U.S. Fish & Wildlife Service

Fuel and Fire Effects Monitoring Guide

Fire Works!

The ***Fuel and Fire Effects Monitoring Guide*** is a U.S. Fish and Wildlife Service information resource for integrating fuels treatment and fire effects monitoring into an overall refuge management program. Information in the Guide is designed to facilitate refuge adaptive management when evaluating:

- The effectiveness of fuels management projects identified in approved refuge Fire Management Plans.
- Whether fuels management projects may be compromising refuge resource management goals and objectives defined in approved refuge land management plans.

The Guide supplements the monitoring standards and protocols being developed under Fulfilling the Promise WH-8, WH-10, and WH-14 action items.

Successful fuels treatment and fire effects monitoring starts with planning.

The challenges of successful monitoring involve efficient and specific design, and a commitment to implementation of the monitoring project, from data collection to reporting and using results. Rather than develop a standard approach, this reference attempts to provide guidance that will assist field offices think through the many decisions that they must make to specifically design monitoring projects for their site, resources, and issues. The Fuel and Fire Effects Monitoring Guide is not a step-by-step guide on how to implement a monitoring project, but a compilation of monitoring information that you need to choose among and put together for your particular situation and issues. Local managers and specialists understand their issues and resources best and, therefore, are best able to design a monitoring project to meet their specific needs.

"Methodology is the last refuge of the sterile mind."

That may be an odd statement to find in a methods guide, but the

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NWCG Fire Effects Guide

NPS Fire Monitoring Handbook

FIREMON

Fuel and Fire Effects Monitoring Guide e-book (e-book requires Acrobat Reader)

success of a monitoring project does not start with choosing methods. On the contrary, the probability of failure increases as the investigator's thinking becomes method rather than problem oriented.

Planning is the selection and prearrangement of events for the predictable attainment of an objective. Planning is the most difficult and even tedious aspect of a project. It requires mental discipline and exercise, which can be frustrating and exhausting even for practiced minds. The investigator must often draw from principles of unfamiliar disciplines, such as business management and statistics. Meanwhile, the romance and excitement of data gathering and a sense of expedience entice the investigator to get busy with something familiar and tangible; they lure you into the "activity trap".

The rewards of planning are great. Planning increases the chances of success and reduces losses, caused by unforeseen difficulties. *Planning without action is futile. Action without planning is fatal.*

Planning is presented as 3 phases:

- Project Planning
- Project Design and Analysis
- Completing Monitoring and Reporting Results

During the project planning phase, the appropriate attribute and monitoring method will be identified.

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WHAT'S NEW

- 6/1/01 - Updated material to facilitate Fuel Treatment Effectiveness Monitoring
- 4/20/00 - KBDI calculations and software
- 2/7/00 - Evaluating fire danger rating index performance
- 1/3/00 - New look!
- 9/23/99 - Monitoring training opportunities
- 6/10/01 - Title change, Introduction update, and Monitoring Plan changes to address new fuel treatment effectiveness monitoring 9263 funding authority.

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PROJECT PLANNING

You live and learn. Or you don't live long.

Every management activity produces outcomes and effects. By monitoring and evaluating these management "experiments", we can determine which treatments or actions achieve our fuel management objectives without compromising our land management objectives. This process of linking management with monitoring is called *adaptive management*. Although few management activities are more important than monitoring, its is rarely done and even more rarely done well. Monitoring requires an investment of time and money with returns from this investment sometime in the future usually accruing to people not making the original investment. It is not simple. It does not always accomplish what is needed, because of cost, procedure or system design flaws. Probably most important it is often difficult to determine or agree upon what to monitor. The monitoring and evaluation process is not easy, but it must be an integral part of fire management if we are to learn from our experiments.

If we change the way we manage fire, how will we know if our new management actions are achieving our resource or protection objectives? - Effectiveness Monitoring. We know little about the ecosystems under our stewardship or the fire management outcomes we anticipate, and we may know even less about post fire restoration if we make a mistake. Yet we continue to try new firing techniques to new fuel types with varying loadings at different seasons under different weather conditions in order to get a more desirable outcome. The only way to understand what we are doing is through systematic effectiveness monitoring.

Effectiveness monitoring is the process of determining if a planned activity achieved the planned goals or objectives. It asks the basic question "Did we get what we planned on getting?"

We cannot and do not have to monitor the effectiveness of every

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management activity. We should only monitor if opportunities for management change exist. If no alternative management options are available or there is no commitment to change management practices based on monitoring results, expending resources measuring a trend whether positive or negative is futile. Monitoring resources should only be directed toward management activities where there is the possibility and commitment to change those activities based on the monitoring results.

Many monitoring projects suffer one of five unfortunate fates:

- They are never completely implemented.
- The data are collected but not analyzed.
- The data are analyzed but results are inconclusive.
- The data are analyzed and are interesting, but are not presented to decision makers.
- The data are analyzed and presented, but are not for decision-making because of internal or external factors.

The problem is rarely the collection of data. Service personnel are often avid collectors of field data because it is the most enjoyable parts of their jobs. Data collection, however, is a small part of successful monitoring.

Monitoring is only successful when it is fully integrated into management plans that are supported by both management and affected interest groups. Communications with all affected internal and external interest groups is essential and should begin early in the planning process to begin building ownership of the project.

The challenges of successful monitoring involve efficient and specific design, and a commitment to implementation of the monitoring project, from data collection to report and using results.

1. Planning Monitoring Projects

Not everything that counts can be counted and not everything that can be counted counts - Albert Einstein

Monitoring as part of the adaptive management cycle is driven by objectives. What is measured, how well it is measured, and how often it is measured are design features that are defined by how an objective is articulated. Objectives form the foundation of a monitoring project.

The first step is to establish simply stated, single-purpose, clearly expresses specific, measurable, achievable, relevant, and trackable management objectives that communicate the identity, nature, and depth of the problem. Defining objectives calls for a modicum of guts, if you are trying to create the future, not be managed by it. Why is the project being done? Who wants the information and why? What are you looking for? What kind of output is expected? The objectives should be quantifiable and achievable. They should state what will be done and how much, who will do it, and when it will be finished. Progress or attainment can be measured only if the objectives are definitive. The objective statement should be agreed to by all parties to the project.

Every monitoring project must be supported by some form of management objective, sampling objective, management response, location, and methodology documentation - a MONITORING PLAN. Monitoring plans provide a full description of the management activity, objectives, and proposed methodology, are a means to communicate with and solicit input from all interested parties, and documents a management commitment to implement the monitoring project and the management changes that will occur based on the results. A monitoring plan should be signed by all participants to demonstrate their support of the project and acceptance of the proposed management changes that may result. The basic monitoring plan should cover all the elements necessary to communicate who, what, when, where, how the monitoring project will be conducted and used to make management decisions.

2. Setting Priorities, Selecting Scale and Intensity

Resources and funding for monitoring are limited. You are not likely be able to develop objectives and monitoring activities for all fuel and fire effects which you are responsible. Therefore, only resources and attributes identified in approved refuge fire and land use plans should be considered. Priorities must be set, and the scale and intensity describes the complexity and cost of the monitoring. The scale of monitoring can range from microplot subjectively placed within a burned area to all burned and unburned areas. Intensity can vary from a single photopoint that is revisited every 5 years to a labor-intensive demographic technique that requires annual assessment of every affected attribute.

Clearly, as you increase the scale and intensity you will know more about each attribute, but the monitoring will be more expensive. With limited funds, you can monitor one or a few attributes at a large scale and high intensity, or more at a more limited scale and lower intensity. The setting of priorities is the first step in determining the importance and number of attributes that require attention, the monitoring resources that should be allocated to each, and the complexity of the objective for each attribute that can be monitored.

This explicit consideration of the interplay of priorities, resources, scale, and intensity is critical to the effective allocation of monitoring resources. In the absence of this analysis, we tend to ignore inexpensive monitoring solutions and focus on intensive data-collecting techniques. Other techniques, such as qualitative methods and photographs, are generally less time-consuming to design and implement, but can be effective for many situations. Low-intensity monitoring may be designed as a warning system that triggers a more intensive monitoring and research if a problem appears. In other situations, low intensity techniques may provide data needed for making decisions. Most changes monitored by these techniques must be fairly large or obvious before they are detected; thus, it is often appropriate to take immediate management actions based on these measures. Implementing a high-intensity study to quantify a problem that is obvious only delays remedial action.

Allocating monitoring resources is a critical initial stage in the development of a monitoring project. Ranking priorities and selecting scale and intensity are not trivial activities, but are fundamental to the effective design of good monitoring. Using teams and soliciting review will help focus decisions about allocation, and avoid premature sidetracks into selecting methods.

Integrating fuels treatment effectiveness monitoring with other refuge monitoring activities (i.e., wildlife inventories, etc.), is the next critical stage. Involving all refuge program areas is important at this stage.

3. Choosing a Method

In the simplest terms, methods should be matched to your objectives (which include required precision and accuracy). Effectiveness monitoring can be done at every planning level to determine if the management plan's objectives are achieved. Every level of management planning will define desired goals and/or objectives. What is monitored at each level is dependent on the specific management objective. The monitoring attribute is directly related to the sampling objective, and from the monitoring attribute a specific monitoring method can be selected. For example, a mixed grass prairie example might have the following management objectives and monitoring attributes:

Planning Level	Management Objective	Monitoring Attribute
Comprehensive Conservation Plan	Restore and sustain an ecological functional mixed grass prairie	ecological function
Habitat management plan	Restore vegetation species diversity to 1870 conditions as reported in *Smith, K. 1870. Plant communities of the Northern Dakota mixed grass prairie. University of North Dakota Press, Bismarck, ND. 123p*.	species composition
Fire management plan	Restore a historic wildland fire regime (low to moderate intensity late spring to early fall fires at 3 to 8 year intervals) to all mixed grass prairie communities by 2003 in order to sustain community stability.	spatial fire frequency
Prescribed fire plan	Reduce post fire (~ 1 month post fire) litter to ~ 100 (50 - 500) lbs./acre (dry weight) in all mixed grass prairie communities to restore historic soil moisture conditions.	post fire litter loading

But, practically, choice of methods is also governed by a combination of money, purpose, available equipment, project site, experience of personnel, measuring efficiency, and standardization with previous projects. Each monitoring project is unique because any of these factors exert varying degrees of influence for widely different reasons.

Compatibility with methods of other monitoring projects, so that the projects may be compared, is a factor easily overlooked, but it may be essential to the objectives of some projects. Standardization of units, sampling methods, sampling times, definitions, criteria, classification systems, cartographic scales, and data-reduction procedures are necessary to permit comparisons. Compatibility with other projects or efficiency in the field may be deciding factors when faced with the choice of two otherwise equal methods. On the other hand, the nature of the project site may not allow any choice of methodology. Monitoring projects need to be coordinated with other program areas, other appropriate state and federal agencies and interested publics. Monitoring should be planned and implemented on an interdisciplinary basis.

4. Location of Project Sites. Following establishment of objectives, the project area must be defined. For this step, maps and large-scale aerial photos are necessary. Factors to consider in defining the project area are management objectives, areas where expected physical and/or biological changes directly or indirectly related to the fire had/will occur, contiguous areas with strong physical or biological links to the area of actual physical effect, and interrelationships of species that currently exist or could exist.

Proper selection of project sites is critical to the success of a monitoring program. Errors in making these selections can result in irrelevant data and inappropriate management decisions.

The site selection process used should be documented. Documentation should include the management objectives, the criteria used for selecting the sites, and the kinds of comparisons or interpretations expected to be made from them.

Common locations for projects include critical areas and key areas. Some of the site characteristics and other information that may be considered in the selection of project sites are:

1. Burned area
2. Soil
3. Vegetation (kinds and distribution of plants)
4. Ecological sites
5. Seral stage
6. Topography
7. Location of water, fences, and natural barriers
8. Size of area
9. Location and extent of critical areas
10. Cultural resources
11. Threatened, endangered, and sensitive species-both plant and animal

A. **Critical Area**. Critical areas are areas that should be evaluated separately from the remainder of a management unit because they contain special or unique values. Critical areas could include fragile watersheds, sage grouse nesting grounds, riparian areas, areas of critical environmental concern, etc.

