Ecological Monitoring

On Army Lands

LAND CONDITION TREND ANALYSIS II

LCTA II
Technical Reference Manual

Chapter 2
Introduction to Resource Monitoring

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2 Introduction to Resource Monitoring

2.1 Introduction

2.1.1 What is Monitoring?

Natural resource inventorying is the process of acquiring information on resources, including the presence, distribution, condition, and abundance of resources such as vegetation, soil, water, natural processes, biotic communities, and natural and human-induced changes in resources (National Park Service 1992). Monitoring is the process of collecting specific information over time to assess conditions and changes or trends in resource status and predict or detect natural or human-induced changes in resource conditions. Indicators of resource condition are often used to evaluate the "condition" or "health" of populations, communities, and landscapes.

Three types of monitoring can be described: implementation, effectiveness, and validation monitoring. Implementation monitoring is used to determine if activities and projects are implemented as designed or intended, or at all (Was the activity that was planned actually done?). Effectiveness monitoring determines if activities or projects are effective in meeting management objectives or established guidelines (Did the prescription work or have the desired effect?) Validation monitoring determines whether the data, assumptions, and relationships used in developing a plan are correct (Is there a better way to meet management objectives?). Validation monitoring is often synonymous with research. Most of what is described in this document refers to effectiveness monitoring.

Resource monitoring at various landscape scales (i.e. entire installation vs. training area vs. vegetation community, etc.) is a challenging task for land managers and Integrated Training Area Management (ITAM) staff. Monitoring efforts should specifically address management objectives articulated by trainers, land managers, and those presented in integrated natural resource management plans. Management objectives are often placed in categories such as vegetation condition/status (i.e. for different communities), animal habitat, and soil erosion status. Monitoring is valuable also in evaluating different approaches to land rehabilitation and maintenance.

Long-term changes or trends in resources will not be detected reliably if the examination of data is restricted to inconsistent or short-term data. Success of long-term assessments using monitoring data largely depend on creating and using a variety of efficient methods and designs that are both robust and widely useful (Hinds 1984).

2.1.2 Purpose of Monitoring

It is important to distinguish between the respective purposes of inventory and monitoring activities. Inventory activities typically precede and contribute significantly to monitoring efforts. Some inventories involve a number of years to collect the necessary information. The primary purposes of resource inventories are to: (1) document the occurrence, location, and current condition of physical habitat and features (site conditions) and major associated biota; (2) identify locally rare or threatened and endangered species, locating fragile or rare ecosystems and potential indicator species; and (3) assess the full range of populations, ecosystem components, processes, and stresses (i.e., both natural and human-caused disturbances), which form the framework for subsequent sampling during the monitoring process (National Park Service 1992). The first cycle of data collection for a monitoring program is sometimes referred to as the "initial inventory" or "inventory year".

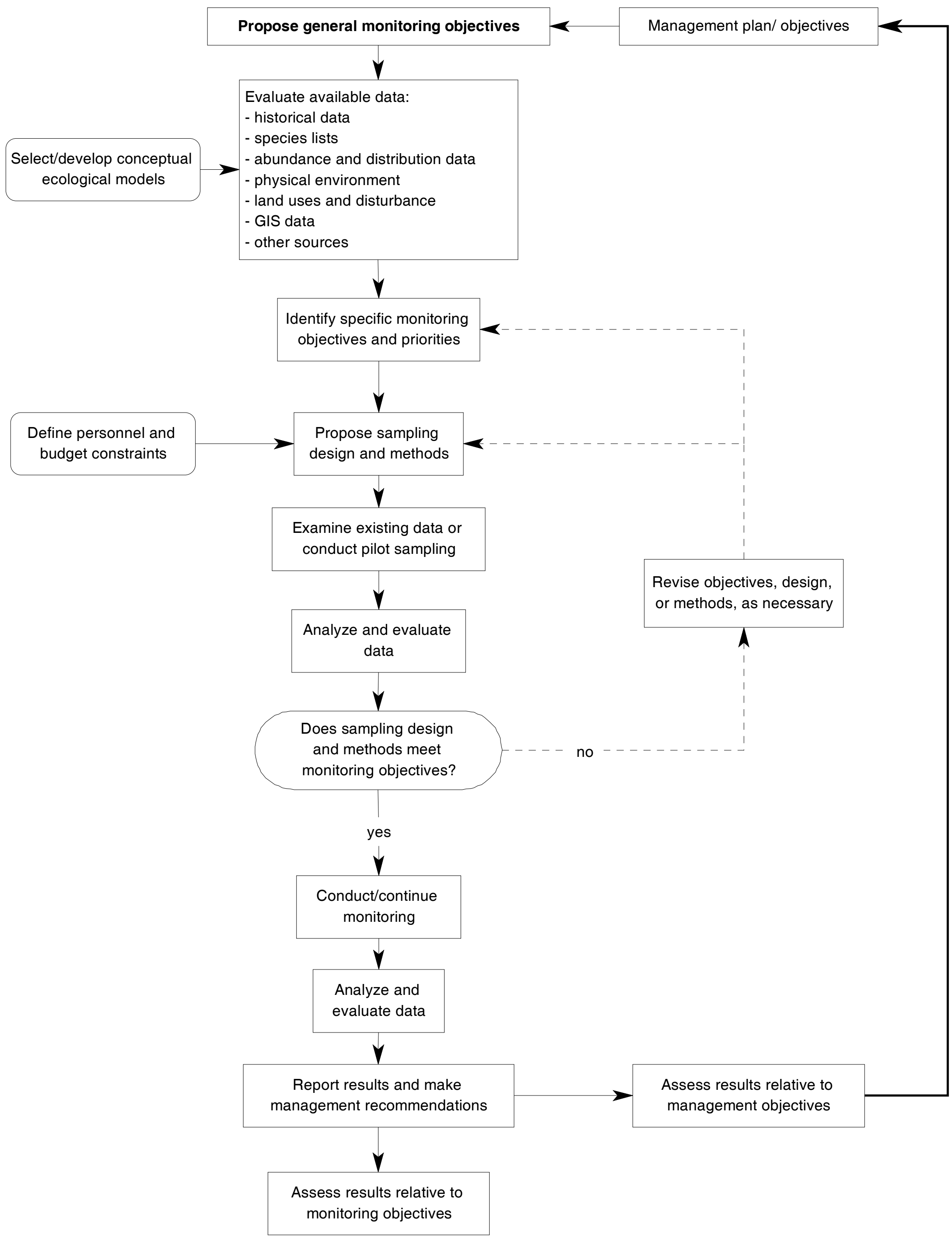
The primary purposes of monitoring are to: (1) provide indicators of ecosystem health or status; (2) define limits of normal variation (i.e. natural variability); (3) detect changes in condition, abundance, structure; and (4) identify and understand the effects of management and land-uses. In some cases, monitoring is used to determine compliance with environmental regulations and standards. If properly designed, monitoring activities can provide information linking changes in resource conditions and potential causes.

Monitoring provides a rational and objective basis for taking management actions and expands current knowledge of ecosystem properties and processes (Spellerberg 1994). Monitoring should also provide feedback between natural resource conditions and management objectives, an essential component of adaptive resource management. Because inventorying and monitoring help to bridge the gaps between land managers, training and range operations, and research activities, they require both communication and support at a number of administrative levels to be efficient and effective.

