bank-full flow events generally occur an average of every 18 months (R. Baker, pers. comm.). They occur less frequently in incised channels.

Bank angle* The slope of the bank. See Chapter 14 for calculations.

Bare ground* (bare soil) All land surface not covered by vegetation, rock or litter (SRM 1999). As used in this document, visible biological crusts and standing dead vegetation are included in cover estimates and are not bare ground. Bare ground should always be clearly defined for each monitoring program because there are many definitions.

Bare ground (%)* Bare ground occurs where there are no plant or litter intercepts, and mineral soil is intercepted. Bare ground (%) is calculated by counting the number of points with "None" in the top layer column, nothing in any of the "Lower layers" columns and "S" in the "Soil surface" column. Divide this sum by the total number of points sampled. Multiply this value by 100.

Basal area* (plants) (syn. **basal area**) The cross-sectional area of the stem or stems of a plant or of all plants in a stand. Basal area is measured at or near ground level (SRM 1999).

Basal cover (%)* Basal cover is the area covered by plant bases. Basal cover (%) is the percent of the soil surface covered by plant bases in the Line-point intercept method. Basal cover (%) is calculated by counting the number of basal intercepts in the "Soil surface" column. Divide this sum by the total number points sampled. Multiply this value by 100.

Basal gap A space between plant bases that is not occupied by rooted vegetation when viewed as a vertical projection from the transect tape edge to the ground. Minimum gap sizes are defined by the user, and are usually 20 cm (0.7 ft). Vegetation stems of any diameter, even 1 mm, can start or stop a basal gap, as long as they are rooted in soil. Vegetation may occur as live or standing dead. User must define if gaps can be terminated by any plant, or by perennial plants only.

Biennial plant* A plant that completes its life cycle and dies in two years or less. See also **annual plant** and **perennial plant**.

Biological crust* Microorganisms (e.g., lichens, algae, cyanobacteria, microfungi) and non-vascular plants (e.g., mosses, lichens) that grow on or just below the soil surface.

Biomass* (plants) The total amount of living plants above and below ground in an area at a given time (SRM 1999).

Biotic integrity* 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 such disturbance. See also **soil and site stability***, **hydrologic function*** and **rangeland health***.

BLM* Bureau of Land Management (**USDI***).

C-3 plant A plant employing the pentose phosphate pathway of carbon dioxide assimilation during photosynthesis; a cool-season plant (USDA-NRCS 1997).

C-4 plant A plant employing the dicarboxylic acid pathway of carbon dioxide assimilation during photosynthesis; a warm-season plant (USDA-NRCS 1997).

Canopy cover The amount of ground covered by the vertical projection of the outer foliage and branches of a plant. Canopy cover overestimates the area of ground covered by vegetation because open spaces within a plant's canopy are not excluded from the canopy cover estimate. Compare to Foliar cover.

Glossary

Canopy gap A space between plant canopies that is not occupied by rooted vegetation when viewed as a vertical projection from the canopy edge to the ground. Minimum gap sizes are defined by the user, and are usually 20 cm (0.7 ft). Vegetation may occur as live or dead. Edges of canopy gaps are defined as a point along a transect tape where at least 50% of a 3 cm segment of tape edge intercepts live or dead plant canopy. User must define if gaps can be terminated by any plant, or by perennial plants only.

Climate* The average or prevailing weather conditions of a place over a period of years (SRM 1999).

Community pathway Shifts in plant species compositions among biological communities within a single state.

Compaction layer* A layer of dense soil at or near the surface, caused by repeated impact on or disturbance of the soil surface. When soil is compacted, soil grains are rearranged, pore spaces are decreased and soil particles are brought into closer contact with one another, thereby increasing bulk density (SSSA 1997).

Composition* The proportions of various plant species in relation to the total on a given area; it may be expressed in terms of cover, density, weight, etc. (SRM 1999).

Cover* The proportion of the soil surface covered by a vertical projection of the cover class of interest, regardless of what is above or below the object: plant parts (**foliar cover***), plant bases (**basal cover***), woody and herbaceous litter (**litter cover***), lichens, mosses, duff, etc. The opposite of **bare ground***.

Cover by functional group (%)* A subset of **foliar cover***. Cover by functional group is the proportion of the soil surface covered by the vertical projection of plant canopies belonging to a specific **functional group**. Calculate cover by functional group by first determining which plant species belong to the functional group. Then count the total number of sample points where species in the designated functional group are intercepted. Divide this sum by the total number of sample points. Multiply this value by 100.