B. **Key Areas**. Key areas are indicator areas that are able to reflect what is happening on a larger area as a result of on-the-ground management actions. A key area should be a representative sample of a large stratum, such as a fuels treatment area, pasture, grazing allotment, wildlife habitat area, herd management area, watershed area, etc., depending on the management objectives being addressed by the study. Key areas represent the "pulse" of an area. Proper selection of key areas requires appropriate stratification. Statistical inference can only be applied to the stratification unit.

(1). **Selecting Key Areas**. The most important factors to consider when selecting key areas are the management objectives found in approved refuge fire, and land use plans. An interdisciplinary team should be used to select these areas. In addition, interested publics should be invited to participate, as appropriate, in selecting key areas. Poor information resulting from improper selection of key areas leads to misguided decisions and improper management.

(2) **Criteria for Selecting Key Areas**. The following are some criteria that should be considered in selecting key areas. A key area:

a. Should be representative of the stratum in which it is located.
b. Should be located within a single ecological site and plant community.
c. Should contain the key species where the key species concept is used.
d. Should be capable of and likely to show a response to management actions. This response should be indicative of the response that is occurring on the stratum.

(3) **Number of Key Areas**. The number of key areas selected to represent a stratum ideally depends on the size of the stratum and on data needs. However, the number of areas may ultimately be limited by funding and personnel constraints.

(4) **Objectives**. Objectives should be developed so that they are specific to the key area. Monitoring plans can then be designed to determine if these objectives are being met.

(5) **Mapping Key Areas**. Key areas should be accurately delineated on aerial photos and/or maps. Mapping of key areas will provide a

permanent record of their location.

C. **General Observations** General observations can be important when conducting evaluations of designated management areas. Such factors as fire history, rodent use, insect infestations, animal concentrations, vandalism, and other uses of the sites can have considerable impact on vegetation and soil resources. This information is recorded on the reverse side of the method forms or on separate pages, as necessary.

D. **Reference Areas**. Reference areas are areas where natural biological and physical processes are functioning normally. Reference areas serve as benchmarks for comparing management actions. Reference areas differ from key areas in that they represents areas where impacts are minimal. Reference areas are found in exclosures, natural areas, or areas that receive minimal impacts.

Reference areas should if possible be included in any monitoring project to evaluate the influences of natural variables (especially climate). Cause-and-effect relationships are better determined if the effects of climate can be separated from management effects. Monitoring projects, especially trend studies, should therefore be established both on key areas and reference areas located on the same ecological sites. Of course, monitoring priorities and funding resources must be considered in planning and establishing monitoring projects on reference areas.

5. Monitoring Schedule

Now that you know what measurements are required and where monitoring will take place, compile pertinent data, some of which may have been compiled to delineate time periods. Sometimes data from a very similar, and usually nearby, area can be applied to the project area. Use caution if you do apply data from other areas to your project area, and try to limit such use to a guiding role rather than one from which conclusions are drawn.

6. Field Work

Build a working knowledge of the project area and the life history of the evaluation species. Combine this knowledge with common sense to construct a sampling schedule and to appropriately apply the chosen methods. Avoid vague criteria and definitions, and demand that measurements adhere to the definitions as completely as possible. A pilot project is recommended whenever possible. It serves to determine variability for designing a sampling scheme, to identify critical variables, to practice and help identify and remedy methodological problems, to revise data sheets, to reassign crew jobs or groups, and even to change methods or equipment. pilot sampling may reveal that it is impossible to address your objectives within the time and funding constraints. In such an instance, you could refine your design in several ways:

- Change the type of monitoring to a less resource-intensive type, perhaps on that is more qualitative or semi-qualitative.
- Refine the issues of interest.
- Increase statistical risk by selection lower confidence limits.
- Choose a different attribute to measure.

A. **Recording Field Data** Allow plenty of time to devise a system in which to record field data. Arrange the data tables so that data can be efficiently recorded in the field (e.g., all data collected at the same time along the same transect might be on the same table). The table should include columns for a clear sequence of data reduction and for data and means of replicates or data pairs. Each sheet should be identified with project name, date, time, project area, project site or transect, and personnel. Allow room for comments--such as weather; method modification; calibration procedures; unusual conditions or observations; and film role, frame number, and subject of photographs. Don't forget data sheets to record identification numbers of samples removed from the project site to be analyzed off site.

Electronic data recorders are handheld "computers" that are constructed to withstand the harsh environmental conditions found in the field. They are used to record monitoring data in a digital format that can be transferred directly to a personal computer for storage and retrieval. They require minimal maintenance, are generally programmable, and allow easy data entry using a wand and bar codes. Recording field data using an electronic data recorder takes approximately the same amount of time as using printed forms. The advantage with electronic data recorders is that they improve the efficiency by reducing errors associated with entering data into a computer for analysis. They can also reduce the time needed for data compilation and summarization. The cost of electronic data recorders and computer software programs is considerable and should be evaluated prior to purchase. It is also important to have good computer support assistance available to assist users in operating, downloading, and troubleshooting electronic data recorders, especially during the initial use period.

B. **Avoiding Errors** Regardless of method, it is vital that it be applied with the most unbiased and precise technique possible. When methods are applied carefully, consistently, and to the full extent of their capabilities, maximum precision is achieved; bias is then a concern that can be eliminated, or at least dealt with.

Long before the first sampling visit, compile, inventory, and test all equipment, including spare parts and repair kits for everything. Equipment includes everything from weather-proof criteria, definition, and calibration sheets to living and emergency gear. Use a checklist.

C. **Roles and Responsibilities** Brief the crew on the objectives of the project and the sampling visit. Assign jobs to all crew members and have them practice their assigned tasks, especially if the tasks are subjective evaluations.

One of the most important roles is that of recorder, which may be synonymous with crew chief. This person must understand the data organization and is responsible for efficient, complete data collection.

Although he/she may not be physically recording all data, because data collection is assigned to more than one group, he/she must be aware of the progress of the whole crew and be prepared to assist in any capacity. Finally, the data recorder is responsible for equipment inventory at the end of the day.

7. Making Adjustments

The methods described are guides for establishing and sampling monitoring attributes. They are not standards. Methods can be modified or adjusted to fit specific resource situations or management objectives as long as the principles of the method are maintained. All modifications such as changes in quadrat size or transect layout should be clearly documented each time the method is used.

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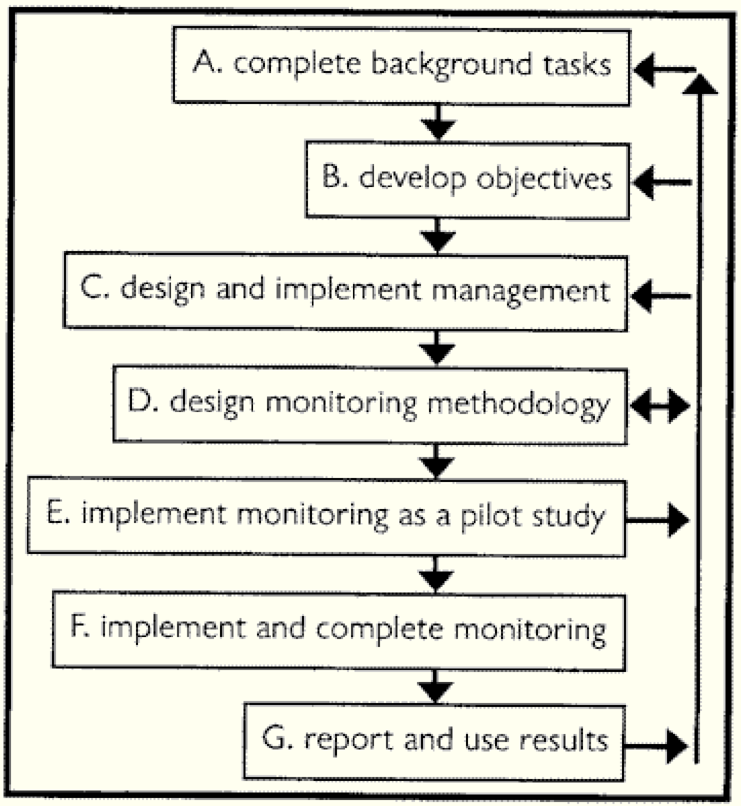
ADAPTIVE MANAGEMENT CYCLE

The steps described below and illustrated in the flow diagrams provide an overview of the development of an adaptive management cycle. The following steps should not be considered sequential. Feedback loops and reviews are many, shown by the multidirectional arrows in the flow diagrams. At nearly any point in the process of developing a monitoring project, earlier decisions may have to be revisited and changes made.



Seven major steps of project planning and implementation

COMPLETE BACKGROUND TASKS

1. Compile and review existing information Compile relevant information on the physical, cultural, and/or natural resources to be monitored. For those monitoring projects where the target resource is predetermined, you will only need the information specific to the resource. For management programs that are just beginning, you'll likely want to assemble the information needed to set priorities among all the resources occurring in your administrative unit. If you manage many resources, you may wish to start with a short list of resources that are high priority, perhaps because of legal reasons, such as federally listed species, significant historic properties, safety and health concerns, etc.

2. Review upper level planning documents Consistent local land management depends on following upper level planning documents. These documents describe to the public the agency's planned activities. Because managers are accountable for implementing these plans, specific management activities should demonstrate progress toward meeting goals and objectives described in them. Even if you believe your refuge's land use plans provides little specific direction (many of the older ones don't), you will increase support for your specific project if you can show a clear relationship between it and the general directives outlined in planning documents.

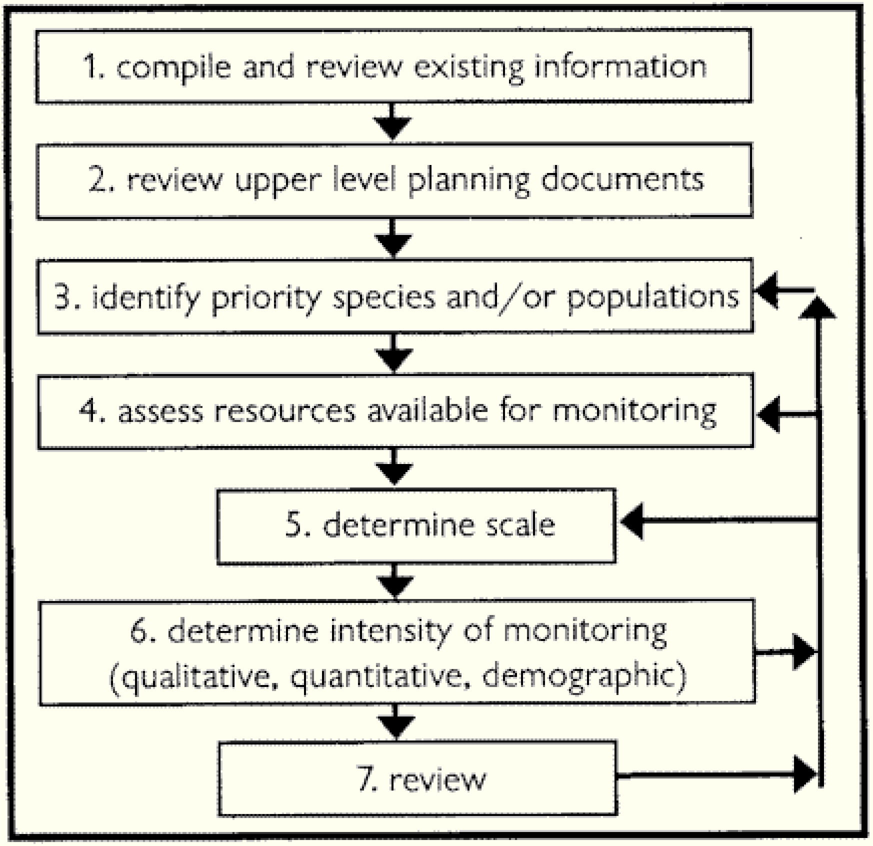
3. Identify priority resources Prioritize the resources for monitoring, and document your thought process. This documentation will be useful to you and your successor if managers and other parties question your priorities. For priority resources select priority targets. These priorities may periodically require reassessment due to changes in threats, management, conflicts, and the interest of outside parties.

4. Assess the monitoring resources available Monitoring resources depend on management support, priorities, and the people and equipment available. Has management placed a priority on this monitoring project, or is support and funding limited? You may need to promote the importance of the project before you begin working on it. Are qualified personnel available to do the work? Do you have the necessary field equipment such as vehicles and measuring tapes? Is any high-tech equipment available (e.g., geographic information systems, global positioning systems, survey or forestry equipment)? Are people willing to give reviews and help sharpen your thinking? Do you have access to people with specialized skills? The types and amounts of resources will limit the extent and complexity of a monitoring project.