2.1.3 Steps in Monitoring

Once management objectives have been established, a monitoring program can be designed and reviewed. A conceptual overview of the monitoring process is presented in Figure 3. Monitoring efforts must be continually evaluated to ensure that the selected attributes and indicators are sensitive to change and the methods employed are effective. The steps outlined in Figure 3 are universally applicable regardless of the scale or duration of the project. Although monitoring is an ongoing process, periodic reporting, ideally following each data collection period, should be performed consistently in order to provide valuable feedback regarding management activities and the success of the monitoring program itself. Analysis involves examining individual components to establish status and interrelationships. Data synthesis subsequently examines the results at multiple scales over time to examine changes and trends. Analysis, synthesis, and reporting of results should be presented in a format that is consistent with the needs of decision makers.

Figure 3. Steps in the development and implementation of a monitoring program (Modified from USDI National Park Service 1992 and The Nature Conservancy 1997).



2.2 Levels of Monitoring

Approaches to monitoring can be described as “planes” or “levels” of monitoring ranging from the inexpensive and fast to the costly and more time-consuming. Monitoring information and methodologies can be classified as qualitative/semi-quantitative (Level 1), quantitative (Level 2), and demographic (individual/age/stage class analysis) (Level 3) (Menges 1996, The Nature Conservancy 1996). Parameters that are measured or estimated include abundance (e.g., number, density, cover, frequency), condition (e.g., vigor, reproductive success, size, biomass, level of damage or disease, etc.), and population or life-history structure (e.g., size class, age-class, number of individuals or that meet specific criteria). The level of monitoring and parameters chosen will depend largely on the management and monitoring objectives supported by the chosen approach and the availability of resources to carry out the monitoring, including time, fiscal resources, and staff resources. A discussion of parameter and indicator selection is presented in section 2.5.

Well-written monitoring goals and objectives indicate which level of monitoring is initially appropriate. Most objectives are best addressed by monitoring resources using several levels of intensity. Monitoring a mixture of parameters within the different monitoring levels is also beneficial. For example, quantitative measures of abundance are often combined with qualitative information such as presence-absence records and ranked data. Efficiency of data collection can often be improved by using diversified approaches. The addition of photographic documentation (Level 1) to almost any other type of monitoring is almost always beneficial. Level 1 and 2 information is most commonly used to assess resource condition. Level 3 studies are often reserved for research activities or in the case of small populations at risk. A generalized summary of goals and analytical approaches to different levels of monitoring is presented in Table 1. The discussion of monitoring levels, which emphasizes vegetation monitoring, is based on information provided in Menges and Gordon (1996) and The Nature Conservancy (1996).

Table 1. Levels of monitoring vegetation, with goals and statistical approach (modified from Menges 1996).

Level	Goals	Analysis Approaches
1. distribution of populations/ communities	measure trends across populations, hypothesize trends in size	descriptive
2. population/community size or condition	measure trends within populations and hypothesize mechanisms/causes	trend analysis
3. demographic monitoring (individuals)	anticipate population trends and understand mechanisms	population variability, age class analysis

2.2.1 Qualitative and Semi-quantitative Monitoring (Level 1)

Abundance information includes:

- presence/absence of a population/individuals at a particular location

- size of the area encompassed by the population or community
- estimates of abundance using broad categories or log-scale rankings (1-10, 10-100, 100-1000)
- photo monitoring

Level 1 monitoring is used for both single or multiple locations of species/communities of interest. For example discreet populations or communities can be mapped through field surveys or aerial photo interpretation. The occurrence, extent, or distribution of populations/communities can be effectively monitoring using this approach. Where multiple occurrences are monitored, the number of locations provides Level 1 information about abundance. This approach allows for examination of changes in populations and locations, changes in area occupied, and large changes in abundance. Using broad ocular estimation categories will only permit coarse indicators of population changes. Increasing the number of estimation categories improves the potential for data analysis but makes repeatability more difficult.

Level 1 condition information includes descriptions and presence of attributes or conditions at one or more locations. For example, the presence or absence of different types of erosion, disturbance, hydric soils, seedlings and regeneration, snags of a particular size or type, or stage of vegetation phenology. In addition to presence/absence type data, observers can make estimates of abundance for the condition being exhibited (e.g., 15% crown dieback).

Level 1 structure information includes presence/absence of individuals within specified age or height classes, or coarse estimates of abundance within age or size classes. This information gives an indication of population or community structure and recruitment.

Advantages of Level 1 information include relatively low costs and rapid procedures. Communities or populations are assessed in their entirety or by sampling a portion. Disadvantages of Level 1 information include low repeatability and precision, susceptibility to interpretation and observer bias, inability to perform quantitative analysis, and ability to detect only large or changes.

2.2.2 Quantitative Monitoring (Level 2)

Quantitative monitoring and methods consists of data that is collected using methods and approaches which attempt to have high precision and minimal observer bias and subjectivity. The principal difference between Level 1 and Level 2 monitoring is that actual measurements are made and items counted using Level 2. Examples of methods include density counts, frequency frames, prism cruises, and canopy measurements. Ocular estimates of canopy cover may be treated as either Level 1 or Level 2 information, depending on the method used and the number of cover classes employed. However, increasing the resolution of the estimates (e.g, estimating cover to the nearest 1% or %5) does not necessarily increase the precision of data collection). In fact it may comparisons among observers more problematic. Cover estimation using fairly broad classes is often analyzed using the midpoint of each class as the cover value. The size of the sampling unit (0.5 m X 1.0 m vs. 10 m X 10 m) also influences the use of the data as Level 1 (relatively large quadrats for descriptive purposes) or Level 2 (relatively small quadrats for analytical purposes) data.

Population and community abundance is sampled or censused quantitatively using a number of measurements, including the number of individuals, density of individuals, percent cover, and frequency. These measurements can be made on individual species, groups of species, or all species present. Temporary or permanent plots or transects are used with Level 2 information gathering. Condition information consists of relative cover (by species or ecological group) and number or percent exhibiting a particular condition. Population structure measurements typically involve counting the number of individuals in size distribution or height classes (e.g., number of inflorescences, number of insect galls, height).

Applying Level 2 methods allows for data analysis, interpretation, and prediction. Smaller changes in condition, structure, and abundance are detectable versus Level 1 methods. Another advantage is that the effects of management on sites, areas, and species are more readily evaluated. From a sampling perspective, data collection is repeatable by different individuals over time. Disadvantages include higher requirements of expertise, time, and effort. Also, no information about individual responses or fates is collected.

2.2.3 Quantitative Monitoring (Level 3): Age or Stage Class Analysis

Level 3 monitoring consists of collecting information for assessing life history or demographic parameters such as survival and mortality and age or size distribution of the population. These studies often measure marked or mapped individuals over time, whereas Level 2 monitoring may make similar measurements on plants but not track individuals over time. By tracking individuals, relationships between recruitment, survivorship, and mortality can be assessed for different age and size classes. Causality can sometimes be determined from these studies.

Data collection typically involves measuring abundance attributes and assessing condition. Other qualitative or quantitative information is often collected to help establish relationships between site factors and demographic responses.