Cover by species resistant to fire, grazing, traffic, etc.* A subset of **foliar cover***. Cover by species resistant to fire, grazing, traffic, or cover by invasive species is the proportion of the soil surface covered by the vertical projection of plant canopies belonging to the specific group. Calculate cover by species resistant to fire, grazing, traffic, or cover by invasive species by first determining which plant species belong to the designated group. Then count the total number of sample points where species in the designated group are intercepted. Divide this sum by the total number of points sampled. Multiply this value by 100. See also **foliar cover***.

Culm A jointed grass stem. This may or may not be hollow.

DBH* See **diameter at breast height*.**

Declination* Angle, in degrees, between magnetic north and geographical north.

Decomposition* The biochemical breakdown of organic matter into its original compounds and nutrients.

Diameter at Breast Height (DBH)* The diameter of a tree at breast height (1.4 m or 4.5 ft above the ground), measured outside of the bark (USDA Forest Service 2003).

Diameter at Root Collar (DRC)* The diameter of a tree measured at the ground line or stem root collar, measured outside of the bark.

DOQQ* Digital Orthophoto Quarter Quadrangle.

DRC* See **diameter at root collar**.

Duff* Partially decomposed plant litter. It consists of decomposing leaves and other organic material. You should see NO recognizable plant parts. When moss is present, the top of the duff layer is just below the green portion of the moss. The bottom of this layer is the point where mineral soil (A horizon) begins. See also **litter*** and **embedded litter***.

Ecological processes* Ecological processes include the water cycle (the capture, storage and redistribution of precipitation), energy flow (conversion of sunlight to plant and animal matter) and nutrient cycle (the cycle of nutrients, such as nitrogen and phosphorus, through the physical and biotic components of the environment). Ecological processes functioning within a normal range of variation at an ecological site will support specific plant and animal communities.

Ecological reference area An area representing a single ecological site in which ecological processes are functioning within a normal range of variability, and the plant community has adequate resistance to and resiliency from most disturbances. These areas do not need to be pristine, historically unused lands (e.g., climax plant communities or relict areas).

Ecological site* (syn. **rangeland ecological site**) A kind of land with specific physical characteristics, which differs from other kinds of land in its ability to produce distinctive kinds and amounts of vegetation and in its response to management. Apparently synonymous with ecological type used by USDA Forest Service (SRM 1999).

Ecological site description* Description of the soils, uses and potential of land with specific physical characteristics that produces distinctive kinds and amounts of vegetation.

Ecosystem* Organisms, together with their abiotic environment, that form an interacting system and inhabit an identifiable space (SRM 1999).

Embedded litter* Non-decomposed, detached plant material (**litter***) partially implanted or set in the soil surface such that, if the litter is removed, it will leave an indentation in the soil's surface. See also **litter***, **duff***.

Energy flow Conversion of sunlight to plant and animal matter; one of the **ecological processes***.

Erodibility* (syn. **soil erodibility***) The degree or intensity of a soil's state or condition of, or susceptibility to, being eroded by wind or water (adapted from SSSA 1997).

Erosion* Detachment and movement of soil or rock fragments by water, wind, ice, gravity; the process whereby the land surface is worn away by running water, wind, ice or other geological agents, including such processes as gravitational creep (SRM 1999).

Erosivity* The capacity of rainfall to detach soil particles. This is a function of raindrop size and rainfall intensity.

Exotic plant* A plant growing or occurring in an ecosystem that is beyond its natural range of existence or natural zone of potential dispersal (SRM 1999).

Flow pattern The path that water takes (i.e., accumulates) as it moves across the soil surface during overland flow.

Foliage height diversity (FHD)* Foliage height diversity is the vertical structural diversity of vegetation. It is calculated using the Shannon-Weiner diversity index. See Chapter 11 for calculations from the Vegetation structure method. The same calculations can be applied to the Line-point intercept with Height method (Ch. 15); given height classes are developed (such as 0-50 cm, 51-100 cm, 101-150 cm and 151-200 cm). See also **vegetation structure***.

Foliar cover* Proportion of the soil surface covered by a vertical projection of a plant cover. This is effectively the area that is protected from raindrops and the area in shade when the sun is directly overhead. This is the definition used in erosion models.

Foliar cover (%)* Foliar cover (%) is calculated by counting the number of plant intercepts ("Top layer" = species code). Divide this sum by the total number of points sampled. Multiply this value by 100.