5. Determine scale Identify the scale of interest for monitoring (e.g., the range of the species, the populations within a certain watershed, populations in certain types of management units, a single population, a portion of a single population such as a key area or macroplot). Decide the scale of interest early in the monitoring process because it will influence later decisions and design. If, for example, the scale of interest is the species across its entire range, you will need to coordinate with various administrative units to develop a network of monitoring studies.

6. Determine intensity of monitoring Will qualitative monitoring be adequate? Do you need quantitative data? Does the rarity of the resource, the degree of threats, or the political sensitivity of potential decisions warrant the use of an intensive demographic approach? You may need to reevaluate the selected intensity of monitoring as you work through the remaining monitoring decisions.

7. Review At this point, management should be briefed, and opinions and review solicited. For small projects, you could complete these steps on your own and then solicit internal and possibly external review. For larger programs or highly controversial species and populations, you may need to assemble a team.



DEVELOP OBJECTIVES

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1. Develop an ecological model Completing a narrative or diagrammatic summaries (models) of the ecological and management interrelationships of the resources of interest will help develop objectives, focus your monitoring, and improve interpretation and application of the data.

2. Identify general management goals Using the model, try to refine conservation goals. Should the fuel load be significantly reduced and by how much? Should the population size of the species be increased? Maintained? Recruitment increased? Mortality decreased? Describing these general management goals is the first step toward developing specific objectives.

3. Select indicator You may choose to monitor the resource itself or some indicator that serves as an indicator success (i.e., black rail vs. black rail habitat). Monitoring threats as indicators can form an effective basis for management changes. Indicators are also useful for resources that are difficult to measure or monitor (e.g., very small species, annual plants, long-lived species, particulate matter concentrations).

4. Identify sensitive attribute The first and second order fire effects attribute frame lists the common measurable fire effects attributes. Attributes also include qualitative and semi-quantitative measures such as presence or absence, estimates of cover by cover class, and visual estimates of population size. The attribute most sensitive for measuring progress toward the described goal will vary by resource and situation. For example, individuals of some species such as rhizomatous grasses are difficult to count. Instead of density, you would need to select another measure of success or improvement such as cover or frequency. The attribute most sensitive and useful for monitoring depends on the life history and morphology of the species and the resources available to measure the attribute. Some resources are so poorly known you may have difficulty identifying a sensitive parameter. Make the best choice you can or postpone monitoring until you know more about the natural history of the species.

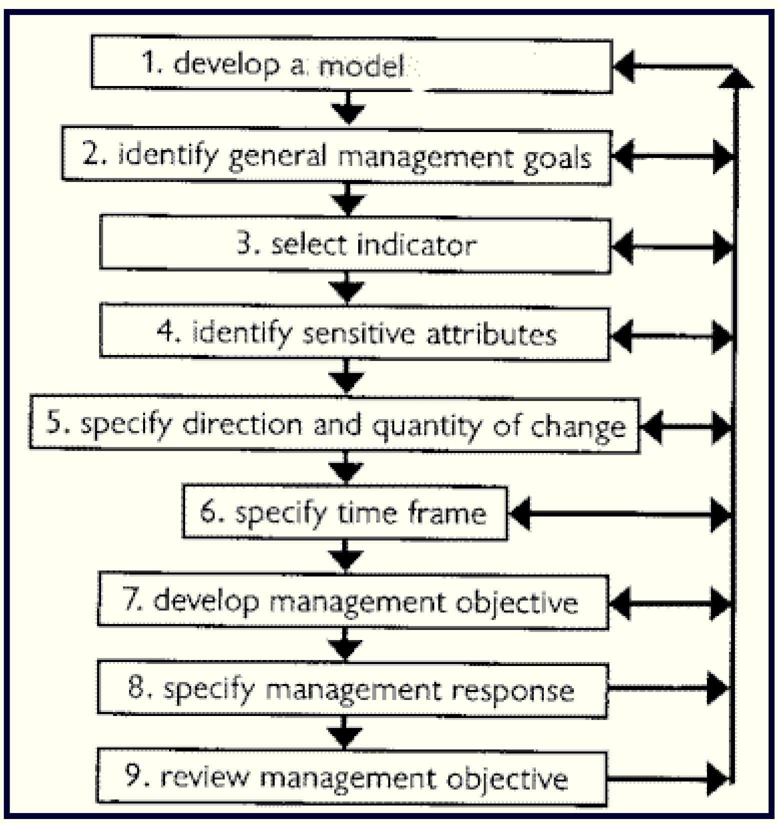
5. Specify direction and quantity of change Will you monitor for a percentage change or an absolute change, a target or threshold value? What increase do you want to see, or what decrease will you tolerate? Can you specify a target population size? The quantity has to be measurable (confidently measuring a 1% change in average density is extremely difficult) and biologically meaningful (a 10% change in density of an annual species is probably not important). Again, you may be limited by lack of information. You may also be limited by the amount of change you can detect in a sampling situation.

6. Specify time frame How soon will management be implemented? How quickly do you expect the species to respond? How long do you want this monitoring program to continue if some threshold is not reached? The time frame should be ecologically meaningful for the change you are anticipating. A 50% increase in the density of a long-lived woody plant, for example, is unlikely to occur over the next 3 years (although a decline of that magnitude may be possible and alarming).

7. Develop management objective The priority resources, selected scale (location), sensitive attribute, quantity and direction of change, and time frame of change are the critical components of the objective. Combine them into a simple, measurable, understandable objective.

8. Specify management response Given the potential alternative results of monitoring, what management changes would be implemented in response to each alternative? These management responses should be clarified before monitoring begins so all parties know the implications of monitoring results.

9. Review management objective Preferably, several of these steps would be completed by a team of specialists and management, but often the fire effects monitoring specialist will work alone through these steps. Before proceeding to the design of monitoring, solicit internal and external review, especially from parties that may be affected by management changes made in response to monitoring data. Do others have information about the resources that you should incorporate into the model? Do all agree on the management objective? Do all agree with the proposed management response?



DESIGN AND IMPLEMENT MANAGEMENT

Depending on the situation, current management may be continued or new management proposed. Often current management is continued and monitored because little is known about how fire effects a particular resource. In some cases, however, previous monitoring data or natural history observations may suggest a need for management change. The model may provide insight on needed changes as well. If new management is required, it must be completely described so it can be implemented effectively.

The design of conservation management strategies for fire involves consideration of the relationship between fire and other resources, funding, management options, conflicting uses and activities, and communication and coordination with public and user groups. This complex and difficult step is unique to each situation, and appropriately addressed in the Service planning process.

Refuge planning begins with the Comprehensive Conservation Plan (CCP). The CCP describes what role fire historically played on the refuge and to what degree fire may need to be included in the future in order to achieve refuge objectives. During the CCP environmental assessment process, both the positive and negative (i.e, smoke, property risk, implementation costs, etc.) effects of both using fire or excluding fire are evaluated. Where fire is not the preferred ecological alternative or where overcoming the negative effects of using fire to achieve refuge objectives may not be possible, the appropriate fire regime will be fire exclusion. Otherwise, the use of fire is appropriate.

Next refuge step-down plans (Habitat Management Plan (HMP), Cultural Resources Management Plan, etc.) identifies the preferred habitat management treatments needed to achieve specific refuge habitat objectives, historic properties of importance and those that need protection from fire, and other values at risk from fire. During the plan's environmental assessment process, fire's habitat specific effects are evaluated and compared to other management alternatives. The refuge management plans will identify the specific fire regime(s) needed (i.e., fire intensity and severity, temporal and spatial distribution, etc.) to achieve refuge habitat objectives. Fire secondary effects (i.e., air quality degradation, liability risk, cost, etc.) are also evaluated.

It is only after the CCP and other refuge management plans determine and justify how fire will be managed and used on a refuge that the operational Fire Management Plan can be developed. The Fire Management Plan develops the fire management strategies and tactics and fuel treatments and needed to implement the fire regime(s) identified in the CCP and HMP, and protect values at risk identified in other refuge plans. The Fire Management Plan may be supported by other plans directing specific elements of the fire management program - Dispatch Plan, Prescribed Fire Plan, Step-Up Plan (preparedness), Pre-attack Plan, etc.

DESIGN THE MONITORING METROLOGY

1. Qualitative monitoring

A. **Design general methodology** Methods for qualitative monitoring include estimating quantity (e.g., ranked abundance, cover class) and quality (e.g., population stage class distribution, habitat condition), and using a permanent recording method, such as a photopoint or a video sequence.

B. **Design methods to reduce variability among observers** The biggest drawback of using qualitative techniques is that estimates among observers can vary significantly. Between-observer variability can be reduced by training observers, articulate qualitative assessments quantitatively, photographs. etc.

C. **Identify number of measurement units** Some qualitative monitoring situations may require several to many measurement units, such as macroplots or photoplots. These are not sampling units, since they will not be combined and analyzed as a sample. Many design decisions, however, are similar to those required for sampling units and include selecting size, shape, and permanence.

D. **Determine arrangement of the measurement units** How will these measuring units be distributed in the population or across the landscape? Will you selectively place them based on some criteria such as threat or ease of access? Will you distribute these units evenly across the population to enhance dispersion and avoid bias?

2. Census

A. **Define the counting unit** Will you count individuals, stems, clumps, or some other unit? Will you count all individuals or only certain classes (such as flowering)? These questions must be clearly addressed in the design to ensure different observers conduct counts using the same criteria.

B. **Develop methods to ensure complete counts** Will you have standardized methods (transects, plots, or grids)? Counts that are intended to be a complete census are often incomplete. What strategies will you use to ensure small individuals are not overlooked?

3. Quantitative Studies with Sampling

A. **Develop sampling objectives** If you are using sampling to estimate population sizes or mean values (such as density, cover, or frequency), you must also identify an acceptable level of precision of the estimate. If you are sampling and determining the statistical significance of changes over time, you must identify the size of the minimum detectable change (previously specified in your management objective), the acceptable false-change error rate, and missed-change error rate (or statistical power level). What is the risk to the species if your monitoring fails to detect a real change (missed-change error), and how confident must you be of detecting a change over time (statistical power)? What is the risk to alternative uses/activities if your monitoring detects a change that is not real (false-change error)?

B. **Define the sampling unit** Will sampling units be individually placed plots, plots or points placed along a line, a line of points, individual plants, seedpods, or some other unit? The sampling unit must be explicitly identified to ensure the selected units are random and independent.

C. **Describe unit size and shape** The most efficient size and shape of the sampling unit depends on the spatial distribution of the resources you are sampling. Most plants grow in clumps. Unless careful consideration is made of plot size and shape, most plots will rarely intersect clumps of the target species. Many plots will be required in such a design to meet the specified precision and power of the sampling objective. Efficient sampling design using plots of appropriate size and shape can dramatically reduce the number of sampling units that must be measured, reducing the time and resources required for the field work and data entry. The size and shape of the sampling unit may be the most important decision affecting the success of projects where sampling is used.

D. **Determine sampling unit placement** Sampling units must be positioned without bias.

E. **Decide whether sampling units will be permanent or temporary** Permanent sampling units are suitable for some situations, while temporary ones are more suitable for others. If the sampling units are permanent, monumenting or another method of relocation becomes critical and will require additional field time for plot establishment during the first year of the monitoring project.

F. **Estimate the number of sampling units required** Data from a pilot study are the most reliable means to estimate the number of sampling units required to meet the targets of precision and power established in the sampling objective.

4. Design issues common to all three types

A. **Design data sheet** While some studies may use electronic tools to record data, in most studies the researcher will record measurements on a data sheet. A well-designed data sheet can simplify rapid and accurate data recording and later computer data entry.