Strengths of Level 3 monitoring include all those listed for Level 2 monitoring. Additional strengths include increased change detection capability, enhanced knowledge of life histories and response to site conditions, and ability to predict demographic changes over time. Weaknesses include those listed for Level 2 monitoring and high cost and time requirements.

2.3 Management and Monitoring Objectives

Monitoring should be objective-based. The success of a monitoring effort is based upon its ability to assess the success or failure of specific management objectives. Objectives must be realistic, specific, measurable, and written clearly. A limited suite of attributes should be chosen for assessing changes in the overall condition of plant communities. It is up to the individual who implements and manages resource monitoring to articulate objectives for his or her program. This collection of exercises illustrates how to develop and articulate both management and monitoring objectives. If good management objectives already exist at an installation, then the remaining task is to define monitoring objectives related to them. Monitoring objectives may also be influenced by original program goals, need for continuity with historic data, methods, and available resources. A good discussion of management and monitoring objectives is presented in Elzinga et al. (1998).

2.3.1 Management Goals and Objectives

Management objectives will vary depending on the management mission of a particular organization. For example, management objectives driven by military training (or the training community) may be very different from those established by land management or conservation professionals.

Management objectives help to direct resource management by defining desired conditions or trends in resource conditions. Sources of information for setting objectives include existing management plans and environmental (e.g., NEPA) documents, ecological models, reference sites or comparison areas, related or similar species and communities, expert opinion, and historic records and photographs (Elzinga et al. 1998). A complete management objective, which forms the basis for one or more monitoring objectives, should include the following components:

what will be measured – direct measurement of species/community or habitat indicator (indirect)

location or geographic area of interest – defines the limits to which results will be applied

attribute measured, e.g., size, density, cover, frequency, qualitative estimate of abundance, areal extent

objective action - maintain, increase, or decrease

quantity/status - measurable status or degree of change for attribute – can be quantitative or qualitative

time frame - length of time specified for management to prove effective.

Objectives can describe either a *desired condition* or a *change* relative to current conditions:

The first type can be described as **target or threshold** objectives. This type of objective uses a predetermined threshold to gauge the effectiveness of management. For example: *maintain the size of population A at 450 individuals; increase the acreage of open woodland to 6000 ha; maintain the presence of threatened species A and B at Site C.* The success of meeting the objective is assessed by comparing the current state of the measured attribute either to the desired state or an undesired state. Presence of the undesired state should serve as an indication that management should be altered.

The second type can be described as **change or trend** management objectives. This type of objective specifies a change relative to the existing situation. For example: *increase perennial grass cover by 40%; decrease severe off-road disturbance by 20%; decrease frequency of weed species Y by 50%.* Trend objectives are useful when little information is available to describe a desired future condition, or where the current status is less important than trends over time. Change detection objectives are often appropriate when a significant change in management occurs and change is anticipated. If preliminary sampling provides information about the population status, then a *change* objective may be rewritten as a *threshold* objective.

Based on experience drawn from a number of military installations, some of the major management concerns related to resource condition and military land uses include:

- off-road vehicle and other training impacts to vegetation and soils
- spread of noxious weeds or species which outcompete desirable vegetation
- changes in structural attributes of plant communities – loss of concealment resources, wildlife habitat
- impacts of altered fire intensities/frequencies and other natural processes
- soil erosion, sedimentation, and water quality impacts

In light of these management concerns, the following are examples of general management goals related to vegetation and soils:

1. Sustain and maintain healthy and diverse ecosystems.

2. Maintain soil stability and susceptibility to erosion at acceptable levels.

3. Maintain realistic and sustainable training environments for desired training loads.

4. Revegetate selected disturbed areas to pre-disturbance conditions.

5. Minimize the establishment and spread of undesirable non-native plants.

These general management goals should be refined so that corresponding monitoring objectives can be developed to address specific needs. If the success or failure of the management objective cannot be gauged, then there is no way of knowing if management activities are effective, or if management goals are met. The following are examples of specific **management** objectives:

- Maintain the current (1997) spatial distribution and abundance, i.e., acreage, of each major plant community from 1997-2002 (target objective).
- Within each community type, maintain 1997-1999 native grass, forb, shrub, and tree cover from 1999-2004 (target objective).
- Within each community type, maintain 1997-1999 native grass, forb, shrub, and tree diversity from 1999-2004 (target objective).
- Increase the forb diversity of woodland communities by 25% between 1999 and 2009 (change objective).
- In existing shrub communities, maintain current (1997-1999) densities for each shrub species from 1999-2004 (target objective).
- Allow a decrease in the ranked abundance of *Chlorogalum purpureum var. purpureum* (Purple Amole) in each of the 5 permanent macroplots at the Jones Mountain Site of no more than 1 rank class between 1998 and 2000.
- Within each training area, maintain current (1997-1999) soil erosion rates from 1999-2004 (target objective).
- Within each community type, maintain current (1997-1999) levels of bare ground from 1999-2004 (target objective).
- Maintain the current (1997) areal extent of forest, woodland, and grassland communities from 1997-2002 (target objective).
- In forested areas used for bivouac, maintain an overstory tree density of at least 40 trees/ha from 1997-2002 (target objective).
- For revegetation sites, increase cover of desirable plant species to within 50% of undisturbed plant cover after three years of recovery (change objective).
- For revegetation sites, provide at least 20% perennial grass cover, 10% shrub cover, and 5% perennial forb cover after 2 years of recovery (target objective).

- For burn sites, increase total plant canopy cover to 25% after 1 year (target objective).

- Maintain the current distribution and abundance of weed species X on Fort USA from 1997 to 2002 – this could be treated as quantitative or qualitative, depending on the approach that is most feasible (target objective).

- Decrease the number of hectares on Fort USA infested with species Y (species is common to abundant) to 400 ha (target objective).

- For sites treated for weed infestations, decrease the density of target weed species by at least 50% one year after treatment (change objective).

- Maintain the number of km of road shoulders with a knapweed (all species) ranked abundance of 5 or more (target objective) .

2.3.2 Monitoring Objectives

Complete management objectives form the basis for monitoring or sampling objectives. In addition to the “what”, “where”, and “when”, a monitoring objective should specify information such as the target level of precision (acceptable error), power, confidence level (false change error rate), and the magnitude of change we want to detect. Without specified targets for these parameters, estimates of population parameters might have excessively large confidence intervals or low power (e.g., only a 20% chance of detecting the magnitude of change that was desired). The necessary components of monitoring objectives differ for target management objectives and change management objectives.

The sampling objective for target objectives is to estimate a parameter in the population, estimate a proportion, or to estimate total population size. This estimate is then compared to the threshold value specified. To accomplish this, it is necessary to specify the confidence level (i.e., how confident do you want to be that your confidence interval will include the true value?), and the confidence interval width (i.e., how close to the estimated mean do you want to be?).

Example:

Management objective: Decrease the density of *Juniperus* trees less than 10 cm in diameter in abandoned agricultural fields to 15 trees/acre between 2000 and 2005.

Monitoring objective: Estimate the density of *Juniperus* trees less than 10 cm in diameter. We want to be 90% confident that mean density is within 10% of the estimated true value.