Forb* Any broad-leafed, herbaceous plant, other than those in the Poaceae (grasses), Cyperaceae (sedges) and Juncaceae (rushes) families (SRM 1999). May or may not be woody.

Functional/structural groups* A suite or group of species that, because of similar shoot or root structure, photosynthetic pathways, nitrogen-fixing ability, life cycle, etc., are grouped together.

GIS* Geographic Information System.

GPS* Global Positioning System.

Grassland* An area of vegetation dominated by herbaceous grasses. Grassland constitutes a major world vegetation type and occurs where there is sufficient moisture for grass growth, but where the environmental conditions, both climatic and anthropogenic, prevent tree growth. Its occurrence, therefore, is correlated with a rainfall intensity between that of desert and forest.

Greenline* The first perennial vegetation that forms a lineal grouping of community types on or near the water's edge. It occurs most often at or slightly below the bank-full stage (Winward 2000).

Ground cover* The percentage of material (e.g., **litter***, **standing dead vegetation***, gravel/rocks, vegetation and **biological crust***) excluding **bare soil***, covering the land surface. See also **soil surface***.

Gully A furrow, channel or miniature valley, usually with steep sides, through which water commonly flows during and immediately after rains or snow melt (SRM 1999).

Half-shrub (syn. **sub-shrub**) A perennial plant with a woody base, whose annually produced stems die each year (SRM 1999).

Hillslope profile component* The landscape element along a hill's slope. Distinguished by shape, position and long-term erosion or sedimentation related to soil formation. These components include: summit, shoulder, backslope, footslope and toeslope (Wysocki and Zanner 2003).

Horizontal slope shape* The geometric shape along an elevation contour across the hillslope (the elevation contour). Slope shape can be convex, concave or linear. Compare with **vertical slope shape***.

Humus (syn. **stabilized organic matter**) Usually a synonym for stabilized organic matter, but is sometimes used to refer to all soil organic matter (SSSA 1997). See **stabilized organic matter**.

Hydrologic function* The capacity of a site to capture, store and safely release water from rainfall, run-on and snowmelt (where relevant); to resist a reduction in this capacity; and to recover this capacity following degradation (one of the three attributes of **rangeland health***). See also **biotic integrity*** and **soil and site stability***.

Indicators* Components of a system whose characteristics (e.g., presence or absence, quantity, distribution) are used as an index of an attribute (e.g., **biotic integrity***) that is too difficult, inconvenient or expensive to measure.

Infiltration* The entry of water into the soil (SSSA 1997).

Infiltration rate (mm/hr)* The rate (or speed) at which water infiltrates the soil during a specified time period. See Chapter 8 for calculations. **Ratio of interspace:under plant canopy*** is calculated by dividing the average infiltration rate in plant canopy interspaces (Veg class = NC) by the average infiltration rate under plant canopies (Veg class = G, Sh, F or T). See also **infiltration***.

INIFAP* Instituto Nacional de Investigaciones, Agricolas y Forestales (Mexico).

Interspace* An area between the canopies of two or more plants, or between the bases of two or more plants. Interspaces can consist of **bare soil**, **litter***, plants of a different **functional group*** (i.e., grass between shrubs), or soil surface features, including rocks, **biological crusts***, **duff*** and **embedded litter***.

Invasive plant* Plants that are not part of (exotic) or a minor component of (native) the original plant community or communities that increase above what's expected given the normal range of variability of a site.

Inventory (syn. rangeland inventory): **(1)** The systematic acquisition and analysis of resource information needed for planning and management of rangeland; **(2)** the information acquired through rangeland inventory (SRM 1999).

Landscape unit* A type of land that can be defined based on slope, aspect, landscape position (including elevation) and soil. Landscape units repeat across the landscape for a particular region. Landscape unit is a generic term that is generally equivalent to ecological sites used by the NRCS and ecological types used by the USFS. The only difference is that ecological sites and types are defined at a particular scale (generally including several soil series). Landscape units can be defined very coarsely (e.g., basin vs. range) or extremely finely (e.g., Stellar fine sandy loam on east-facing 1-2% slopes), depending on objectives. It is appropriate to substitute either the term "ecological site" or "ecological type" for "landscape unit" throughout this manual.

Lineal* Along a line.

Litter* The uppermost layer of organic debris on the soil surface; essentially, the freshly fallen or slightly decomposed plant matter (SRM 1999). Includes persistent and non-persistent organic matter that is in contact with the soil surface (i.e., not rooted in the soil). See also **embedded litter***, **duff***, **woody litter*** and **litter cover (%)***.