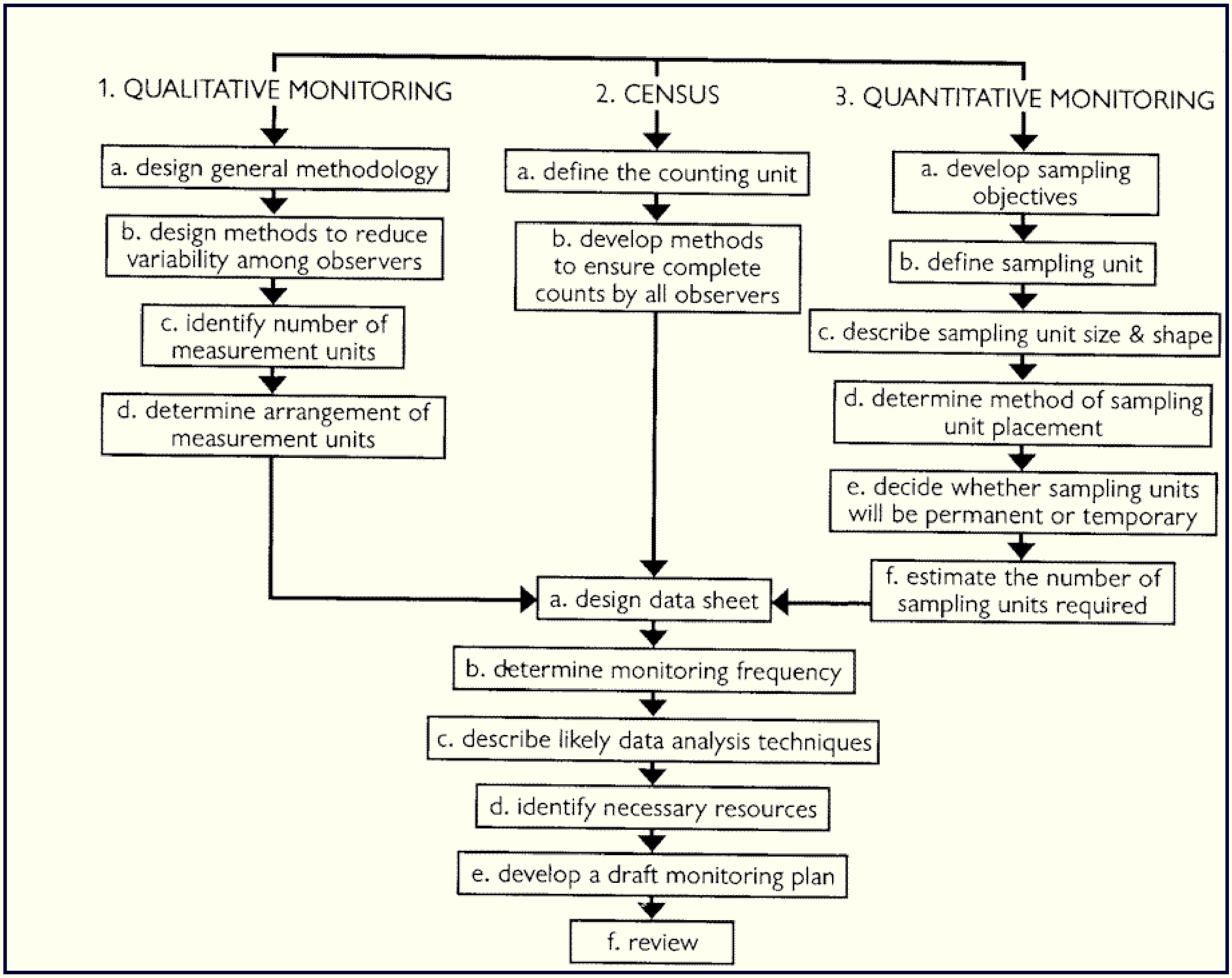
B. **Determine monitoring frequency** How often should the parameter be measured? Will you be monitoring annually? Every 3 years? The frequency varies with the the expected rate of change (long-lived plants may require infrequent measurement), the rarity and trend of the resource (the risk of loss for very rare or very threatened species is higher), and the resources available for monitoring.

C. **Describe the likely data analysis techniques** For all projects, describe how the data will be evaluated and analyzed. If you are using quantitative sampling, identify the statistical tests appropriate for the data you're planning to collect so the assumptions of the tests can be considered in the design stage. Don't assume you can collect data, give it to an "expert" and expect meaningful results. Useful data analysis starts with good field design and data collection. This is also a good point to check whether the data will actually address the objective, given the analyses you plan to use.

D. **Identify necessary resources** Now that you have specifically designed the monitoring project, estimate the projected annual and total costs, analyze the resources needed, and compare to resources available. Reevaluate equipment and personnel required to successfully implement your project and ensure they are available. Document the responsible individual/team for implementation of the monitoring, the source and amount of the funding for monitoring (annually and over the life of the project), and the necessary equipment and personnel.

E. **Develop a draft monitoring plan** If all these steps have been documented and reviewed, many components of your monitoring plan have been completed. The draft monitoring plan provides four important benefits: (1) it focuses the thinking of the author by forcing articulation; (2) it provides a vehicle for communication and review; (3) it documents approval and acceptance when finalized; and (4) it provides a history of the project and guards against the untimely end of the monitoring project if the primary advocate leaves. For those monitoring projects requiring minimal review from people outside the agency, the monitoring plan may be postponed until after data from the pilot stage have been analyzed.

F. **Review plan** Use the monitoring plan to solicit review of your proposed project. Do all reviewers agree with the methodology? Does the proposed methodology really monitor the objective? It may be necessary to revise either the methodology, or the objective, or both. For example, your objective may involve increasing cover of the target species, but as you design the monitoring you may realize that measuring cover of this particular species will be difficult. Treat development of objectives and design as an interactive process; the objective drives the design of the monitoring, but the practical constraints of the resource, the characteristics of the site, or the availability of monitoring resources may require reevaluation of the objective.



IMPLEMENT MONITORING AS A PILOT STUDY

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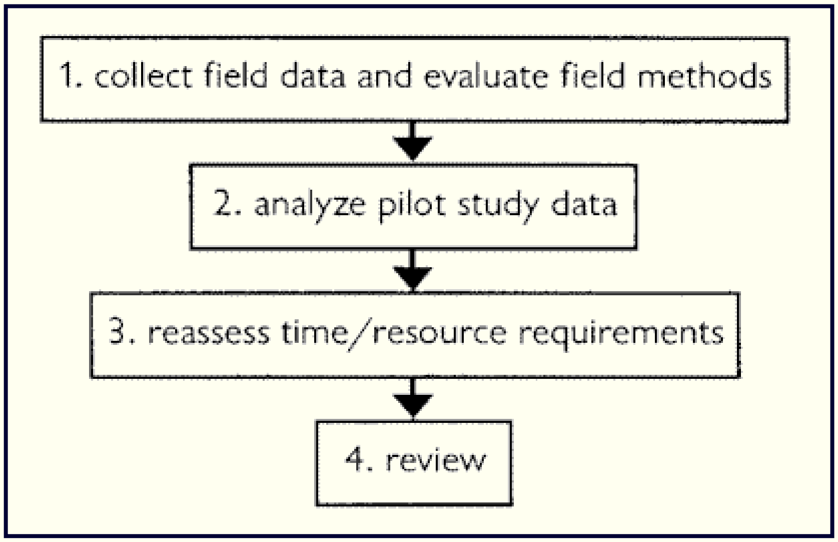
1. Collect field data and evaluate field methods The first trial of a monitoring method in the field often exposes problems with the methodology (e.g., plots cannot be positioned due to dense vegetation; the proposed counting unit cannot be applied consistently; lacy vegetation proves a problem for measuring shrubs along a line intercept). This is why the pilot period is important for testing the feasibility of the proposed monitoring approach and identifying improvements. You may find at this stage that the project cannot be implemented as planned and requires substantial revision, or even abandonment, in spite of all the work done to this point.

2. Analyze pilot study data Analyze data from the pilot study. Do assumptions of the model still appear correct? Are sampling objectives of precision and power met? If not, you may need to alter your monitoring design (add more sampling units or improve the efficiency), the sampling objective (accept lower precision and/or power), or perhaps abandon the entire project. Is the level of change or difference you've specified seem realistic? Do changes due to weather seem larger than you anticipated, thus swamping the quantity specified in your objective, or do the plants appear so slow-growing that the proposed change is unrealistic? You may need to reassess the quantity or time frame component of your objective.

3. Reassess time/resource requirements The pilot project should provide a better estimate of the resources required for monitoring. Your estimate of costs should include the amount of time it has taken to develop the monitoring to this point as well as how much time it will take to continue the monitoring annually and complete final data analysis and reporting.

4. Review Solicit review of the results of the pilot period. Do all parties still agree to continue the monitoring and abide by the results? Are the resources available to implement monitoring throughout its life span? Make necessary changes to the monitoring design and the monitoring plan and solicit final review.



IMPLEMENT MONITORING

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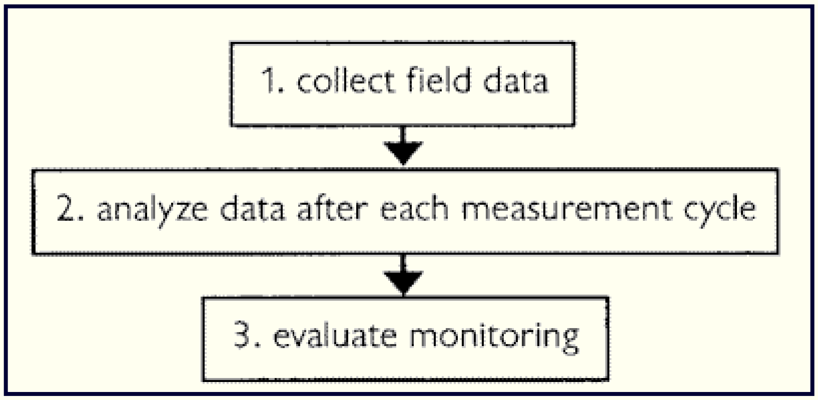
1. Collect field data Complete data collection at specified intervals. Ensure data sheets are completely filled out, duplicated, and stored in a safe place.

2. Analyze data after each measurement cycle Complete data analysis soon after data collection. Data should not be stored over several years before analysis for a final report. Timely analysis identifies problems early, reduces the work associated with the final report, and ensures that questions requiring additional field visits can be addressed. In addition, questions that occur as field data sheets are entered into the computer can often be answered because the field work is still fresh in your memory.

3. Evaluate monitoring Evaluate field methods, costs, sample size, and relevancy of the monitoring project after each data collection. Recognize that at any time in the process a problem may arise that causes you to change or abandon your monitoring effort. All the steps preceding this one reduce that risk but do not eliminate it.



REPORT AND USE OF RESULTS

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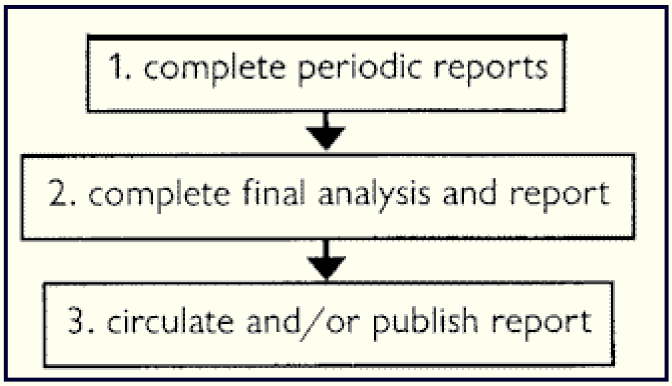
1. Complete periodic reports Completing a summary report each time data are collected will yield the following benefits: (1) display the importance and usefulness of the monitoring to management, thus increasing continued support; (2) provide a summary for successors in the event of your departure; and (3) provide a document that can be circulated to other interested parties.

2. Complete final analysis and report At the end of the specified time frame (or earlier if objectives are achieved), prepare a final monitoring report and distribute to all interested parties. This final report presents and summarizes the data, analyses, and results, and provides recommendations. If the monitoring project has been designed and documented as described above and data have been analyzed periodically, this final report should be easy to complete and not contain major surprises.

3. Circulate and/or publish report Sharing the results of your monitoring increases the credibility of the agency, assists others in the design of their monitoring projects, enhances partnerships, and reduces redundancy. Sharing the results in a technical forum such as a symposium or a journal article is also good professional development for you.



COMMON MONITORING PROBLEMS

Monitoring projects often do not function as intended. The following are common scenarios and suggestions for avoiding problems.

1. Monitoring Not Implemented

A. **Priorities changed and monitoring was not implemented after the first two years.** A signed monitoring plan represents a commitment by the agency to implement monitoring as designed. Although not a guarantee in the changing world of agency budgets and priorities, a monitoring plan provides some insurance that the monitoring will be implemented. If other parties outside of the agency were part of the development of the monitoring plan, they may provide additional incentive to implement the planned monitoring.