The sampling objective for change objectives is to determine if there has been a change in a population parameter for two or more time periods. These objectives must include the desired power (missed change or Type II error), the acceptable false change errors rate (Type I error), and the desired minimum detectable change (MDC) (the smallest change you are hoping to detect).

Example:

> **Management objective:** Increase the density of flowering individuals of *Tauschia hooveri* (Hoover's desert parsley) at the Yakima Ridge site by 25% between 1999 and 2009.
>
> **Monitoring objective:** We want to be 90% confident of detecting a 25% increase in mean density with a false change error rate of 0.10. This objective specifies a power of 90%, a false change error rate of 10%, and an MDC of 20%.

If the sampling interval is not specified in the management objective, it should be specified in the monitoring objective (i.e., seasonally, annually, every 2 years, 5 years, etc.). The sampling interval can be less than the timeframe specified in the management objective. For example, if a given change is desired over a 6 year period, monitoring every 2 or 3 years may be appropriate to see if there has been progress toward the objective.

When monitoring does not involve sampling, the management objective should provide enough information to evaluate its success or failure. This is the case where qualitative assessments are done for areas or where a complete census is performed. Management objectives of this type therefore do not need to provide additional components beyond *what, where, and when*.

2.3.3 Paired Management and Monitoring Objectives

2.3.3.1 Examples of Training-oriented Objectives

> **Example 1:**
> Management Objective (desired status or condition - management threshold)
> "Mean soil erosion status (estimated soil loss/published soil loss tolerance) shall be maintained at levels of less than 100% for all major landcover types on the installation."
>
> Monitoring Objective
> "We want to make annual estimates of erosion losses for all the major landcover types. We want to be 90% confident that the estimate is within 10% of the true value."

Example 2:
Management Objective (desired condition)
"[Given that sagebrush is sensitive to off-road maneuvers and fire] we want to maintain mean big sagebrush cover of at least 25% in existing shrub stands across the installation."

Monitoring Objective
"We want to obtain an estimate of the average canopy cover of big sagebrush in existing shrub stands every two years. We want to be 90% confident that the estimate is within 20% of the true value."

2.3.3.2 Examples of Land Management-oriented Objectives

Example 1:
Management Objective (desired trend)
"We want to see a 50% decrease in yellow star thistle in areas sprayed with herbicides on Fort Hunter Liggett during the next three years."

Monitoring Objective
"We want to be 90% sure of detecting a 50% change in the density of yellow star thistle on herbicided areas and untreated areas annually for the next 3 years. We are willing to accept a 10% chance that we conclude a change took place when in fact there was no change."

Example 2:
Management Objective (desired trend)
"Through the application of management activities, we want to see a 30% increase in the cover of native warm-season grasses at the McLaughlin Cemetery Glade (MO) between 1998 and 2001."

Monitoring Objective
"We want to be 90% sure of detecting a 30% change in the aerial cover of native warm-season grasses at the McLaughlin Cemetery Glade 3 years after the initiation of restoration activities. Monitoring will be done annually. We are willing to accept a 10% chance that we conclude a change took place when in fact there was no change."

Example 3:
Management Objective (desired status)
"We want to maintain the current flowering population of *Tauschia hooveri* (Hoover's desert parsley) at the Yakima Ridge site (WA) over the next ten years."

Monitoring Objective
"We want to obtain annual estimates of the population of Hoover's desert parsley at the Yakima Ridge site from 1997-2007. We want to be 90% confident that the estimates are within 20% of the estimated true mean."

2.3.3.3 Additional Examples of Paired Management and Monitoring Objectives

1. In grassland communities, decrease the frequency of *Bromus tectorum* (cheatgrass) by 30% from 1999-2002.

We want to be 80% certain of detecting a 30% decrease in frequency with a false change error rate of 0.20.

2. Maintain native grass and forb species diversity at 1997-1998 levels.

Obtain estimates of grass and forb diversity at 2 year intervals with 90% confidence intervals no wider than ± 10% of the estimated diversity.

3. Maintain the areal extent and distribution of minimally, moderately, severely, and completely, disturbed (e.g., off-road maneuver and assembly) areas at 1999 levels.

Estimate annually the extent (i.e., number of square meters, ha) of disturbed lands in each disturbance category and map areas using GPS – the objective has all the information for evaluating results.

4. In areas subject to extensive off-road maneuvers, allow a decrease in the cover of native plants of no more than 30% relative to undisturbed conditions between 1999 and 2002 (compared to undisturbed areas).

Be 80% confident of detecting a 30% relative decrease in native plant cover with a false-change error of 20% (20% chance of concluding that a change took place when in fact there was no change).

5. In forested areas used for bivouac, maintain an overstory tree density of at least 40 trees/ha from 1997-2002.

We want to be 95% certain that the estimates are within 15% of the estimated true density.

6. In existing shrub communities, maintain current (1997-1999) densities for each shrub species from 1999-2004.

We want to be 95% confident that annual density estimates are within 10% of the estimated mean density.

7. Increase the forb diversity of woodland communities by 25% between 1999 and 2004.

We want to be 90% sure of detecting a 25% relative increase in forb diversity. We are willing to accept a 10% chance of a false-change error.

8. Increase the Jones Mountain population of *Chlorogalum purpureum var. purpureum* (purple amole) to 500 individuals by the year 2003.

We want to be 95% confident that the population estimate is within ± 10% of the estimated true value. This objective applies where sampling is used. If all of the individuals in the population are counted (census), then the monitoring objective is already specified within the management objective (are there at least 500 individuals by 2003 – yes or no?).

9. Decrease the ranked abundance of *Lythrum salacaria* (purple loosestrife) in each of the four permanent macroplots at the Ives Road Fen site by 2 rank classes between 1998 and 2000.

Estimate the ranked abundance of purple loosestrife in each macroplot – the objective has all the information for evaluating results. Estimates could be made annually or in 1998 and 2000.

10. Do not allow erosion status estimates (estimated loss/allowable loss) for each training area to exceed 100% in any given year from 1998-2008.

Estimate erosion status annually for each training area. We want to be 90% confident that the estimate is within ± 20% of the estimated true value.

2.4 Determining Benchmarks

Benchmarks or management thresholds provide goals for resource management, which in turn help to guide monitoring efforts. In the context of quantitative monitoring, benchmark conditions must be defined for the attributes of interest, which are measured during sampling. Benchmarks are often a set of well-defined conditions as opposed to a qualitative ranking such as "poor", "fair", or "good". However, qualitative benchmarks may be used where monitoring resources are limited or where qualitative management objectives are specified. In some cases, monitoring data are compared to initial conditions to gauge improvement or degradation, emphasizing trend over the attainment of specific conditions. In fact, both approaches can be employed simultaneously without expending additional effort or cost, the only difference being that attention must be given to defining benchmarks.