Litter cover (%)* The proportion of the soil surface covered by a vertical projection of **litter***. Calculate litter cover (%) by counting the total number of sample points where litter (L or WL) is intercepted. Divide this sum by the total number of points sampled. Multiply this value by 100. See also **litter***, **woody litter***, **foliar cover***, **bare ground*** and **basal cover***.

Minimum estimate of species richness* A minimum estimate of the total number of species in an area. This can be estimated from the Line-point intercept or Plant production methods. Simply count the number of species detected with either method, making sure not to count the same species twice. See also **species richness***.

Monitoring* The orderly and quantitative collection, analysis and interpretation of resource data to evaluate progress toward meeting management objectives. The process must be conducted over time in order to determine whether or not management objectives are being met (SRM 1999).

Monitoring plot* A transect or set of transects (plot) permanently located within a monitoring unit from which monitoring data are collected.

Monitoring site* (syn. **monitoring plot***) Locations selected for monitoring.

Monitoring unit* Areas located on a particular part of the landscape (e.g., valley bottom), within which vegetation, soil type, use intensity, and the status of the soil and vegetation are relatively homogeneous. Monitoring units may range in size from less than an acre to a square mile or more and may be repeated across the landscape. Not all monitoring units will actually be monitored. A monitoring unit in riparian zones is equivalent to a riparian complex. Monitoring units are typically smaller than, and subsets of, a **landscape unit***.

Normal variability or **normal range of variability*** The deviation of characteristics of biotic communities and their environment that can be expected, given natural variability in climate and disturbance regimes.

Noxious weed Any plant designated by a federal, state or county government to be injurious to public health, agriculture, recreation, wildlife, or any public or private property (Sheley et al. 1999).

NRCS* National Resources Conservation Service (**USDA***)

Number of strikes per depth increment* The number of impact penetrometer strikes for each depth increment (0-5 cm, 5-10 cm, 10-15 cm, 15-20 cm, etc.). This is not the cumulative number of strikes per depth (see Chapter 7). **Ratio of interspace:under plant canopy*** is calculated by dividing the average number of strikes in plant canopy interspaces (Veg class = NC) by the average number of strikes under plant canopies (Veg class = G, Sh, F or T) for each depth increment. See also **compaction layer***.

Organic matter* Any material that is part of, or originated from, living organisms. Includes **soil organic matter***, plant residue, mulch, compost, and other materials (SSSA 1997). See also **soil organic matter***.

Parent material The unconsolidated and more or less chemically weathered rocks, mineral matter or organic accumulations (e.g., peat) from which soils are developed by pedogenic processes (simplified from SSSA 1997).

PDF* Portable Document Format. Documents in a format easily downloaded, viewed and printed from the Internet.

Pedestal (erosional)* Plants or rocks that appear elevated as a result of soil loss by wind or water erosion (does not include plant or rock elevation as a result of non-erosional processes such as frost heaving). Compare to **terracette**.

Pedon. A three-dimensional body of soil with lateral dimensions large enough to permit the study of horizon shapes and relations. Its area ranges from 1 to 10 m^2 (10 to 100 ft^2) (see SSSA 1997 for more detail).

Percent basal cover* See **basal cover (%)***.

Perennial plant* A plant that has a life span of three or more years (USDA-NRCS 1997). See also **annual plant** and **biennial plant**.

Physical crust* Impact of raindrops on bare soil causes the soil surface to seal and form a thin surface layer that inhibits water absorption.

Plant base* Located above the roots and below the stems of a plant, at and just above the soil surface.

Plant decadence In a plant community, decadence refers to an overabundance of dead or dying plants relative to what is expected for a site, given the natural range of variability in disease, climate and management influences.

Plant density* The number of individuals per unit area (see Chapter 15).

Plant density by size class* The number of individuals, within a given size class, per unit area. See Chapter 15 for calculations.

Plant production* See **total annual production***.

Polypedon. A group of contiguous similar pedons. The limits of a polypedon are reached where there is no soil, or where the pedons have characteristics that differ significantly (SSSA 1997).

Precision* The closeness of repeated measurements of the same quantity (Elzinga et al. 2001). See also **accuracy***.

Primary production See **annual production***.

Production by plant species* (or annual production by plant species) All aboveground plant biomass produced during a single growing year for a given plant species. Production by plant species is expressed in pounds per acre (lb/ac). See Chapter 9 for methods of estimating and calculating total annual production. See also **total annual production***.