B. **Data collection went as planned during the pilot period, but when we started using student interns for the field work after the pilot period, we found that they sometimes confused seedlings of a common shrub with the species of concern.** The pilot period should function as a true test run of the monitoring. If technicians will be used for data collection over the life of the project, they should be used in the pilot period. Monitoring design needs to accommodate the skill levels of those who will be doing the field work as well as those involved in analysis and interpretation.

C. **The specialist in charge of the monitoring project was transferred to Washington and the monitoring project is faltering because of lack of an advocate.** Again, a monitoring plan may prove useful, especially if more than one person within the agency was involved in its development and can function as a replacement advocate, and if outside parties are actively involved.

D. **The specialist in charge of the monitoring project retired, and no one remaining knows where the transacts are or what size quadrats were used.** Again, a monitoring plan can help. Not only are monitoring plans useful for communication, they also provide a link between predecessor and successors. A cover sheet that describes monitoring methods provides further insurance that information such as transact locations is not lost. Monitoring that has been poorly documented will not be continued once the originator leaves. Even worse, it is likely that all of the data already collected will be thrown out, since no one can interpret it.

2. Monitoring Data Not Analyzed

A. **The field work was completed, but there is not enough time to analyze the data and report the results.** When planning for monitoring, the time required for data entry, analysis, summary, and reporting are often forgotten, and only the field costs considered. Office work will likely require two to eight times the field time and need to be included in the budget.

Commitment by decision makers to allocate the time and resources required for the entire project, not just data gathering, should be part of the development of the monitoring plan.

B. **The field work was completed, but no one in the office knows how to analyze the data.** Part of the monitoring design should be the identification of analysis methods. If those can't be identified by available staff during the design stage, additional expertise should be brought in during design, not after the data are collected.

C. **The field work was completed by student interns, who have since returned to college. We can't find some of the field notebooks, and no one in the office can decipher the notes in the ones we have.** Field data sheets should be developed for each project, rather than using field notebooks for data recording. Data collected by short-term employees or volunteers should be checked immediately, duplicated, and stored in a secure place.

3. Monitoring Yields Inconclusive Results

A. **After 4 years of monitoring, the data were analyzed. The estimate of population size from the first year's data is 342 individuals, +/- 289 individuals at the 90% confidence interval. Estimates of population size in subsequent years were no more precise.** If the first year's data had been analyzed immediately as a pilot study, it would have been apparent that the methodology was not producing reliable estimates of population size. As it is, four years of useless data have been collected.

B. **During 10 years of monitoring, the population has exhibited an annual decline. It is still uncertain, however, whether the heavy livestock use in the area is responsible, and no decision to alter livestock management can be made.** Developing a monitoring strategy of two phases-the first to identify an unacceptable decline and a second to determine reasons-would avoid this scenario. Ten years is a long time to monitor a population decline and do nothing but watch.

C. **After 12 years of monitoring, we've learned that the population size fluctuates up and down dramatically from year to year.** While this may be an interesting observation, it is not very useful for monitoring, and the fluctuations probably became apparent after 3-4 years of monitoring. Population size is not a sensitive measure to use for monitoring this species, since any trend is swamped by the annual variability. The measured attribute (here population size or density) should have been changed after a few years, rather than continuing to measure it for 12 years. The potential for large annual variation in a chosen attribute should also be considered during the design phase.

D. **After 5 years of monitoring, we brought our data set to a statistician who said it was "nearly worthless."** Several mistakes were made here. During the design and pilot stages, a statistician should have been consulted if the necessary skills were not available locally. Data should have been analyzed after the first year or two, so that changes in the monitoring could have been made before 5 years of time and effort were invested in the monitoring.

4. Monitoring Data Analyzed But Not Presented

A. **I don't have time to make fancy graphs and reports. I'm convinced of what the monitoring results say, and I'll use it to make better professional judgments concerning this species.** Such an attitude has two drawbacks. The first is that using the actual data is usually much more powerful than filtering it into "professional judgments," and the necessary changes will more likely be made if there are data to back them up. The improvement in the professional judgment of the specialist is important, but unless that translates into a management change, the monitoring really has not been successful. Second, failing to complete a report eliminates an important communication tool to describe results to successors, outside interested parties, and decision makers.

B. **The results are inconclusive. I don't have anything to report.** Inconclusive results need to be reported so others can avoid making the same mistakes.

5. Monitoring Results Encounter Antagonists

A. **After 4 years of monitoring showing a significant decline in the population, the decision maker refuses to change the grazing management because the range conservationist claims livestock never use the population area. I know I've seen herbivory and trampling in the population, but I don't have any data to prove it.** Other specialists may have information or concerns that need to be addressed when designing the monitoring. Failing to include potential internal opposition during planning ensures their appearance after the data are collected.

B. **We've monitored for 3 years, and have shown a statistically significant decline, but the timber company hired a consulting firm that has discredited our methodology.** Rare is the monitoring project that is not susceptible to criticism. Including the timber company during the development phase, and ensuring their support for the monitoring methodology and the potential results, would have helped avoid this scenario.

MANAGEMENT OBJECTIVES

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1. Introduction

The Fuel and Fire Effects Monitoring Guide promotes objective-based monitoring whose success depends upon developing specific management objectives. Objectives are clearly articulated descriptions of a measurable standard, desired state, threshold value, amount of change, or trend that you are striving to achieve for a particular fuel condition, fire effect, or habitat characteristic. Objectives may also set a limit on the extent of an undesirable change.

As part of the adaptive management cycle, management objectives:

- Focus and sharpen thinking about the desired state or condition of the resource.
- Describe to others the desired condition of the resource.
- Determine the management that will be implemented, and set the stage for alternative management if the objectives are not met.
- Provide direction for the appropriate type of monitoring.
- Provide a measure of management success.

As the foundation for all of the management and monitoring activity that follows, developing good management objectives is probably the most critical stage in the monitoring process. Objectives must be realistic, specific, and measurable. Objectives should be written clearly, without any ambiguity.

The ideal condition is that the approved refuge fire or land used management plan already has useful management objectives that are realistic, specific, and measurable. If not, it may be necessary to formulate useful management objectives from the vague and general objectives that exist. .

2. Components of an Objective

Six components are required for a complete management objective:

- Fuel Condition, Fire Effect, Habitat, or Community Indicator: identifies what will be monitored
- Location: geographical area
- Attribute: aspect of the species or indicator (e.g. size, density, cover)
- Action: the verb of your objective (e.g., increase, decrease, maintain)
- Quantity/Status: measurable state or degree of change for the attribute
- Time frame: the time needed for management to prove itself effective

Management objectives lacking one or more of these components are unclear.

A. **Fuel condition, fire effect, habitat, or community indicator**

Monitoring may involve measuring the change or condition of some aspect of the fuel condition itself of the effects of the fuel treatment. If the objective will address a subset of the fuel condition, fire effect (e.g., 10 hr., live, crown scorch, tree mortality, species composition, etc), this should be specified.

Measurement attributes can also focus on aspects of the fuel condition, fire effects, or the ecological community rather than direct measurements of the plant or animal population itself. Attributes may be selected that serve as indicators or surrogates for the condition of interest. Useful indicators may focus directly on known or perceived threats or management concerns.

Other potential indicators or surrogates for directly measuring attributes of fire effects include abiotic variables (e.g., fuel loading, fuel moisture, drought).

Using indicators to indirectly measure species success or condition is a common practice in resource management, but is not without problems. Your chosen indicator may have a weaker relationship with the variable of interest. Another factor may have important effects on the variable of interest, but have little relationship to the selected indicator (e.g., cattle grazing of a wetland species and a selected indicator of soil water levels). For these reasons, when threats-based attributes, indicator species, or abiotic variables are used as surrogates, it is usually advisable to periodically assess the variable of interest itself to insure the validity of the surrogate relationship.

(2) **Location**

Clear delineation of the specific entity or geographic area of management concern allows all interested parties to know the limits to which management and monitoring results will be applied. The spatial bounds of interest defined in a management objective will vary depending on land management responsibilities (e.g., you may only have access to a portion of an area due to multiple land ownership patterns) or particular management activities (e.g., you may only be interested in fire effects located within a fenced macroplot that is located within a larger area). The location is related to the selected scale of monitoring, which is affected by management goals and responsibilities, the ecology of the area, and the realities of limited monitoring resources.

(3) **Attribute**

First order fire effect measures include:

- Fuel Consumption
- Burn Severity
- Plant Mortality
- Wildlife Mortality
- Soil Properties
- Air Quality
- Water Quality

Second order fire effect measures include:

- Vegetation Community
    - Frequency
    - Cover
    - Density
    - Production
    - Structure
    - Composition
- Wildlife Population
- Hydrology
- Air Quality
- Soil Characteristics

When selecting an attribute, first narrow the list of potential attributes given constraints of species morphology and site characteristics (e.g., density is not an option if your species lacks a recognizable counting unit). Then narrow the list further by considering the following criteria:

- The measure should be sensitive to change (preferably the measure should differentiate between human-caused change and "natural" fluctuation).
- Ecologically meaningful interpretations of the changes exist that will lead to a logical management response.
- The cost of measurement is reasonable.
- The technical capabilities for measuring the attribute are available. The potential for error between observers is acceptable.

4. **Action**

There are three basic choices: increase, decrease, and maintain. There is a tendency when managing rare things to want to have them increase. Some attributes, however, may already exceed maximum potential and a decrease is necessary (i.e., fuel loadings). For other attributes you may wish to set a threshold that will trigger a management action if that attribute increases or decreases.

The following is a list of common action verbs used in management objectives and guidelines describing when each is appropriate:

- Maintain: use when you believe the current condition is acceptable or when you want to set a threshold desired condition (e.g., maintain surface fuel loading of 2 tons/acre ± 0.5 tons).
- Limit: use when you wish to set a threshold on an undesirable condition or state of the species or habitat (e.g., limit bluegrass cover to 10%).
- Increase: use when you want to improve some habitat or fire management factor (e.g., increase the average density by 20%, increase burn severity to level "lightly burned").
- Decrease: use when you want to reduce some negative aspect of the species or habitat (e.g., decrease livestock utilization of inflorescences to 50% or less; decrease cheatgrass cover by 20%).

(5) **Quantity/state**

The condition or change must be described with a measurable value. This can be a quantity (e.g., 500 individuals, 20% cover, 30% change), or a qualitative state (e.g., all herbaceous species present at the site, cover class 4, burn severity "scorched").

Determining these quantities or states requires consideration of a number of factors:

- How much can the burn site respond? Populations of long-lived plants (like trees or some cacti) or on low productivity sites may be very slow to respond to management changes. Changes may be small and difficult to detect, or take many years to express.
- What is necessary to ensure adequate treatment (e.g., how much change, what population size, what qualitative state)?
- How much change is ecologically meaningful? Some species (such as annuals) can have tremendous annual variability, and an objective that specifies, for example, a 10% reduction of surface fuel loadings on a frequent fire regime site that has been under a full fire suppression policy for 50 years is meaningless.
- What is the intensity of management? Will you continue existing management, remove current threats, or implement a radical alternative?
- What is the implementation schedule of management? If the monitoring project is scheduled to last 5 years, but new management will not be implemented until the second year of the study, the change results from only 3 years of management.
- What are the costs and problems associated with measuring the amount of change specified? Small changes are often difficult and expensive to detect.

The task of specifying a measurable quantity or state is usually a challenging one. The ecology of fire adapted ecosystems is poorly understood. Predicting the response of a ecological community to a fire or change in fire regime is often difficult. Many communities undergo natural fluctuations as they respond to varying climatic and weather conditions, herbivory, human use, etc. Most fire adaptive communities have been subject to impacts from human activities (e.g., long-term suppression policies) and there may be little or no knowledge of historical conditions. Few communities have been studied in enough detail to reliability determine optimal sustainable conditions. These challenges should not serve as obstacles to articulating measurable objectives. Use the tools described in Resources and Tools for Setting Objectives section below and do the best that can be done. If you do not articulate a measurable management objective, you have no way to assess if current management is beneficial or deleterious to the species of interest.

(6) **Time frame**

The time required to meet a management objective is affected by community ecology, the intensity of fuel management, and the amount of change specified. Populations of short-lived plants and animals or productive communities can probably respond fairly quickly, but long-lived plants and animals, those with episodic reproduction, or low productive communities may require more time. Intense management will result in more rapid changes than low intensity or no special management. Large changes will require more time than smaller ones.

