A COST-EFFECTIVE SOIL AND VEGETATION MONITORING PROTOCOL FOR ADAPTIVE MANAGEMENT

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1. INTRODUCTION

Rangeland monitoring is frequently limited by high costs and low relevance to management. Furthermore, most protocols continue to focus on the average status of a single ecosystem property, such as forage production, while our evolving understanding of non-equilibrium dynamics and local threshold responses require information on how complex ecosystem processes vary across the landscape over time (National Research Council 1994; Society for Range Management 1995).

We describe a simple, quantitative monitoring protocol that is designed to be used in conjunction with state and transition models to increase management effectiveness at multiple spatial and temporal scales (Herrick *et al*. 2003). The protocol integrates ground-based soil and vegetation measurements with simple remote sensing technologies (e.g. aerial photographs). This approach allows relatively large areas to be monitored while focusing most of the effort on those areas with the highest probability of change. The protocol also clearly distinguishes between long-term and short-term indicators. Long-term indicators are used to monitor relatively persistent management effects, while short-term indicators are used to adjust management on a daily to seasonal basis (Figure 1).

2. MULTI-OBJECTIVE MONITORING

The protocol is based on a hierarchical set of objectives. The basic indicators are used to monitor three fundamental ecosystem attributes: soil and site stability, hydrologic function and biotic integrity. These attributes are essential to the sustainability of most ecosystems and therefore serve as the foundation for nearly every monitoring program we have evaluated (Figure 1, top). A complementary qualitative assessment protocol that addresses the same three fundamental attributes is described by Pyke *et al.* (2002) and Pellant *et al.* (2003). The measurements used to generate basic indicators for the three attributes can also be used to generate information relevant to more specific management objectives such as forage production, biodiversity conservation and wildlife habitat management (Figure 1, top). Additional measurements are included to more fully address more specific management objectives and site-specific issues. Where possible, drivers or threats of change are also monitored to provide early-warning information of potential future changes (Figure 1, top; see also Havstad & Brown (2003)).

3. MONITORING DESIGN BASED ON REMOTE SENSING, STATE AND TRANSITION MODELS AND QUALITATIVE ASSESSMENT

Simple remote sensing imagery (e.g. aerial photographs) is used together with other available spatial data to stratify the landscape into relatively similar geomorphic units (Figure 1, below). Where possible these units should be further subdivided based on current vegetation and the status of the three attributes (soil and site stability, hydrologic function and biotic integrity). These spatial data can then be used together with state and transition models (Bestelmeyer *et al.* 2002) and information on current and potential future drivers (Havstad & Brown 2003) to identify landscape units with a relatively high potential for degradation or recovery.

Incorporating remote sensing imagery into the monitoring design process at an early stage can dramatically increase cost-effectiveness and reliability by focusing monitoring on representative areas with a high potential for change, while avoiding areas that are post-threshold or anomalous. The imagery used for this step should be as recent as possible, but the actual date is not critical and variability in image quality is much less critical than when the imagery is being used directly for monitoring change.

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4. GROUND-BASED MEASUREMENTS: LONG-TERM

Basic measurements used to monitor changes in the three attributes across most ecosystems include line-point intercept, a "gap" intercept, a field soil aggregate stability test and a belt transect. Line-point intercept was selected over other vegetation measurements because it is relatively precise, repeatable, and can be used to generate cover data for all vegetation layers and the soil surface. The gap intercept measurement is used to rapidly measure changes in the size and number of large gaps in the vegetation. The area covered by gaps that are large relative to typical gaps in the native plant community is a sensitive indicator of changes in the resistance to runoff, erosion and weed invasion. A soil stability kit (Herrick *et al.* 2001) can be used to quantify the erodibility of up to 20 soil surface samples in 10 minutes. The belt transect is used to quantify the density of relatively uncommon species of special interest. It can also be used for trees, though for widely spaced trees a plotless method is preferable. Additional measurements included to address more specific management objectives and site-specific issues include double sampling for production, a constant-head infiltrometer constructed from a 1 liter plastic bottle and 12 cm diameter pipe and a simple impact penetrometer (Herrick & Jones 2002) to assess compaction.

5. GROUND-BASED MEASUREMENTS: SHORT-TERM

One of the criteria for long-term monitoring indicators is that they should be relatively insensitive to short-term management. A related, but independent, set of measurements is used to help managers determine whether or not they are following their management plan. These measurements need to be even faster and more sensitive to management decisions than the long-term measurements and are therefore only semi-quantitative. They include residual cover using a step-point approach, stubble height, and a modified gap intercept method that simply involves counting the number of paces that land completely within a non-vegetated space. Where smaller gaps are of interest, the pace can be replaced with an object attached to the end of a walking stick. The relationship between short-term and long-term monitoring is illustrated in the lower section of Figure 1.