Commonly used benchmarks include current conditions or those preceding changes in management, pristine or near-pristine sites (reference areas), historic or presettlement conditions, desired plant community, and projections from biotic and abiotic information – "climax" or potential vegetation. Some of these benchmarks represent hypothetical ecological standards. Desired plant community (DCP) is a concept that has been adopted by some land managers as a practical benchmark for vegetation management. Wagner (1989) describes the DCP concept:

> "The DCP is … an expression of the site specific vegetation management objectives instead of the more common, subjective way of stating objectives such as changing vegetation condition from poor to fair or from fair to good. The description of the characteristics of the DPC (species composition, production, cover structure, etc.) is based on those of a real, documented community occurring on the same or like site in another area. Therefore, vegetation management objectives expressed as a DCP, besides being more specific and measurable, are ultimately more realistic… The DCP is consistent with the site's documented capability to produce the required vegetation attributes through management, land treatment, or a combination of the two. The DCP is a management determination which may correspond to the existing plant community, the potential plant community, or some intermediate community."

Where resource conditions generally meet management objectives and changes in management are minimal, current conditions may be chosen as a benchmark for quantitative or qualitative monitoring. The emphasis might therefore be on maintenance of conditions versus improvement over time.

2.5 Selecting Variables to Measure

Assessing the condition of any ecosystem, be it forest, woodland, grassland, shrubland, or arid ecosystem, is highly complex, requiring the examination of a number of factors which characterize or contribute to the degradation or improvement of various ecological units. Changes or trends in ecological resources can be detected in the short and long-term by monitoring resources either directly or indirectly through indicators. The selection of variables to measure is largely determine by program objectives and corresponding data requirements. Required data is simply whatever has been requested by the responsible party or agency. Population-level monitoring can be straightforward if the species lends itself to being measured directly. Community and landscape-level monitoring can present the most difficulties in the selection of attributes. For this reason, indicators are used most often at the latter scales. Whatever the variables chosen, they should be robust yet specific enough to respond to anticipated or unknown stresses and changing conditions.

Compliance-type monitoring generally specifies the attributes to be monitored. Standardization of data collection requirements across organizational units (e.g., MACOM requirements for installations, range condition ratings by BLM districts) simplifies the process of determining what to measure by specifying data needs. For example, the Army Training and Testing Area Carrying Capacity (ATTACC) model, currently being developed by Combat Training Support Center (CTSC) for the Office of the Deputy Chief of Staff for Operations and Plans (ODCSOPS) requires soil loss estimates by training area in order to estimate the capacity of lands to support training. Soil erosion status is used to help determine "land condition". Training load and land rehabilitation costs are also required by the ATTACC model. The ATTACC requirements and calculation of carrying capacity estimates are presented in the ATTACC Program Handbook (CTSC 1998).

2.5.1 Selecting Indicators of Resource Condition

Assessment of condition requires that judgements are made regarding the ecological significance of the indicator variables measured. Multiple indicators are preferable to single indicators because of the decreased chance of false positive and false-negative signals. Qualitative measurements of indicators may be appropriate and cost effective where large impacts are anticipated and readily apparent.

The importance of indicator selection cannot be over emphasized, since any long-term monitoring project will only be as effective as the indicators chosen (Cairns et al. 1993). Once management goals have been specified, a framework must be developed for selecting indicators and utilizing the data that is collected. The number of potential indicators is relatively high, and the selection of several "good" indicators is not an easy task. However, economic and ecological considerations help to limit the number of indicators that can be measured to a fraction of those available.

The following list of indicator characteristics was developed for applications to environmental and water quality, but are widely applicable to terrestrial ecosystems as well (Cairns et al. 1993). The ideal indicators are:

1. Biologically relevant, i.e., important in maintaining a balanced community,
2. Sensitive to stressors without an all or none response or extreme natural variability,
3. Broadly applicable to many stressors and sites,
4. Diagnostic of the particular stressor causing the problem,
5. Measurable, i.e., capable of being defined and measured using a standard procedure with documented performance and low measurement error,
6. Interpretable, i.e., capable of distinguishing acceptable from unacceptable conditions in a scientifically and legally defensible way,
7. Cost-effective, i.e., inexpensive to measure, providing the maximum amount of information per unit effort,
8. Integrative, i.e., summarizing information from other, unmeasured indicators or variables,
9. Historical data are available to define "natural" variability, trends, and possibly acceptable and unacceptable conditions,
10. Anticipatory, i.e., capable of providing an indication of degradation before serious harm has occurred: early warning,
11. Nondestructive of the ecosystem,

12. Potential for continuity in measurement over time,
13. Of an appropriate scale to the management problem being addressed,
14. Not redundant with other measured indicators
15. Timely, i.e., providing information quickly enough to initiate effective management action before unacceptable damage has occurred.

In Arches National Park, Utah, Belnap (1998) used a systematic approach to select indicators of natural resource condition. The basic approach involved sampling a number of vegetation and soil variables in impacted and unimpacted areas. Variables that differed significantly between compared sites were chosen as potential indicator variables. Potential indicators were subsequently evaluated using site-specific criteria. The required selection criteria for indicators included low impacts of measurement, repeatability of measurements, correlation with land-use (i.e., visitor/recreation) disturbances, and ecological relevancy. Those indicators that met the required criteria were then evaluated for additional desirable characteristics, including: (1) quick response to land-use disturbance and management actions, (2) minimal spatial, temporal, and climatic variability, (3) ease of sampling, (4) large sampling window, (5) cost effectiveness, (6) short training time, (7) baseline data available, and (8) response over a range of conditions (impacts are evident even for minimal disturbance). The remaining indicators were then examined for ecological relevancy. A final set of indicators was then chosen and field tested. This approach should prove applicable in situations where indicators are required to measure both land-use impacts and response to management actions. Several years may be required to survey habitats, develop a list of potential indicators, determine ecological relevance, and field-test chosen indicators (Belnap 1998).

Examples of vegetation and soil indicators selected for areas in Utah (Whitford et al. 1998) and New Mexico (Belnap 1998) include:

- bare patch index
- cover of long-lived grasses
- weighted soil surface stability index
- cover of plant species toxic to livestock
- cover of exotic species
- cover of increaser species
- number of social recreational trails
- soil crust index
- soil compaction
- soil aggregate stability
- vascular plant community composition
- soil surface protection index
- soil biological characteristics

Some of these indices were measured directly while others were derived from several measurements/variables.

Harper et al. (1996) have outlined several indicators of community quality specific to southern pine woodlands, including: a) wiregrass dominance as an indicator of little fire suppression or soil disturbance, b) old growth pine as an indicator of high quality sites for many TES, c) other indicator species, and d) structural and compositional aspects.

Land-use impact issues on military installation in the Southeast include: fragmentation and land-use conversion, fire and fire suppression, alteration of hydrology, groundcover disturbances, erosion and sedimentation, soil compaction, exotic and pest species, and unnatural fertilization. Indicators must accordingly be applicable to these and other management issues.

2.6 Monitoring Intensity and Frequency

Determining the intensity (level of monitoring approach and effort) of sampling is influenced by three principal factors: 1) program objectives, 2) funding and other resources, and 3) actual or perceived threats or level of risk. Intensity and frequency of data collection is influenced also by program or management objectives, including documents such as Integrated Natural Resource Management Plans (INRMPs); or ongoing mission, restationing, or land acquisition environmental documents including Environmental Impact Statements (EISs) and Environmental Assessments (EAs). In addition to supporting training activities and conservation goals, monitoring is often specified as mitigation for activities that potentially impact the environment.