Production by functional group* (or annual production by functional group) All aboveground plant biomass produced during a single growing year for a given plant **functional group***. Calculate production by functional group by first determining which plant species belong to the functional group. Using the methods described in Chapter 9 for estimating and calculating total annual production, measure and calculate production by plant species. Then add together annual plant production for each individual species in the functional group to determine plant production for the functional group. Production by functional group is expressed in pounds per acre (lb/ac). See also **total annual production***, **production by plant species*** and **functional/structural groups***.

Proportion of dead plant intercepts (by species)* For a given species, count the number of dead plant intercepts (i.e., hit a dead plant part; the entire plant does not have to be dead). Divide this sum by the total number of plant intercepts for the selected species. Multiply this value by 100.

PVC* Polyvinyl Chloride.

Qualitative data* Non-quantitative data derived from observations, commonly visual, and recorded descriptively. Qualitative data is not measured (e.g., descriptive or non-numerical data).

Qualitative rangeland health assessment The determination of the functional status of an attribute(s) through non-numerical observations of indicators. Qualitative assessments have an element of subjectivity.

Quantitative data* Data derived from measurements, such as counts, dimensions, weights, etc., and recorded numerically; may include ratios or other values. Qualitative numerical estimates, such as ocular cover and production estimates, are often referred to as "semi-quantitative."

Quantitative rangeland health assessment The determination of the functional status of an attribute(s) through measurements of vegetation, soil or landscape characteristics that are indicators, or can be used to derive indicators. Quantitative assessments have a known level of precision and accuracy, and require a quantitative reference value for comparison.

Rangeland* Land on which the indigenous vegetation (climax or natural potential) is predominantly grasses, grass-like plants, forbs or shrubs and is managed as a natural ecosystem. If plants are introduced, they are managed similarly. Rangelands include natural grasslands, savannas, shrublands, many deserts, tundra, alpine communities, marshes and wet meadows (SRM 1999). Oak and piñon-juniper woodlands could also be included in this definition.

Rangeland ecological site See **ecological site*.**

Rangeland health* The degree to which the integrity of the soil, vegetation, water and air, as well as the ecological processes of the rangeland ecosystem, are balanced and sustained. Integrity is defined as maintenance of the structural and functional attributes characteristic of a locale, including normal variability (SRM 1999) (see footnote at end of Glossary).

Ratio of interspace:under plant canopy* See **infiltration rate (mm/hr)*** for infiltration (Single-ring infiltrometer) and **number of strikes per depth increment*** for compaction (Compaction test).

Reference area or **site** A landscape unit or monitoring unit at the **reference state**. Often used or referred to for **qualitative** and **quantitative assessments.**

Reference state* The state where functional capacities represented by soil and site stability, hydrologic function and biotic integrity are performing at an optimum level under the natural disturbance regime. This state usually includes, but is not limited to, what is often referred to as the potential native plant community (PNC).

Resilience* The capacity of ecological processes to recover following a disturbance. Resilience can be defined in terms of the rate of recovery, the extent of recovery during a particular period of time, or both.

Resistance* The capacity of ecological processes to continue to function without change following a disturbance.

Rhizomatous plant A plant that develops clonal shoots by producing rhizomes. Rhizomes are horizontal underground stems that usually produce roots and shoots from nodes (SRM 1999).

Rill* A small, intermittent watercourse with steep sides, usually no more than several centimeters deep (SSSA 1997). Rills generally are linear erosion features.

Riparian colonizing species* Plant species that become established in open, barren areas. They are often among the first plants to occupy open sites. In riparian areas they "colonize" edges of bars or areas where stream banks have freshly eroded. They are rhizomatous/stoloniferous in growth form, but the roots are shallow and the stems are relatively weak. Although they are short-lived, they have a capacity to grow very rapidly—up to one to four centimeters per day. They initiate shallow roots every few centimeters and, as water force aligns their stems parallel to the water's edge, they develop temporary bands/stringers of vegetation along stream edges. Their primary function is to filter and catch very fine (flour-like) sediments and build substrate for the stronger, more permanent "stabilizing" species (see definition for **riparian stabilizing species***). As such, they play a crucial role in initiating recovery/maintenance of stream banks. Typical examples include brookgrass (*Catabrosia aquatica*) and water-cress (*Rorippa nasturtium-aquaticum*) (Winward 2000).