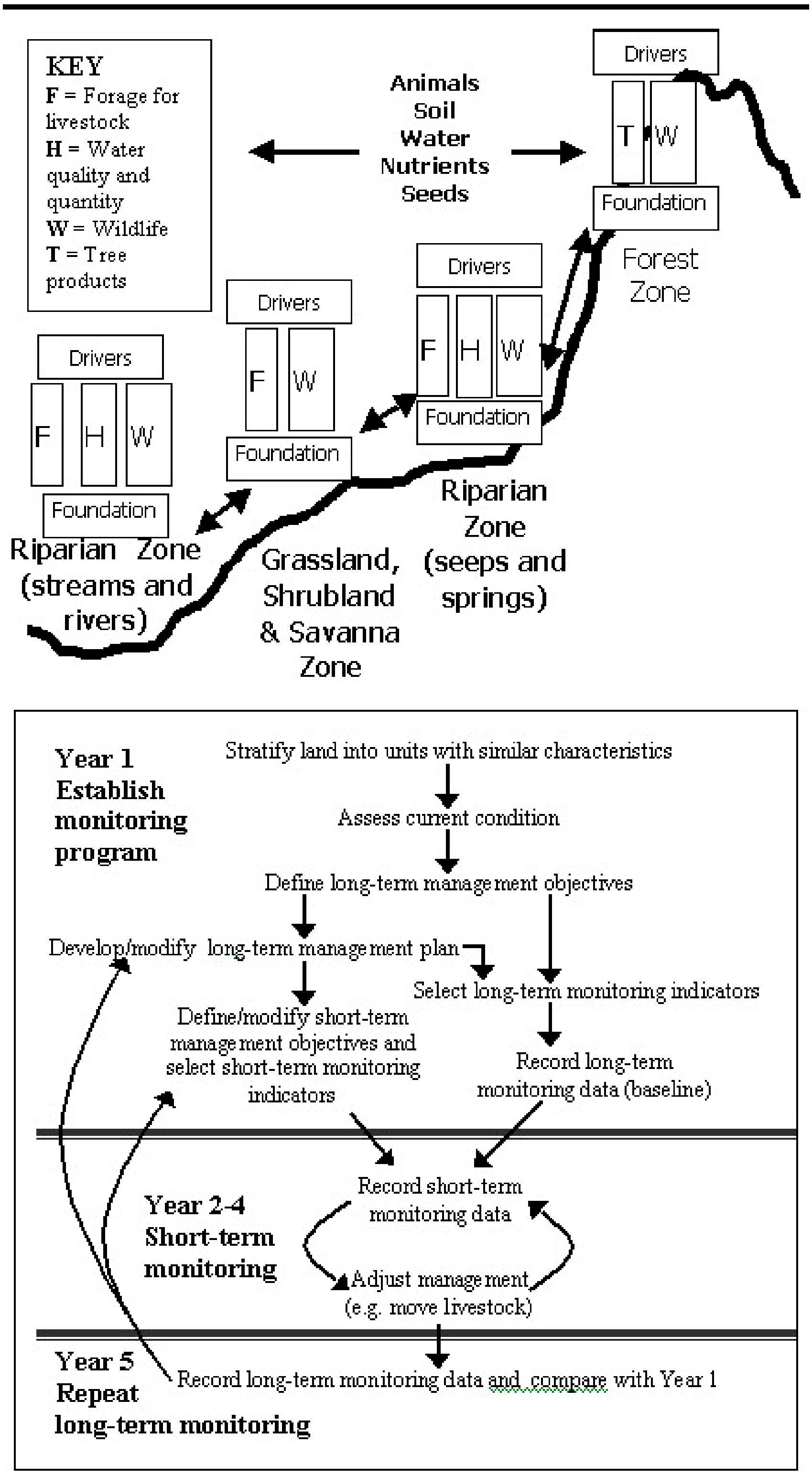

Figure 1. General structure of the monitoring protocol showing how monitoring for specific objectives and drivers is built on a common foundation of basic measurements that reflect status of the three attributes (soil and site stability, hydrologic function and biotic integrity) (top), and how short-term and long-term indicators are integrated to generate information that is relevant to adaptive management (bottom).

6. EXTRAPOLATION USING REMOTE SENSING

Three extrapolation options (Options 1, 2 and 3) are compared in Table 1. The first option is more appropriate where remote sensing imagery availability is limited, or where it is impossible to reliably obtain imagery for the periods when field data are to be collected. The second two options require training or extensive experience in remote sensing and GIS. The third is generally only applicable across relatively small areas (farms, ranches or conservation areas).

Table 1. Comparison of options for integrating remote sensing into ground-based monitoring programs.

Option	Application	Imagery type and scale	Knowledge	Cost
1	Monitoring unit stratification for increased sampling efficiency, general extrapolation	Air photos (any time in last 10 years)[1]	Ability to visually classify geomorphic and vegetation units	Low[1]
2	Broad-scale extrapolation based on repeated, ground-truthed imagery	Landsat, MODIS and other multi-spectral imagery that is regularly 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 multi-spectral imagery	Same	High

[1]Often already available from government survey offices, development agencies and mineral exploration companies.

7. CONCLUSIONS

By using remote sensing imagery primarily to improve monitoring program design, we exploit the strengths of these technologies while avoiding the pitfalls of over-reliance on relatively abstract indicators, many of which require new ground-based calibration data for each new set of imagery. Where it is possible to obtain repeated, concurrent ground-based and remote-sensing data, the imagery can be used to generate a more precise extrapolation than is possible with the initial stratification alone. 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.

8. REFERENCES

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