It is recommended that time frames be as short as possible for several reasons:

- Changes in agency budgets and personnel often doom long-term monitoring projects.
- Short-term objectives promote regular reassessment of management and implementation of management changes.
- Monitoring often uncovers unexpected information; short-term objectives encourage modification of objectives and monitoring based on this information.
- Short-term objectives circumvent the trap of monitoring ad infinitum while avoiding difficult decisions.

Objectives with time frames as short as several months to a year may be appropriate in some situations. The adaptive management cycle must occur within a short enough period that opportunities for species recovery or alternative management are not lost.

3. Types and Examples of Management Objectives

Objectives can be described in one of two ways:

- A **condition** (e.g., decrease litter loading to 0.5 tons/acre, increase the population size of Species A to 5000 individuals; maintain woody stems to not more than 2500 ; maintain Site B free of noxious weeds X and Y). We will call these *target/threshold management objectives*.
- A **change** relative to the existing situation (e.g., decrease surface fuel loadings by 50%, increase mean density by 20%; decrease the frequency of noxious weed Z by 30%). We will call these *change/trend management objectives*.

For target/threshold objectives, you assess your success in meeting your objective by comparing the current state of the measurement attribute to the desired state or to an undesirable state that operates as a red flag or threshold. With a change/trend objective you measure the trend over time. The two objectives are obviously related. Consider the following change/trend objective:

- Increase stem mortality of *Baccharis* spp. following a prescribed fire at St. Johns NWR by 100% between 1998 and 2005.

You could sample *Baccharis* spp. stem mortality following a prescribed fire and estimate the current stem mortality (say 35%). Once the current frequency is known, you could write your objective as follows:

- Increase stem mortality of *Baccharis* spp. from prescribed burning at St. Johns NWR to 70% by 2005 (a target/threshold objective).

In spite of this relationship, the two types of objectives are appropriate for different situations. You may choose a change/trend objective when you have insufficient information to describe a realistic future desired condition. You would also use a change/trend objective when you believe the current state is less important than the trend over time. For example, whether a population has 8000 individuals or 6000 individuals may not matter; a decline from 8000 individuals to 6000 individuals (a 25% decline), however, may be very important to detect. Usually change objectives are more appropriate than target/threshold types of objectives when management has changed and you want to monitor the response (trend) of the selected attribute.

The two types of objectives also require different considerations in designing the monitoring methodology and analyzing the results, especially when the monitoring of the objective requires sampling.

Management objectives can be written to describe either desirable or undesirable conditions and trends. You would frame your objective in desirable terms if you believe improvement is necessary and you have implemented management you believe will result in improvement. These objectives are sometimes referred to as "desired condition objectives" because they describe the target condition or trend of the resources (e.g., increase to 2000 individuals, decrease cover of a noxious weed by 40%).

If you believe that the current condition is acceptable, and that a continuation of current management will likely maintain that condition, you could frame your objective using undesirable thresholds of condition or trend. These are sometimes referred to as "red flag objectives" because they state the level of an undesirable condition or change that will be tolerated (e.g., mean surface fuel loading not exceeding 3 tons/acre, no fewer than 200 individuals; no more than 20% cover of the noxious weed; no more than a 20% decrease in density). These objectives act as a warning signal that management must change when the threshold is exceeded. Red flag objectives can be written to identify an unacceptable decline in a rare species or a surrogate habitat variable, or an unacceptable increase in a negative factor (e.g., an exotic species, encroaching shrub cover, etc.).

Different types of management objectives require varying intensities of monitoring. Qualitative objectives can be monitored using techniques that assess condition or state without using quantitative estimators. Simply finding if the plant still occurs at a site is a type of monitoring that can be very effective for some situations. Another approach is to use estimates of abundance such as "rare," "occasional," "common," and "abundant," or to map the aerial extent of the population. Objectives may also be written so they can be monitored by complete counts. Complex objectives may require more intensive monitoring involving quantitative sampling or demographic techniques.

The following examples are arranged in order approximating increasing intensity and include desired condition and red flag types.

A. Examples of Target/Threshold Objectives

- Maintain the presence of *Aristida stricta* in the 12 photoplots located in the Agency Creek drainage over the 10-year time span of annual low intensity summer burning.
- Maintain the current turkey oak-free condition of the *Aristida stricta* population in the Iron Creek drainage for the next 10 years.
- Increase the number of population areas of *Aristida stricta* within the Kenney Creek Watershed from 8 to 15 by 2010.
- Maintain forb and grass canopy cover of 60% - 80% at the Lime Creek site over the next 10 years.
- Allow no more than two of the 25 presence/absence photoplots at the Lake Creek mule deer wintering area to show a loss of bitterbrush between now and 2002.
- Increase the Basin Creek aspen stand to 120 stems by 2005.

- Maintain at least 100 individuals of *Penstemon lemhiensis* at the Iron Creek site over the life of the Iron Creek Allotment Management Plan.
- Increase the number of individual aspen sprouts in the Iron Creek population to 4500 individuals by the year 2000.
- Maintain at least 200 individuals of whispering bells at the Malm Gulch site over the 10-year mechanical fuel reduction special use permit period (current estimated population size: 300).

B. Examples of Change Objectives

- Increase the ranked abundance of *Aristida stricta* in each of the 10 permanently marked macroplots at the Grizzly Ridge population by one rank class by 2005.
- Double the area occupied by grasses and forbs at the Williams Creek sage grouse site by the year 2010.
- Allow a decrease in the ranked abundance of *Aristida stricta* in each of the 10 permanently marked macroplots at the Grizzly Ridge population of no more than one rank class between now and 2005.
- Decrease the frequency of *Bromus tectorum* by 30% at the Iron Creek population of *Penstemon lemhiensis* between 1997 and 2005.
- Increase the mean density of *Andropogon gerardi* at the Warm Springs population by 20% between 1997 and 2000.
- Allow a decrease of no more than 20% from the current cover of *Astragalus diversifolius* at the Texas Creek site between now and the year 2005.
- Allow a decrease of no more than 30% in the population size of *Pimula alcalina* in the first 5 years after cattle are reintroduced to the Birch Creek burn site.
- Decrease the population size of *Bromus inermis* at the Iron Creek site by 50% by 2005.

4. Resources and Tools for Setting Objectives

A. Existing plans

Fuel treatment management goals are provided in approved refuge Fire Management Plans. General resource management goals are described in other planning documents such as the approved Comprehensive Conservation Plan and Habitat Management Plan. Linking a fuel and/or fire effects monitoring project to these higher level planning documents will improve management effectiveness and may increase management support and funding for the project. The goals in these plans may also serve as a useful starting point for developing more complete and specific fire management and prescribed fire objectives.

B. Ecological models

Ecological models are simply conceptual visual summaries that describe important ecological components and their relationships. Constructing a model stimulates thinking about the ecology and biology of the treatment site and the role of fire at that site. You don't have to be mathematically inclined to develop and use a model; the type of model described here rarely involves complicated formulas or difficult mathematics.

Ecological models have three important benefits. First, they provide a summary of your knowledge of the ecological community and fire as an ecological process, enabling you to see the complete picture of the community's ecological processes. For example, because fire causes direct plant and animal mortality, you may consider that relationship first. Fire may, however, also affect the community positively through indirect effects on nutrient cycling, hydrology, community composition by reducing competition, etc. Burning may positively affect the population by exhuming seeds from the seed bank and increasing germination. During the development of an ecological model, you will have to think about these indirect and sometimes hidden relationships. The model will often identify several factors that can cause the change you hope to detect by monitoring, and perhaps help isolate the most important and interesting mechanism.

Second, ecological models identify the gaps in your knowledge and understanding of the ecosystem. Your model may suggest that these gaps are not important, in which case you may choose to ignore these unknowns. Conversely, the model may suggest an unknown relationship is extremely important for understanding the total ecological and management scenario. You may need additional studies before effective monitoring can begin.

Third, ecological models help identify mechanisms and potential management options. If the ecological model suggests, for example, that seedling establishment appears rare, that succession processes of canopy closure may be occurring, and that litter buildup on the ground provides few germination sites, you may be inclined to think about prescribed fire, or some other management strategy that induces germination or reverses succession. Lacking an ecological model, you may have focused on only a single attribute, such as the lack of seedling establishment, which can result from a multitude of causes.

An ecological model can be as simple or complex as you wish.

C. Reference sites

The goal in fuels treatment is to ensure that when a fire occurs fire behavior conforms to suppression capabilities or burn severity does not exceed ecological integrity. For most fire managers, this translates into maintaining fuel loads within the range of natural variation of their administrative boundaries or in concert with partners across several administrative units. Defining and measuring a range or natural variation, however, is difficult. This creates a problem in identifying quantities in objectives: How much fuel should there be? What fuel variable equates "natural"? What percentage of the fuel should be in what size class?

Reference sites can serve as comparison areas to help set quantitative targets in objectives. These are areas with minimal human impact, such as Research Natural Areas (RNAs) or wilderness areas. Reference sites may also be an undesignated area where wildlife populations that appear thriving and healthy.

Reference sites can be valuable, but use them with caution. Simply because a population is located in a protected area does not ensure that it is viable or healthy. Lack of management activities within protected areas may be allowing successional processes to occur that are detrimental. In addition, populations that appear "healthy and thriving" to casual observation may be on the brink of decline or actually be declining.

D. Related or similar ecological communities

Comparisons with more "successful" ecological communities or communities that appear ecologically similar may help set objective quantities that are biologically reasonable. For example, the role of fire in *Pinus contoria* communities may be similar to that in *Pinus bardsiana*, *Pinus rigida*, or *Pinus serotina* communities.

E. Experts

Experts can provide additional information and opinions on the assumptions within the ecological model. In-house experts include regional and refuge wildlife biologist and fire management specialists, as well as specialists in other disciplines such as fire management, botany, forestry, range management, and riparian management. External specialists include academic, professional, and amateur ecologists and botanists who may know about the species of interest, or a closely related one, or may be knowledgeable about the ecological system in which the species resides. These people can help set realistic, achievable objectives.

F. Historical records and photos

Recent historical conditions at a site may have been captured in old aerial photos or in historical photos or other historical records housed in museums or maintained by local historical societies. Human disturbances such as roads, trails, and buildings may be visible, Wood species density and/or cover may also be visible. Early survey records by the General Land Office often contained descriptions for general vegetation and habitat characteristics during the mid to late 1800's. Long-term elderly residents can be a fascinating source of information on historical conditions. Keep in mind that historical conditions and fire regimes prior to European settlement may have been quite different than what is represented in turn of the century documents or even early explorer reports.

5. Management Implications

Management implications of monitoring must be identified before monitoring begins. If there are no management implications or options, monitoring resources are better spent on another activity. Usually, however, there are options, but some of them may be expensive, or politically difficult to implement. There is a tendency in resource management agencies to continue monitoring, even when objectives are not met, rather than make the difficult decisions associated with changes in management. Because of this hesitancy, we recommend that management implications be an integral part of pre-monitoring planning. Management implications of monitoring are more likely to be applied if they are identified before the monitoring begins, and if all parties agree to the objectives, monitoring methods, and response to monitoring data.

Identifying management implications is difficult, because the needed management changes are unknown. At a minimum, a management commitment can be made before monitoring begins that additional, more intensive investigation into the management needs of the species will begin if objectives are not achieved.

COMMUNICATION AND MONITORING PLANS

Communication doesn't start when the monitoring results have been analyzed. Beginning with the planning stage, those who will be making decisions based on the monitoring and those who may be affected by those decisions must be included in the design of the monitoring project. You can increase the likelihood of seeing needed management actions implemented by involving all interested parties in developing the management objective and designing the monitoring, and reaching agreement that all parties will abide by the results. Objectives should clearly identify the management changes that will be implemented based on monitoring results. This point cannot be stressed enough, especially when potential decisions may adversely affect other parties or interests. If you fail to include all who should be involved in the initial stages of objective setting and monitoring design, you can expect problems implementing new management once monitoring is completed.

1. Participants

Several classes of participants needed in the development of a monitoring project are described. The number of people and groups to involve in a monitoring project depends on the potential impacts of the management changes that may occur based on monitoring results. Developing objectives for historical properties, plant and animal populations, air and water quality values in areas that are not affected by consumptive or non-consumptive human use may require little interaction with interest groups or other agency specialists. Large populations, or populations in high use/high visibility areas, may require extensive communication efforts before monitoring is initiated.