Riparian complex* A unit of land characterized by a unique set of biotic and abiotic factors. Complexes are identified on the basis of their topography, soils, stream gradient, associated water flow features, and their general vegetation patterns. A riparian complex is similar in definition to a valley segment, except that the valley segment refers to the stream channel proper, while the riparian complex is used to describe the full width of the riparian area across a particular portion of a valley. Generally, a limited set of stream reaches is nested within a given riparian complex (Winward 2000).

Riparian greenline* See **greenline***.

Riparian stabilizing species* Plant species that become established along edges of streams, rivers, ponds and lakes. Although they generally require hydric settings for establishment, some may persist in drier conditions once they become firmly established. They commonly have strong, cord-like rhizomes as well as deep fibrous root masses. In addition, they have coarse leaves and strong crowns, which, along with their massive root systems, are able to buffer stream banks against the erosive force of moving water. Along with enhancing streambank strength, they filter sediments and, with the force of water, build/rebuild eroded portions of stream banks. They likewise filter chemicals, which is important in improving water quality. The presence of these species, thereby, plays a significant role in attaining/maintaining proper functioning of riparian and aquatic ecosystems (based on Winward 2000).

Runoff* The portion of precipitation, snowmelt or irrigation on an area that does not infiltrate, but instead is discharged by the area (SSSA 1997).

Savanna* A plant community found between a tropical, subtropical or temperate forest biome and a desert biome; transitional in character between grassland or desert and forest, it typically has drought-resistant vegetation dominated by grasses with shrubs and scattered tall trees.

Shrub* A plant that has persistent, woody stems and a relatively low-growth habit, and that generally produces several basal shoots instead of a single trunk. It differs from a tree in its low stature (generally less than five meters, or sixteen feet) and non-arborescent form (SRM 1999).

Site* See **monitoring site***. See also **monitoring plot*** and **ecological site***.

Slope shape* The geometric shape of the hillslope (convex, concave or linear). See **vertical slope shape*** and **horizontal slope shape***.

Soil and site stability* The capacity of a site to limit redistribution and loss of soil resources (including nutrients and organic matter) by wind and water; one of the three **attributes*** of **rangeland health***.

Soil association Each delineation on the soil map shows the boundaries, shape and location of a **landscape unit*** composed of two or more **soil components***. The individual bodies of component soils are *large enough* to be delineated at the scale of mapping. Several to numerous bodies of each kind of component soil are apt to occur in each delineation, and they occur in a fairly repetitive and describable pattern (SSSA 1997).

Soil complex Each delineation on the soil map shows the boundaries, shape and location of a **landscape unit*** composed of two or more **soil components***. The individual bodies of component soils are *too small* to be delineated at the scale of mapping. Several to numerous bodies of each kind of component soil are apt to occur in each delineation, although their pattern may not be apparent (SSSA 1997).

Soil component* A subdivision of a soil series based on features that affect its use and management. For example, slope, stoniness and thickness (USDA-NRCS Soil Survey Staff 1993). See also **soil inclusion** and **soil map unit***.

Soil erodibility* See **erodibility***.

Soil inclusion One or more **soil component*** within a delineation of a **soil map unit***, not identified by the map unit name (i.e., is not one of the named component soils). Such soils or areas are either too small to be delineated separately without creating excessive map or legend detail, occur too erratically to be considered a named component, or are not identifiable by practical mapping methods. Inclusions reduce the homogeneity of map units (SSSA 1997).

Soil organic matter (SOM)* The total organic matter in the soil. It can be divided into three general pools: living biomass of microorganisms, fresh and partially decomposed residues (the **active fraction**), and the well-decomposed and highly stable organic material (**stabilized organic matter**). Surface **litter*** is generally not included as part of soil organic matter (SSSA 1997).

Soil map unit* A kind of soil, a combination of kinds of soil, or miscellaneous land type or types, that can be shown at the scale of mapping for the defined purposes and objectives of the survey. Soil map units are the basis for the delineations of a soil survey map (Donahue et al. 1977). See also **soil component***, **soil inclusion**, **soil complex** and **soil association**.

Soil particles (syn. soil separates) Mineral particles, <2.0 mm in equivalent diameter, ranging between specified size limits. The names and size limits of separates recognized by the USDA are: very coarse sand (1-2 mm); coarse sand (0.5-1 mm); medium sand (0.25-0.5 mm); fine sand (0.1-0.25 mm); very fine sand (0.05-0.5 mm); silt (0.002-0.05 mm); and clay (<0.002 mm) (SSSA 1997).