The frequency or periodicity of repeated sampling should reflect the rate of change within the attributes or indicators selected for monitoring. Moreover, the frequency should be designed to give early warning of significant degradation. Monitoring should be frequent enough so that a population, community, or ecosystem would not undergo extreme degradation between sampling periods (Committee on Rangeland Classification 1994). Using this logic, more frequent sampling may be required in areas which receive more disturbance (i.e., are more dynamic). In general, sampling more than once per year is impractical, except perhaps for small scale investigations.

Monitoring intensity and frequency decisions may vary by plant community, sites of special interest or concern, or disturbances levels and may change from year to year. The simplest and most expensive monitoring plan would sample all locations every year. Other plans would survey some plots some years and other plots all years. The costs associated with sampling may be reduced by making alterations to the sampling design.

Several monitoring scenarios are presented to illustrate possible solutions and their respective tradeoffs (monitoring scenarios measure change in bare ground on an installation over a series of years):

a) Sample all plots every year (Figure 4A)**.** This is the best (highest confidence that the data represents actual conditions) and the most expensive sampling protocol. The data set is complete from one year to the next. Options for statistical analyses are the greatest (i.e., data from all years can be used). When all plots are surveyed all years, sample size is the largest and variance, or the difference among the samples, is the lowest. If statistically significant differences ($P<0.05$) among years exists, this data set will most likely identify those differences. The benefits of surveying all plots annually include greater assurance of identifying and interpreting cause and effect and the ability to analyze larger subsets of data. Analyzing subsets of data are beneficial when changes in mission occur. For example, information may be needed for an area not described by a recognized designation. The larger the pool of information, the greater the chance a representative subset is available. When breaks occur between years of monitoring, interpretative and predictive ability decrease, but so do costs.

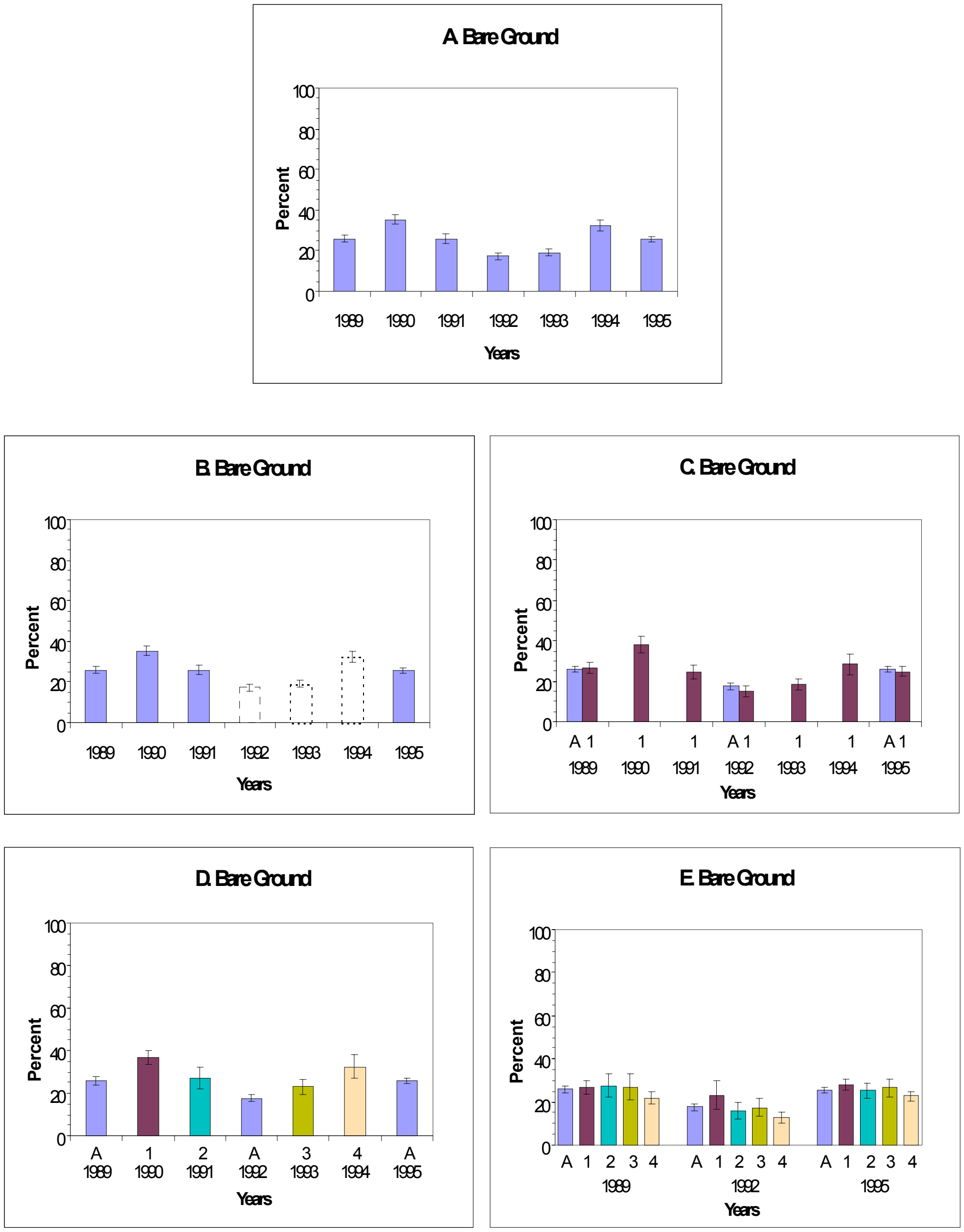


Figure 4. Effect of various sampling schemes on monitoring results.
(A) All plots are monitored all years (n = 66). (B) All plots are monitored annually for a specified number of years and then monitored at designated intervals; in this case, every fourth year. The dashed bars indicate data not quantitatively collected during interim periods. (C) All plots are monitored every third year (n = 66) - a single subset of plots (n = 25) are monitored in interim years. (D) All plots are monitored periodically (n = 66); in this case, every third year. During interim periods subsets are sampled on a rotating basis, (sampling without replacement); in this case, over four interim periods (n = 17).

(E) Comparison of subset data to data from all plots. The letter 'A' designates all plots are monitored. The numbers (1, 2, 3, and 4) designate the subsamples of plots.

b) Sample all plots for several (e.g., three) consecutive years to determine baseline conditions and decrease sampling frequency thereafter (Figure 4B)**.** The intent in using this scheme is to develop a baseline of information that identifies the response of vegetation and soils to changes in weather, training intensity, and other natural or anthropogenic disturbances. Once the variability of the system is known, the sampling frequency may be extended. Data patterns during subsequent collections are explained in part by the more continuous, earlier data set. A possible sampling sequence would be years 1, 2, 3, 4, 5, 10, 15, 20, etc. Plant communities that recover quickly from military and/or non-military impacts would need fewer years to establish a baseline of information and a larger spacing between subsequent surveys (Years 1, 2, 3, 6, 12, 18, 24, etc.). In contrast, an area that recovers slowly or is heavily impacted may require a longer baseline and a shorter time between later surveys (e.g., Years 1, 2, 3, 4, 5, 8, 11, 14, 17, 20, etc.).