Establishing communication and considering alternative points of view can be time-consuming and difficult. An apparently easier route is collecting "really good data" to prove your point and get management changed. In practice, however, monitoring that is specialist-driven usually fails to result in a management change for three reasons. The most common is that the specialist spearheading the monitoring leaves, and the monitoring project is suspended because it lacked the knowledge and support of managers. A second reason is that other priorities take precedence over the monitoring project. In order for monitoring to be completed, managers must support the time and resources it requires. Third, a lack of consensus on objectives and methodology almost ensures that monitoring data will not be used to make a decision. You need to involve people from the beginning to ensure a cooperative effort and the application of monitoring results to the decision-making process.

Communication about monitoring projects associated with non-controversial management actions can safely be limited to decision-makers and internal resource specialists. For example, often you will know too little about a particular resource and its interactions with management activities to develop detailed objectives that identify a specific management response. Many management responses may need to specify a second stage of more intensive monitoring and perhaps research if the change detected is adverse. Such two-stage monitoring requires only the involvement of the decision-maker and resource specialists within the administrative unit in the first stage because implementing increased monitoring or research is rarely controversial.

You may, however, enlist involvement and/or review by a broader spectrum of participants even in non-controversial projects. Review by user groups during the development of objectives will inject fresh perspectives. Review during the design phase by academic specialists, statisticians, experienced professional botanists, and peers may help you avoid potential technical problems.

1. Monitoring Plans

A. **Importance**. Communication with these participants is facilitated by a monitoring plan that explains the rationale for the monitoring project, documents objectives and the management response, and describes the monitoring methodology in enough detail to direct continued implementation. Monitoring plans serve five important functions:

- A plan provides a full description of the ecological model, the objectives, and the proposed methodology.
- Draft monitoring plans provide a means to solicit input from many participants.
- A final monitoring plan consolidates all information into a single document that can be easily accessed and referenced.
- A final monitoring plan documents the location and techniques of the monitoring in sufficient detail that a successor can continue the monitoring.
- A final monitoring plan documents the agency's commitment to implementing a monitoring project and the management that will occur based on monitoring results. A monitoring plan can also be signed by all participants to demonstrate their support for the project and acceptance of the proposed management changes that may result.

B. **Elements of a monitoring plan.** Monitoring plans must be complete, providing all the information needed to judge the quality of your proposed monitoring and to continue it in your absence. Box 2 summarizes the elements to include in an extensive monitoring plan for a complex project. The project complexity will deterring which elements and detail or procedural explanation is needed. A short (1-2 page) nontechnical summary at the beginning of the plan will be useful to decision-makers, nonspecialists, and user groups.

C. **When to write a monitoring plan**. Do all monitoring projects require a monitoring plan? Does a qualitative monitoring project that simply involves taking a picture of the population each year require a full-scale document? Some form of documentation of the management objective, sampling objective (if sampling), management response, location, and methodology is necessary for all monitoring projects, no matter how small or simple.

The monitoring plan should be written before the pilot study. There is a valid concern, however, that if the pilot study demonstrates that the monitoring approach needs significant revisions, the monitoring plan will need to be rewritten. If the primary audience is in-house (other specialists, your successor), draft the plan as an informal communication tool, and finalize it after the methodology proves effective. If, however, the primary purpose of the monitoring plan is to communicate with outside groups and interests, and to gather peer and expert review, complete the plan before the pilot study. Portions of the plan such as the introduction and description of the ecological model will remain useful even if the monitoring project changes significantly.

Clearly, a significant investment of resources is required to complete all the elements of a monitoring plan, and most monitoring specialists prefer field work to writing plans. The temptation is great to skip this stage and get on with "more important" work, like counting plants in plots. Resist the temptation. A monitoring plan is worth the time commitment and is critical to successful long-term implementation of monitoring.

ELEMENTS OF A MONITORING PLAN

- **Introduction (general)**. Describe:
  - Relevance to well defined monitoring objectives in the approved refuge Fire Management Plan and/or an approved refuge habitat management plan. The need for monitoring, or the "why" of monitoring fuels treatment effectiveness.
  - The fuel associations, and wildlife habitat characteristics that will be monitored.
  - Management conflicts.
- **Description of ecological model**. Describe the historic and contemporary fire regime, life history, phenology, reproductive biology, causes of distribution, habitat characteristics, and effects of other resource uses on the species (e.g., herbivory of flower heads by cattle) of the area. The model should describe known fire and other disturbances, biology (based on natural history observations) and conjectural relationships and functions. Sources of information and relationships that are hypothesized should be identified. The purpose of this section is to help identify the sensitive attribute to measure and to describe the relationships between species biology and management activities. This section is the biological basis for the development of objectives.
- **Management objective(s)**. Include the management objectives from approved refuge fire and land management plans that are used to justify the monitoring need. Include rationale for the choice of attribute to measure and the amount of change or target condition.
- **Monitoring design.**
  - Sampling objective. Includes rationale for choice of precision and power levels (if sampling).
  - Sampling design. Describe methods clearly. What size is the sampling unit? How are sampling units placed in the field? How many sampling units?
  - Field measurements. What is the unit counted (for density)? How are irregular outlines and small gaps of vegetation treated (for line-intercepts)? How are plots monumented (if permanent)? Include all the information needed for someone else to implement or continue the monitoring in your absence.
  - Timing of monitoring. What time of year, both calendar and phenologically? How often?
  - Monitoring location. Include clear directions, maps and aerial photographs describing the study location, and the location of individual sampling units (if permanent).
  - Intended data analysis approach.
- **Data sheet example.** Include examples of field data sheets.
- **Information Management.** Discuss data entry, editing, validation, storage, and archiving.
- **Responsible parties.** Identify:
  - Plan authors, peer reviewers, and consultants.
  - Who is responsible for various plan implementation and administrative tasks.
- **Funding.** Identify what portion of the Monitoring Plan the Fuels Treatment subactivity (9263) is responsible for funding.

- **Management implications of potential results.**
    - How will the result be presented and summarized?
    - How will the monitoring results be used?
        - What potential trigger points will cause reexamination of either the monitoring plan and/or management activity.
        - Describe what management actions will occur if monitoring data shows desirable trends.
        - Describe what management actions will occur if monitoring data shows undesirable trends.
- References

PARTICIPANTS IN A MONITORING PROJECT

- **Decision-makers** (managers, or management teams). This is the most important audience. They will decide the amount of resources to devote to the monitoring project and, once monitoring is completed, decide whether management should change or continue. Each manager's "comfort level" varies for making decisions based on monitoring data. Some managers feel confident making decisions based on photographs and their specialist's judgement. Others require much more information.
- **Agency specialists** (in-house). Other resource specialists may have information critical to the design of the monitoring (e.g., the area containing the fire is likely to be rested from grazing for the next three years; the timber stand is set aside from cutting because it is in a protected watershed; the area is used for resource interpretation and outdoor education). These other specialists also tend to be advocates for the resource they manage and may potentially disagree with the management changes resulting from monitoring. Including these specialists in the design creates ownership in the monitoring and reduces the potential for in-house disagreements later.
- **Regulatory** decision makers (U.S. Fish and Wildlife Service, state agencies). Participation by these agencies is required for species listed under the Endangered Species Act or state laws and may be helpful for other species of concern.
- **Non-regulatory agencies**. State agencies that maintain statewide conservation databases, such as the State Historic Preservation Officer, Heritage Program or conservation programs, often have information about the sensitive resources on private lands, on other Federal lands, or on lands in other States. Many of these database agencies also maintain a monitoring database; participation in it can reduce redundancy in monitoring efforts. Local Natural Resource Conservation Service (formerly Soil Conservation Service) personnel and County Extension Agents may function as advocates for agricultural interests. Their participation and support of the monitoring project increase the credibility of the monitoring data with traditional Federal land users such as hunters or grazing permittees.
- **Traditional Federal land users**. These are primarily consumptive resource users such as hunters, fisherman, timber companies, and livestock operators. If the monitoring potentially will affect these interests, you should include them throughout the process. Not only does their involvement from the beginning diffuse much of their disagreement when assessing results, it will also make the monitoring much better. Because their interests are potentially at stake, they will be interested more in false-change errors (e.g., concluding that a problem took place when it really did not). whereas you may be more concerned with missed-change errors (e.g., failing to detect undesirable changes that in fact did occur). The explicit balancing of the two errors is important. In addition, individuals involved in consumptive use on Federal lands often know facts about an area that you do not. A rancher, for example, may know that cows have not used an area for the last 10 fall seasons because of a non-functioning water source. A logger may know that his grandfather cut a patch of timber using horses in the 1930s. These bits of information may improve your ecological model.
- **Non-traditional Federal land users**. Non-consumptive users of the Federal lands such as bird watchers, hikers, nature enthusiasts, and others whose use of the Federal land may be affected by changes in management resulting from monitoring should be included.

- **Special interest groups**. You should include groups that have an interest in the local resources, native flora and biodiversity, especially if local representatives are available. Local archeologists, local historians, native plant societies, etc. not only have a special interest in the preservation of their resource interests within a State, but may also have specialized skills or volunteer labor that will improve the quality of monitoring.
- **Professional and academic interests**. These people may have much to contribute to the development of ecological models, objectives, and monitoring designs. Their contribution to and review of the monitoring strategy will improve the quality and increase the credibility of the monitoring effort.

SAMPLING OBJECTIVES

Development of sound sampling objectives is an extremely critical step in a monitoring program. It may also can be one of the most difficult. A common mistake is for managers to collect data first and rely on statistics to generate a question or objective later.

Sampling objectives differ from management objectives in that management objectives describe the target or change in the condition desire, while sampling objectives describe how to monitor progress toward that target or change. All sampling objectives should include the five essential components

- Target population of interest.
    - Define the groups to be examined (e.g., fuel complex, habitat segment, species, groups of species, etc.)
    - Define the individuals to be included (e.g., fuel size class, all age classes or all trees or only adults of one species)
    - Determine the geographic boundaries of interest (e.g., fire management unit, all wetlands, all burned wetland, all growing season burned wetlands)
- Time frame for the desired change. The time frame must be ecologically and managerially realistic (e.g., historical fire frequency, life history of the target population, available funding, available resources)
- The expected or desired amount of change. Refer to resource management plans. (e.g., topkill 30-60% of brush species, reduce cattail cover by 50%, reduce litter loading to >1500 lbs./ac).
- What is to be counted or measure. Describe the specific attribute that the treatment will affect (e.g., 1, 10, and 100 hr. fuels, total brush cover, cattail cover, litter fuel loading).
- Specify how certain you want to be that the sampling data reflects reality. How confident do you have to be data represents reality in order to make a change in management. Certainty is expressed statistically by confidence intervals and expressed as the confidence level. Highly risky, sensitive, or expensive management decisions will probably require high confidence limits (i.e., 95 or 99% confidence level, a 1 in 20 or 1 in 100 chance of being wrong, respectively). Less sensitive management decisions can accept more risk (i.e., 80% confidence level, a 1 in 5 change of being wrong). If a flip of a coin is good enough (i.e., 50% confidence level), there is really no reason to monitor, just use the coin. In addition to the confidence level, managers much decide on the precision of the estimate. The precision selected should be related to the need to have very good estimates of the true population mean. Monitoring costs increase proportionally to risk aversion and desired precision. Identifying the desired confidence level and precision is important because they along with the sample standard deviation are use to determine the necessary project sample size.

Sampling objective examples:

- In fire management unit 2, your want to be 90% confident that 1,10, and 100 hr. fuels were reduced to <50, 100, and 500 lbs./acre respectively after initial mechanical treatment. You are willing to accept a 10% change of saying that the fuel reduction took place, when it did.
- In the palmetto-gallberry pine understory, you want to be 80% confident of detecting a 50% reduction in total brush cover within 3 years of the initial treatment. You are willing to accept a 20% chance of saying that a 50% reduction took place when it did not.
- Within the cattail marsh, you want to be 100% confident that 50% for the cattail marsh was burned, immediately following the treatment. (The only way to be 100% confident is to conduct a complete census. This could be done by aerial imaging).
- In the mixed-grass prairie, you want to be 95% confident of detecting litter fuel levels are 1500 lbs./ac. within 1 year of the first burn. You are willing to accept a 5% chance of saying that a 60% increase took place, when it did not.