Soil quality* The capacity of a specific kind of soil to function within natural or managed ecosystem boundaries, to sustain biological productivity, maintain environmental quality, and promote plant and animal health (SSSA 1997) (see footnote at end of Glossary).

Soil series* The lowest category of U.S. system of soil taxonomy; a conceptualized class of soil bodies (**polypedon**s) that have limits and ranges more restrictive than all higher taxa. Soil series are commonly used to name dominant or codominant **polypedon**s represented on detailed soil maps. The soil series serve as a major vehicle to transfer soil information and research knowledge from one soil area to another.

Soil structure* The combination or arrangement of primary **soil particles** into secondary units or peds. The secondary units are characterized on the basis of size, shape and grade (degree of distinctiveness) (SSSA 1997). See http://soil.gsfc.nasa.gov/pvg/prop1.htm for diagrams illustrating different types of structure (accessed September 25, 2008).

Soil surface* Term used to indicate classes of material on or at the soil or land surface (e.g., plant base, rock fragments, bedrock, **embedded litter***, **duff***, mosses, lichens, dark cyanobacteria, or soil that is visibly unprotected by any of the above). See also **ground cover*.**

Soil surface in canopy gaps > __* The proportion (or percent) of the soil surface encompassed by gaps between plant canopies (as measured along a vegetation transect) that are longer than a specified minimum length. Determine the minimum gap size of concern, such as the minimum canopy gap at which wind erosion or weed invasion becomes a significant risk. List all canopy gap sizes that are equal to, or larger than the selected minimum canopy gap size. Add these gap sizes together. Divide this sum by the total length of the vegetation transect. Be sure to keep units consistent; if gaps are recorded in centimeters and line length in meters, convert line length to centimeters. Multiply this value by 100. See Volume I: Quick Start and Chapter 17 for further discussion on the Canopy Gap intercept method and canopy gaps.

Soil surface in basal gaps > __* The proportion (or percent) of the soil surface encompassed by gaps between plant bases (as measured along a vegetation transect) that are longer than a specified minimum length. Determine the minimum gap size of concern, such as the minimum basal gap at which water erosion or runoff becomes a significant risk. List all basal gap sizes that are equal to, or larger than the selected minimum basal gap size. Add these gap sizes together. Divide this sum by the total length of the vegetation transect. Be sure to keep units consistent; if gaps are recorded in centimeters and line length in meters, convert line length to centimeters. Multiply this value by 100. See Volume I: Quick Start and Chapter 17 for further discussion on the Basal Gap intercept method and basal gaps.

Soil survey* The systematic examination, description, classification and mapping of soils in an area. Soil surveys are classified according to the kind and intensity of field examination (SSSA 1997).

Soil texture* The relative proportions of the various **soil particles** (sand, silt and clay) (SSSA 1997).

Species composition* The proportions of various species in relation to the total in a given area. Plant species composition may be expressed in terms of cover, density or weight (SRM 1999).

Species richness* The total number of species in an area. This is one indicator of biodiversity. See Chapter 10 for calculations. See also **minimum estimate of species richness***.

SRM* Society for Range Management.

SSSA* Soil Science Society of America.

Stabilized organic matter (syn. **humus)** The pool of **soil organic matter** that is resistant to biological degradation because it is either physically or chemically inaccessible to microbial activity. These compounds are created through a combination of biological activity and chemical reactions in the soil (SSSA 1997).

Standing dead* (or **standing dead vegetation**) Dead plant material still attached to a rooted plant. All standing dead vegetation produced in previous (not the current) growing season(s) not in contact with the soil surface (Pellant et al. 2005). Compare to **litter***, **woody litter***, **duff*** and **embedded litter*.**

State* A state includes one or more biological (including soil) communities that occur on a particular ecological site and that are functionally similar with respect to the three attributes (soil and site stability, hydrologic function and biotic integrity). States are distinguished by relatively large differences in plant functional groups, soil properties and ecosystem processes and, consequently, in vegetation structure, biodiversity and management requirements. They are also distinguished by their responses to disturbance. A number of different plant communities may be included in a state and the communities are often connected by traditionally defined successional pathways (Pellant et al. 2005 based on Bestelmeyer et al. 2003 and Stringham et al. 2001, 2003).

Stratify* To separate, divide or delineate into classes.

Structure (soil)* See **soil structure***.

Structure* (syn. **vegetation structure***) The height and area occupied by different plants or life forms (and spatial diversity thereof) in a community.