This approach is less expensive than continuous monitoring and statistical analysis options are still numerous. Breaks between surveys may cause funding problems in that requirements vary greatly between some years. During interim years other sampling needs can be addressed such as special projects, wildlife surveys, sensitive sites, etc.

Because plots are not monitored during interim years, the condition of the resources of interest is not quantitatively known. Given similar levels of use and an understanding of the effects of weather on the vegetation and the soils, land condition can be estimated if mathematical or other relationships have been established. In the example presented (Figure 4B), the causes of the decline of bare ground in 1992 and the subsequent increase through 1994 would not be known. However, these changes may have been reliably predicted if between the 1991 and 1992 field seasons training intensity or livestock use was known to decrease, precipitation to increase, or precipitation occurred at advantageous times. Any of these or other factors could cause an increase in vegetation or plant litter and the decline of bare ground. The next installation-wide survey would mark current conditions. While data may not be collected yearly, training intensity and timing, weather, and other factors affecting vegetation should be documented.

c) Sample some plots all years and all plots during key years (Figure 4C,D,E)**.** Some monitoring occurs all years; therefore a quantitative value exists. Because sample sizes are smaller, the amount of variation is greater than when all plots are monitored. Fluctuations in funding requirements are not as great as when there are breaks in monitoring. The cost is slightly higher than Option 2.

In this scheme all plots are surveyed periodically (e.g., every third year), and either a single subset (Figure 4C) or rotational subsets (Figure 4D) are sampled during the interim years. Plots surveyed during the interim years are either chosen randomly or by set criteria. Plots monitored during interim years provide a continuous source of information on vegetation and soil responses to weather, training, and other land uses.

The variation within any subset is dependent on the plots in the group. When a single subset is monitored during interim years, the variation within the group may be secondary to the information that group provides, such as continuous monitoring of highly utilized training areas. While variation may be higher than on the rest of the installation, site-specific information will be relevant to training needs.

A rotational monitoring system strives for a random collection of installation information. In this case, some groupings may be more variable than others may and some may be more responsive to change (Figure 4E). Groups 2 and 3 have more variation than Group 1 in 1989; the opposite is noted in 1992, and a similar relationship to 1989 is illustrated in 1995. Statistically, there was no difference among the groups ($P>0.05$).

A condition common to many programs is fluctuations in funding, making it difficult to meet monitoring requirements. In order to minimize the effects of funding oscillations, the program manager may consider various scenarios so the program is not severely impaired or rendered useless by temporary reduction of funds. For instance a 25 percent budget reduction may be remedied by using smaller crew sizes, identifying vegetation to the life form as opposed to the species level, excluding trees from quadrat counts (including belt transects) where no significant disturbance has occurred, acquiring support from installation sources (e.g., project vehicles), or merging other projects into the responsibilities of the field crew. Larger fiscal reductions may not be handled as easily, and may require significant alterations to the monitoring plan and protocols. If so, ask the question -- *If the number of plots monitored is reduced by x%, will that affect data quality to the point that monitoring (i.e., quantitative monitoring) is not beneficial?* Once data are collected and analyzed, an appreciation for the minimum amount of data necessary for a valid survey will be more apparent. If necessary, consider limiting monitoring efforts to visiting each plot, photographing, and collecting qualitative data.

Another consideration in planning monitoring efforts is major changes in land-use patterns, frequencies, and intensities. An example might be the mobilization of troops for active duty, or a large scale exercise (brigade, division) that takes place for the first time or infrequently on an installation or in a particular geographic or training area. These types of events can affect funding and field accessibility. As training intensity can increase exponentially, so can vegetation degradation, habitat loss, erosion rates, sedimentation, and the need for data. Qualitative data, such as qualitative surveys and photographs, may be the only feasible methods under these circumstances.

Ultimately, training activity and intensity, vegetation and physical characteristics, and the land management goals of an installation determine the most appropriate monitoring scheme. Ideally, an installation will be able to survey all plots for a minimum of three consecutive years. Then, following a review of the data, the best long-term monitoring program can be designed. No two installations have the same training uses, vegetation, soils, or management goals. By reviewing the data and testing the various scenarios, an installation can identify the best, least expensive alternative.

2.7 Written Protocols and Program Documentation

A monitoring protocol is an essential tool for program managers to organize, design, and evaluate data collection and analysis efforts. Protocols can provide varying amounts of detail depending upon their intended use. Some provide general guidelines while others provide very detailed information. Protocols are sometimes referred to as inventory and monitoring guidelines, monitoring plans or handbooks, or sampling protocols, but are typically more detailed than general implementation plans. Protocols provide site-specific and detailed information about resources and management concerns; management objectives and their corresponding monitoring objectives; monitoring methodologies and data collection procedures; data management, quality control, and storage procedures; and data analysis and interpretation. It may also contain information about sampling locations and plots, data sheets, photographs, and other important documentation. The protocol can focus on the entire installation (as a complex of communities and land uses), or specific entities such as plant communities/habitats, land-use types, or particular species or populations of concern. Some protocols are comprehensive, including all required components, while others may include a single component of overall procedures (i.e., field methodology, data management, reporting, etc.). Examples of protocols include documents written for the National Park Service System (USDI 1992, Halvorson et al. 1988), longleaf pine communities (Rudd and Sutter 1996), a Biosphere Reserve (Shopland 1998), Army resource monitoring (Tazik et al. 1992), and camping or recreational impact assessment (Cole 1982, 1984, and 1989; Kitchell and Connor 1984).

A monitoring protocol helps to ensure that monitoring goals are well defined and prioritized, cost efficiency is maximized, and scientific standards and statistical rigors are appropriate to the resource or management area (i.e., confidence levels, statistical power, and minimum detectable changes, where quantitative methods are applied). Protocols help to provide continuity for monitoring programs, especially where turnover rates are high and program resources are variable from year to year. By organizing existing information and setting specific goals, it helps program managers to justify ongoing monitoring programs. The development of a protocol is appropriate for both fledgling and well-established LCTA programs.

Different levels of monitoring (i.e., qualitative, semi-quantitative, quantitative) are specified that reflect monitoring objectives and available resources. Program evaluation based on data analysis and professional judgement, continuity with historic data, the tailoring of protocols to individual installations, and flexibility over time are all important attributes of a protocol.

2.7.1 Elements of a Monitoring Protocol

A comprehensive monitoring protocol or site-specific handbook should contain all relevant information for the monitoring project. The following components can be included:

(1) landscape and community information, including status of and threats to major community types;
(2) current status of resource inventories relevant to objectives (e.g., flora, fauna, vegetation mapping, threatened and endangered species);
(3) special management concerns related to management and land uses (e.g., fire, erosion, weeds);
(4) management goals and monitoring objectives, which may relate to a number of resource and geographic areas or types;
(5) sampling design and data collection methodologies;
(6) quality assurance, data management, and quality control procedures and recommendations;
(7) data analysis procedures;
(8) master copies of data sheets and other instructions/notes.

These and other elements are directly related to steps involved in the overall monitoring process (section 2.1.3) and support the preparation of annual or long-term implementation plans (section 2.7.2).

