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

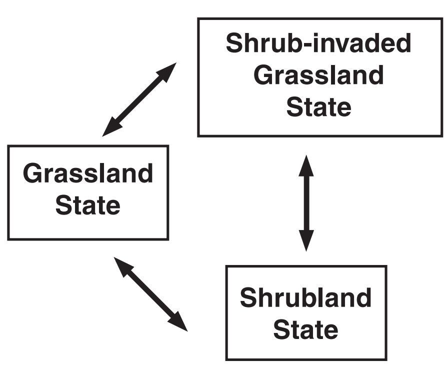
Vehicles/Recreation (Ch. 21)

Photo by Patrick Shaver

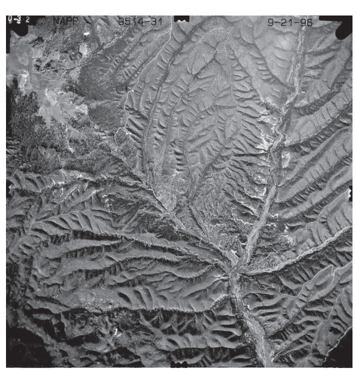
Fire (Ch. 22)

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.

Riparian

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.

Livestock production

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.

Wildlife habitat

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).

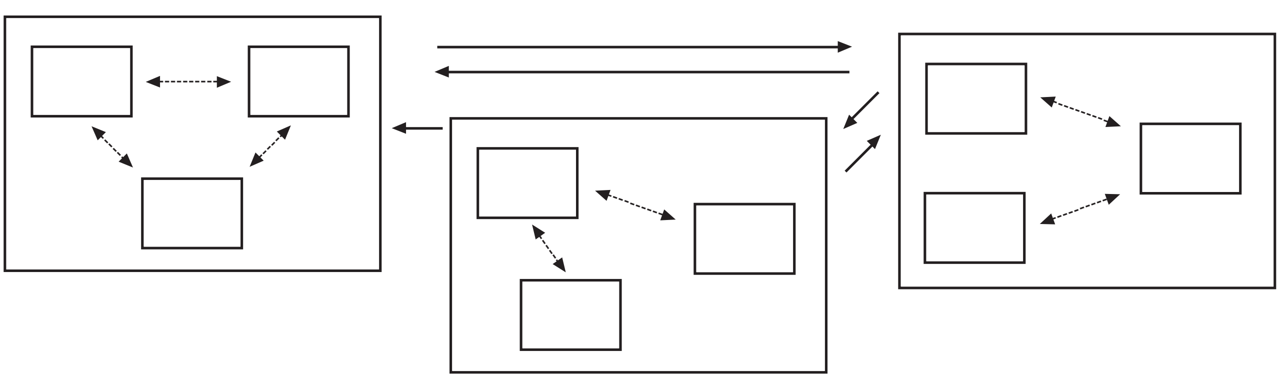


Figure 24.1. Typical state and transition model structure (based on Bestelmeyer et al. 2003 and Stringham et al. 2003). Large boxes are states defined by relatively irreversible transitions. Small boxes within states represent plant communities. Transitions (dashed lines) are relatively reversible. Single-state systems are possible where no thresholds have been identified.