Sub-shrub* See **half-shrub**.

Sub-surface stability (class)* The stability value ranging from one to six that is assigned to a sub-surface stability sample during the Soil stability test. See Volume I: Quick Start for more details.

Surface stability (class)* The stability value ranging from one to six that is assigned to a surface stability sample during the Soil Stability test. See Volume I: Quick Start for more details. Another indicator is the **proportion of surface values = class 6***. Calculate the proportion of surface values = class 6 by counting the number of *surface* samples with a stability class equal to six. Then divide this sum by the total number of surface samples taken. Multiply this value by 100.

T&E* Threatened and Endangered (species).

Terracette. "Benches" of soil deposition behind obstacles caused by water erosion, not wind erosion (Pellant et al. 2005). May or may not reflect current erosion. Compare to **pedestal**.

Threshold* A transition boundary that an ecosystem crosses, which results in a new stable **state*** that is not easily reversed without significant inputs of resources.

Total annual production* All aboveground plant biomass produced during a single growing year, including woody material and regardless of palatability or accessibility to grazing animals. Total annual production is expressed in pounds per acre (lb/ac). See Chapter 9 for methods of estimating and calculating total annual production.

TNC* The Nature Conservancy.

Transition* A shift between two states. Transitions are not reversible by simply altering the intensity or direction of factors that produced the change. Instead, they require new inputs such as revegetation or shrub removal. Practices such as these that accelerate succession (USDA-NRCS 1997) are often expensive to apply.

Tree* A woody perennial, usually single-stemmed plant that has a definite crown shape and reaches a mature height of at least 4 meters (13.1 ft). The distinction between woody plants known as trees and those called shrubs is gradual. Some plants, such as oaks (*Quercus* spp.), may grow as either trees or shrubs (SRM 1999).

Trend* The direction of change in ecological status or resource value rating observed over time (SRM 1999).

USDA* United States Department of Agriculture.

USDI* United States Department of the Interior.

USFS* United States Forest Service (**USDA**).

USGS* United States Geological Survey (**USDI**).

Vegetation class* Used in this document to distinguish between different types of vegetation for the purpose of stratifying soil measurements. The vegetation class is defined as NC (no canopy) if there is less than 50 percent canopy cover over the area measured or sampled. The vegetation class is defined as G if greater than 50 percent canopy cover over the area measured is grass or a grass/shrub mixture; F for perennial forb, Sh for shrub canopy and T for tree canopy.

Vegetation structure* (syn. **structure***) Vegetation structure is the vertical and horizontal distribution of vegetation in space. The height and area occupied by different plants or life forms (and spatial diversity thereof) in a community. See also **foliage height diversity*** and **visual obstruction***.

Vertical slope shape* The geometric shape of the vertical profile (up and down slope) of a hillslope. This can be convex, concave or linear. Compare to **horizontal slope shape*.**

Vesicular crust A type of physical crust that contains numerous small, unconnected air pockets or pores similar to a sponge. As with all physical crusts, they seal the soil's surface, causing a reduction in infiltration rate.

Visual obstruction* An indicator that reflects the vertical plant cover or the density of vegetation at different heights. Observers determine what proportion of a cover pole, Robel pole, or cover board is visually obstructed from view by plant cover at standard height intervals. Visual obstruction measurements can be used to estimate standing crop biomass, **vegetation structure*** and **foliage height diversity***. See Chapter 11 for calculations from the Vegetation structure method. The same calculations can be applied to the Line-point intercept with Height method (Ch. 15); given height classes are developed (such as 0-50 cm, 51-100 cm, 101-150 cm and 151-200 cm). See also **vegetation structure*** and **foliage height diversity***.

Weather* The current state of the atmosphere with regard to wind, temperature, cloudiness, moisture, pressure, etc.

Width-depth ratio* This is the width of a channel or gully divided by its depth. The width is the horizontal distance between the points used for the bank angle (Riparian channel and gully profile) at the top of each bank. The depth is the greatest vertical distance from a straight line drawn between the two points used for the bank angle and the bottom of the channel. See Chapter 14 for more information on calculations.

Woody litter* Detached plant material (**litter***) that is greater than 5 mm (~$^1/_4$ in) in diameter that is in direct contact with the soil.

Footnote: Together, rangeland health and soil quality focus on above - and below - ground soil and vegetation features important for rangeland function. They can be thought of as the foundation upon which most land uses and values depend.

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