2.7.2 Long-Term Monitoring Implementation Plan

Monitoring is a descriptive process that records change over time. An effective monitoring program has a simple design with clearly defined objectives. A monitoring program aids resource conservation, assessment, management, and the advancement of knowledge about the dynamics of ecosystems (Spellerberg 1994). Program plans can be either short-term (one to several years) or long-term (several to many years).

A monitoring plan includes 1) defining the program's objectives, 2) ensuring financial and logistical support, 3) choosing variables to assess data collection methods, 4) determining the frequency and timing of data collection, 5) assessing the costs of monitoring, data storage, rectification, and data analysis, 6) applying practical data uses, 7) identifying long-term data needs, and 8) evaluating the program's success in meeting objectives. An implementation timetable listing tasks and milestones is an important part of an implementation plan. Organizing tasks and required activities in such a manner aids in budgeting and resource allocation in both the near and long term. Monitoring plans will contain information described in a monitoring protocol document (section 2.7), which may comprise a large portion of the plan.

A monitoring program should have flexible components that can be modified as more is learned about the installation and land usage. Take the time to write a detailed monitoring plan, review and make necessary modifications at the conclusion of each field season, and document in detail all of the activities performed every year. When planning a monitoring program, keep in mind data management, analysis, and application. A program that only collects data is destined to failure. Think about how the data will be used and displayed. Will all data elements be collected with the same periodicity? Will collecting data elements at different times cause confusion or prevent valid correlations? How will data collected annually compare and combine with data collected every 5 years? Are installation data needs being addressed specifically?

2.8 Summary: Guidelines for Developing a Successful Monitoring Program

There are three principal difficulties that must be overcome if an ecological monitoring design is to succeed: (1) one of the main ecological difficulties is selecting and quantifying specific biotic conditions within the existing and continuous spatial and temporal variability (e.g., appropriate indicators); (2) the major statistical difficulty is having enough replication in all of the different places and types we want to examine; and (3) the cost of monitoring (Hinds 1984).

Because of these specific reasons and additional complexities associated with monitoring natural resources, their natural variability, unexpected events, and a wide variety of possible sampling designs, program managers are obliged to adapt as conditions change. There is, therefore, is no universally applicable set of guidelines to ensure successful long-term monitoring of large land parcels or landscapes. The following list of attributes was adapted from Stohlgren et al. (1995). It provides a framework to enhance the value of long-term monitoring projects, their associated data, and their value in adaptive management:

(1) **Secure long-term funding and project commitment**. This responsibility lies with a number of individuals involved with the program, including the LCTA program manager, ITAM coordinator, and higher-level installation, MACOM, and Headquarters staff.

(2) **Solicit user's needs early in the process**. Because resource monitoring on military installations is not intended as an academic exercise, practical applications and management needs must drive both the formulation of project goals and the visualization of products and problem-solving scenarios. In the long-term, this may be the ingredient that determines the success of attribute number 1 above, and therefore the success of the project.

(3) **Develop flexible goals**. Goals must be flexible and articulated clearly, reflecting current issues and problems yet providing a basic level of continuity. The goals should also maintain some ability to address unanticipated future issues and concerns. By selecting sets of "core" parameters that address primary concerns and objectives, iterative changes to program goals are not likely to affect the long-term integrity of important parameters.

(4) **Refine objectives**. This process involves the process of reducing general problems to specific ones, identifying specific objectives, and setting priorities for specific inventory and monitoring data needs. For example, priorities for data collection must be weighed against the practical constraints of collecting limited data at many sites or more data at fewer sites.

(5) **Pay attention to data management**. This suite of tasks can include quality control and quality assurance for field data, data acquisition and archive, metadata development, and statistical analyses.

(6) **Be creative and experiment in the sampling design phase**. There is little consensus on sampling designs and methodologies for landscape-level studies, and too often projects have become "locked into" designs too early in the course of the program, precluding the adoption of helpful changes. Considerations such as plot size and shape, the parameters selected for measurement, and the frequency, precision, and accuracy of measurements can be adapted successfully to unique settings. However, radically changing a protocol in long-term studies may require calibrating the new methods to the old ones.

(7) **Obtain peer review of monitoring proposals and reports**. Peer review helps to alleviate problems early in the implementation of a project or even before it begins. Data analysis plans should also be developed prior to data collection, understanding that some features of the design and methodology may change in the initial phase of the program. Moreover, determining adequate sample sizes is an iterative process, which requires recalculating variance and spatial replication needs as data is collected over time.

(8) **Avoid bias in selecting plot locations**. An important feature of landscape-level monitoring is the specific intent to extrapolate information from plots to landscapes (and perhaps from landscapes to regions). Bias in site selection can cause the appearance of trend when in fact none exists (Palmer 1993). When sampling is restricted or biased, such as when sampling locations are intentionally placed close to roads (accessibility sampling), the representativeness of the sample is uncertain (Krebs 1989). The selection of "typical" or "reference" stands is likewise biased and violates the precepts of probability sampling that allow results to be extrapolated across the population. Program managers can minimize bias by first defining the population of interest, and subsequently selecting random sites from that population.

(9) **Ensure adequate spatial replication**. This is one of the main obstacles to statistical extrapolation or inference. Because of the preponderance of unique land uses and types and the variability present within each, sample size adequacy must be addressed through creative restructuring of the landscape. Temporal variability increases sample size requirements because it adds a source of variability beyond sampling errors, non-sampling errors, and inherent spatial variability. Pilot data is typically required to determine adequate sample size.

(10) **Ensure adequate temporal replication**. Temporal (i.e. seasonal, yearly, or cyclic) variability can only be addressed by evaluating several years of data. Because of resource limitations, there is often a tradeoff between spatial and temporal replications. Like the determination of sample size, the determining the frequency of sampling can be an iterative process.

(11) **Synthesize information with other studies and sources of information.** Synthesis involves examining information from different sources in order to answer questions or understand relationships that were not evident from the individual projects. Examples of this include examining data collected at different scales, using quantitative field data to ground-truth remotely sensed information, and gathering different types of information that may complement or be related to the primary data being collected. For example, climatic information is readily available for most locations, and can help explain variability and trends in vegetation data. Training load information organized from a variety of sources can be an important corollary to resource condition data. Water quality and flow information may be collected by another entity within the installation, can be an important indicator of watershed stability and vegetation condition. Experimental and retrospective studies can provide important information regarding effects of specific and integrated stressors, respectively, over time.

(12) **Periodic program review**. It is important to maintain an adaptive approach. Periodic evaluation can help measure the success of the monitoring program (can it effectively accomplish what was intended?). When established as a structured process, evaluation can also involve other program players such as land managers, trainers, and independent scientists, thus promoting positive relationships and interaction. Most importantly, the applicability of the program to training land management and other land management concerns will determine the success of the program.

(13) **Information transfer at different scales**. Information transfer should be addressed at a number of levels of understanding, including installation organizations (land management, range operations, training, etc.), higher headquarters, professional meetings and symposia, and public awareness. Products, reports, and presentations are all essential tools in educating and informing audiences about results and successes. Increasingly, spatial information is communicated through the use of maps and visual tools, which should be used extensively for all audiences. Mechanisms for writing technical reports which address specific objectives and/or hypotheses should be established to promote timely examination of data and information transfer.

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