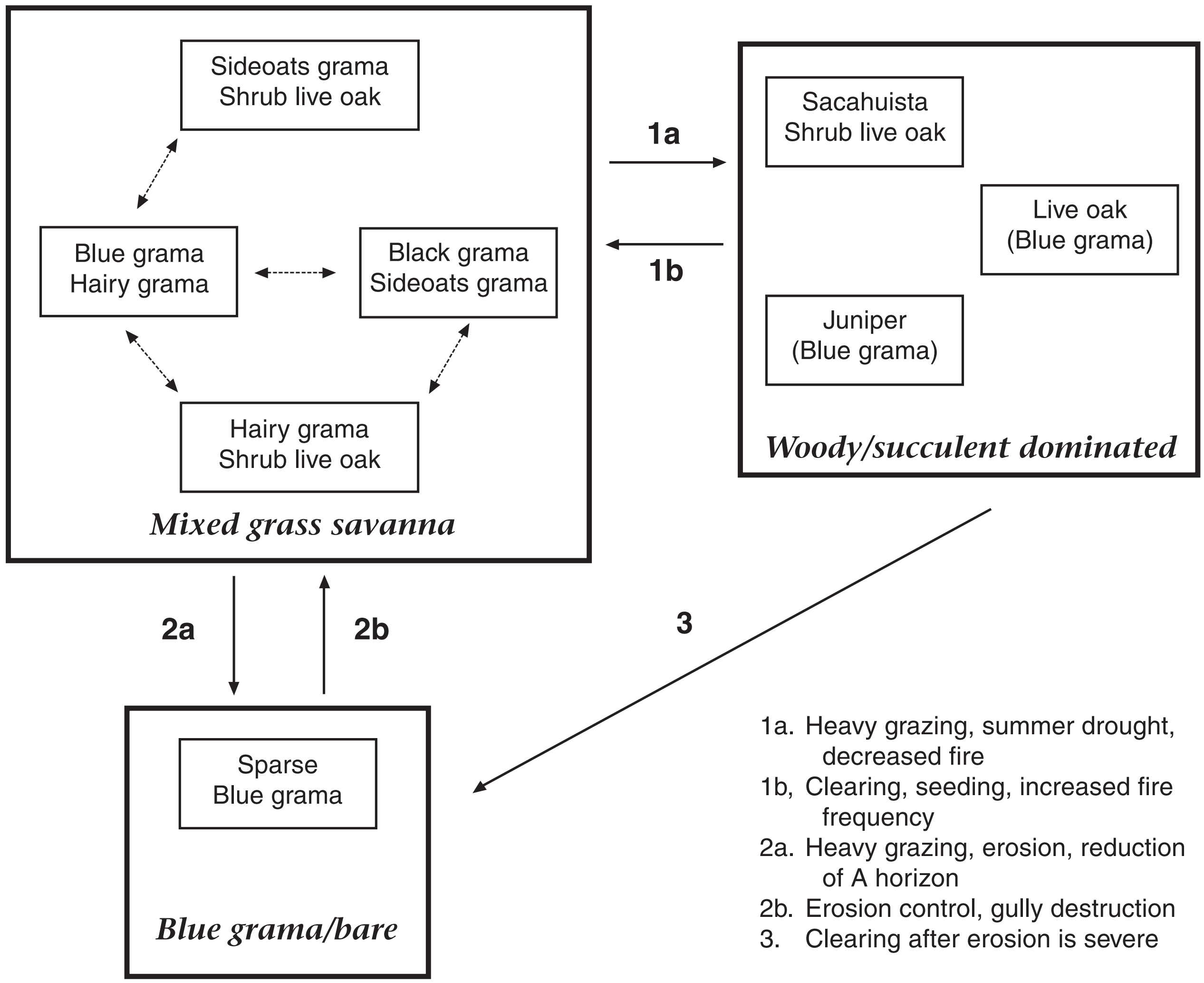


Figure 24.2. State and transition conceptual model for the "Breaks" ecological site in west-central New Mexico (Major Land Resource Area 36, Land Resource Unit WP-3). General structure follows Bestelmeyer et al. (2003) and Stringham et al. (2001, 2003). See description on following page.

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.

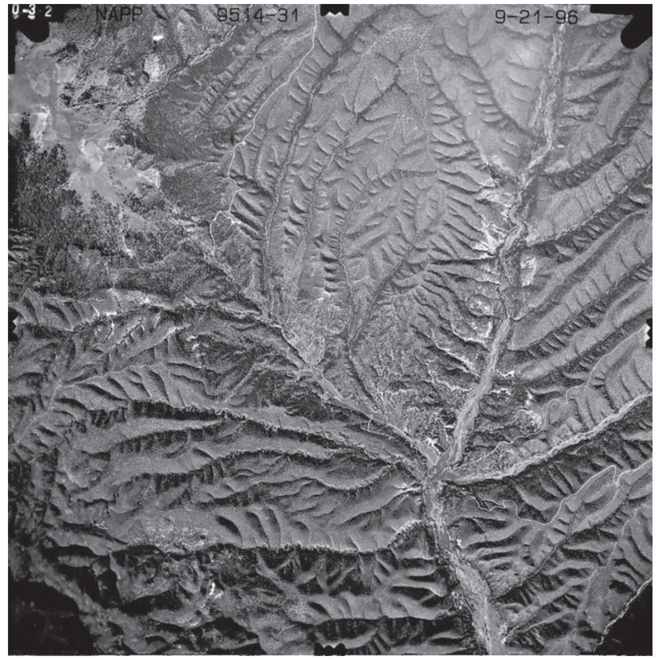


Figure 25.1. Example of a color IR aerial photo of Mimbres Watershed.

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 overreliance 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).