U.S. Fish & Wildlife Service

Fuel and Fire Effects Monitoring Guide

MONITORING DESIGN AND ANALYSIS

Because of the difficulty and importance of effective monitoring, agencies developed standard monitoring approaches in the 1960s through 1980s. While these techniques effectively met the challenges of that time they are inadequate now for several reasons:

- The resources and management efforts of interest today are more variable and complex. Its is difficult for standard designs to keep pace with the rapid changes in issues. Monitoring data from standard techniques are sometimes inconclusive because the studies are not specifically designed for the issue in question.
- Many standard techniques do not address issues of statistical precision and power during design; thus, standard monitoring techniques that involve sampling may provide estimates that are to imprecise for confident management decisions.
- Commodity and environmental groups have become more sophisticated in resource measurement and are increasing skeptical of data from standard agency techniques.
- Funding reductions are restricting resources available for monitoring projects, Concurrently agencies are being required to more clearly demonstrate through monitoring that funds are being used to effectively manage public lands. This situation requires the design efficient monitoring projects that provide data specific to the current issues.

Monitoring methods have a number of common elements. Those that relate to permanently marking and documenting the project location are described in detail below.

Also discussed are statistical considerations (target populations, random sampling, systematic sampling, confidence intervals, etc.) and other important factors (properly identifying fuel types and size classes, plant species and training people so they follow the correct procedures).

Water

Soil

Air Quality

Fire Effects Predictors

TRAINING

Opportunities

CREDITS

Statistical application training courses like the Experimental Design from the FWS and Inventory and Monitoring of Plant Populations and Vegetation from the BLM provide design and analysis insight and guidance.

It is important to read this section before referring to the monitoring attributes and specific monitoring methods.

Permanently Marking the Project Location. Permanently mark the location of each project by means of a reference post (steel post) placed about 100 feet from the actual project location. Record the bearing and distance from the post to the project location. An alternative is to select a reference point, such as a prominent natural or man-made feature, and record the bearing and distance from that point to the project location. If a post is used, it should be tagged to indicate that it marks the location of a monitoring project and should not be disturbed.

Permanently mark the project location itself by driving angle iron stakes into the ground at randomly selected starting points. The baseline technique requires that both ends of the baseline be permanently staked. With the macroplot technique, a minimum of three corners need to be permanently staked. If the linear technique is used, only the beginning point of the project needs to be permanently staked. Establish the project according to the directions found in A.2.

Paint the transect location stake with brightly colored permanent spray paint (yellow or orange) to aid in relocation. Repaint this stake when subsequent readings are made.   Painting may be contraindicated if vandalism is a problem.

Project Documentation. Document the project and transect locations, number of transects, starting points, bearings, length, distance between transects, number of quadrats, sampling interval, quadrat frame size, size of plots in a nested plot frame technique, number of cover points per quadrat frame, and other pertinent information. For projects that use a baseline technique, record the location of each transect along the baseline and the direction (left or right).

Be sure to document the exact location of the project site and the directions for relocating it. For example: *1.2 miles from the fence corner on the Old County Line Road. The reference post is on the south side of the road, 50 feet from the road.*

Plot the precise location of the project on detailed maps and/or aerial photos.

A. Planning the Project. Proper planning is by far the most important part of a monitoring project. Much wasted time and effort can be avoided by proper planning. A few important considerations are discussed below. The reader should refer to the Technical Reference, Planning for Monitoring, for a more complete discussion of these important steps.

1. Identify Objectives. Based on land use, resource management, fire management, and prescribed fire plans, identify objectives appropriate for the area to be monitored. The intent is to evaluate the effects of management actions on achieving objectives by sampling specific attributes.

2. Design the Project. The number of quadrats, points, or transects (sample size) needed depends on the objectives and the efficiency of the sampling design. It should be known before beginning the project how the data will be analyzed. The frequency of data collection (e.g., every year, every other year, etc.) and data sheet design should be determined before projects are implemented. The sample data sheets included with each method (following the narrative) are only examples of data forms. Field offices have the option to modify these forms or develop their own.

All of the methods described in this document can be established using the following techniques:

a. **Baseline**. A baseline is established by stretching a tape measure of any desired length between two stakes. For an extremely long baseline, intermediate stakes can be used to ensure proper alignment. It is recommended that metric measurement be used. Individual transects are then run perpendicular to the baseline at random locations along the tape. The location of quadrats along these transects can be either measured or paced. Transects can all be run in the same direction, in which case the baseline forms one of the outer boundaries of the sampled area, or in two directions, in which case the baseline runs through the center of the sampled area. If transects are run in two directions, the direction for each individual transect should be determined randomly. Quadrats or observation points are spaced at specified distances along the transect. This study design is intended to randomly sample a specified area. The area to be sampled can be expanded as necessary by lengthening the baseline and/or increasing the length between quadrats or sampling points.

This design may need to be modified for riparian areas or other areas where the area to be sampled is long and narrow. For these areas, a single linear transect may be more appropriate.

b. **Macroplot**. The concept with this type of design is to allow every area within the study site or sample area to have an equal chance to be sampled. A macroplot is a large square or rectangular study site. The size of the macroplot will depend on the size of the study site. The macroplot should encompass most of the study site. From the standpoint of statistical inference, it is best, once the macroplot boundaries have been determined, to redefine the study site to equal the macroplot. Examples of macroplot sizes are 50 m x 100 m, 100 m x I 00 m, and 1 00 m x 200 m, but much larger macroplots can be used to cover larger study sites. Macroplot size and shape should be tailored to each situation.

Macroplot size also depends on the size and shape of the quadrats that will be used to sample it. The sides of the macroplot should be of dimensions that are multiples of the sides of the quadrats.

(1) **Macroplot layout**. Pick one corner of the macroplot to serve as the beginning for sampling purposes. Drive an angle iron location stake into the ground at this corner. Determine the bearing of the macroplot side that will serve as the x-axis, run a tape in that direction and put an angle iron stake at the selected distance. This serves as another corner of the macroplot. Leave the x-axis tape in place for sampling purposes. Return to the origin and determine the bearing of the y-axis, which will be perpendicular to the x-axis. Run a second tape along the y-axis and put an angle iron stake in the ground at the selected distance. This serves as the third corner of the macroplot. If desired, a fourth stake may be placed at the remaining corner, but this is not necessary for sampling since sampling will be done using the two tapes serving as the x- and y-axes. Leave the tapes in place until the first year's sampling is completed.

Be sure to document the directions of the x- and y-axes so that the macroplot can be reconstructed if one of the angle iron stakes is missing.

(2) **Quadrat locations**. Quadrats are located in the macroplot using a coordinate system to identify the lower left-hand corner of each quadrat.

(a) For example it has been determined from the pilot project that 40 samples are needed using a 1 m by 16 m quadrat. The quadrats are to be positioned so that the long side is parallel to the x-axis. On a 40 m x 80 m study site, the x-axis would be the 80 m side. The total number of quadrats (N) that could be placed in that 40 m x 80 m rectangle without overlap comprises the sampled population. In this case, N is equal to 200 quadrats.

(b) Along the x-axis there are 5 possible starting points (which always occur at the lower left-hand comer of each quadrat) for each I m x 16 m quadrat (at points 0 m, 16 m, 32 m, 48 m, and 64 m). Number these points 0 to 4 (in whole numbers) accordingly. Along the y-axis there are 40 possible starting points for each quadrat (at points 0 m, I m, 2 m, 3 m, 4 m, and so on until point 39 m). Number these points 0 to 39 accordingly (again in whole numbers)

(c) Now, using a random number table or a random number generator on a computer or handheld calculator, choose at random 40 numbers from 0 to 4 for the x axis and 40 numbers from 0 to 39 for the y axis.

(d) At the end of this process, 40 pairs of coordinates will be selected. If any pair of coordinates is repeated, the second pair is rejected and another pair picked at random to replace it (because sampling is without replacement). Continue until there are 40 unique pairs of coordinates. These 40 pairs of coordinates mark the points at which quadrats will be positioned.

e) Both to increase sampling efficiency and to reduce impacts to the sampling units by examiners, the coordinates should be ordered from smallest to largest first on the axis parallel to the longest side of the quadrat and then on the other axis. For example, the following four sets of coordinates have been randomly selected (presented in the order they were selected):

	x-axis	y-axis
1	3 (48.0 m)	27.0 m
2	4 (64.0 m)	34.0 m
3	3 (48.0 m)	8.0 m
4	1 (I 6.0 m)	28.0 m

Because the quadrats are being placed with their long side parallel to the x-axis, the coordinates are ordered first by the x-axis and next by the y-axis. Thus the new order is as follows:

	x-axis	y-axis
1	16.0 m	28.0 m
2	48.0 m	8.0 m
3	48.0 m	27.0 m
4	64.0 m	34.0 m

In each column defined by an x-coordinate, sampling starts from the bottom of the macroplot and moves to the top. This systematic approach ensures that quadrats are not walked on until after they have been read.

c. **Linear**. This study design samples a study site in a straight line. Because it samples such a small segment of the sample area, this technique is not recommended except for long, narrow study sites such as riparian areas.

Randomly select the beginning point of the transect within the study site and mark it with a stake to permanently locate the transect. Randomly determine the transect bearing and select a prominent distant landmark such as a peak, rocky point, etc., that can be used as the transect bearing point. Attribute readings are taken at a specified interval (paced or measured) along the transect bearing. If the examiner is unable to collect an adequate sample with this transect before leaving the study site, additional transects can be run from the transect location stake at different bearings.

d. **Locating Random Sampling Plots**

B. Statistical Considerations

1. Target Population. Study sites are selected (subjectively) that hopefully reflect what is happening on a larger area. These may be areas that are considered to be representative of a larger area such as a vegetation community or critical areas such as sites where endangered species occur. Monitoring projects are then located in these areas. Since these study sites are subjectively selected, no valid statistical projections to an entire area are possible. Therefore, careful consideration and good professional judgement must be used in selecting these sites to ensure the validity of any conclusions reached.

a. Although it would be convenient to make inferences from sampling study sites regarding the larger areas they are chosen to represent, there is no way this can be done in the statistical sense because the study sites have been chosen subjectively.

b. For this reason it is important to develop objectives that are specific to these study sites. It is equally important to make it clear what actions will be taken based on what happens on the study sites.

c. It is also important to base objectives and management actions on each study site separately. Values from study sites from different strata should never be averaged.

d. From a sampling perspective, it is the study site that constitutes the target population. The collection of all possible sampling units that could be placed in the study site is the target population.

2. Random Sampling. Critical to valid monitoring project design is that the sample be drawn randomly from the population of interest. There are several methods of random sampling, many of which are discussed briefly below, but the important point is that all of the statistical analysis techniques available are based on knowing the probability of selecting a particular sampling unit. If some type of random selection of sampling units is not incorporated into the study design, the probability of selection cannot be determined and no statistical inferences can be made about the population.

3. Systematic Sampling. Systematic sampling is very common in sampling vegetation. The placement of quadrats along a transect is an example of systematic sampling. To illustrate, let's say we decide to place ten 1-square-meter quadrats at 5-meter (or 5-pace) intervals along a 50-meter transect. We randomly select a number between 0 and 4 to represent the starting point for the first quadrat along the transect and place the remaining 9 quadrats at 5-meter intervals from this starting point. Thus, if 10 observations are to be made at 5-meter intervals and the randomly selected number between 0 and 4 is 2, then the first observation is made at 2 meters and the remaining observations will be placed at 7, 12, 17, 22, 27, 32, 37, 42, and 47 meters along the transect. The selection of the starting point for systematic sampling must be random.

Strictly speaking, systematic sampling is analogous to simple random sampling only when the population being sampled is in random order. Many natural populations exhibit an aggregated (also called clumped) spatial distribution pattern. This means that nearby units tend to be similar to (correlated with) each other. If, in a systematic sample, the sampling units are spaced far enough apart to reduce this correlation, the systematic sample will tend to furnish a better average and smaller standard error than is the case with a random sample, because with a completely random sample one is more likely to end up with at least some sampling units close together.

4. Sampling vs. Nonsampling. Errors in any monitoring project, it pays to keep the error rate as low as possible. Errors can be separated into sampling errors and nonsampling errors.

a. **Sampling Errors**. Sampling errors arise from chance variation; they do not result from "mistakes" such as misidentifying a species. They occur when the sample does not reflect the true population. The magnitude of sampling errors can be measured.

b. **Nonsampling Errors**. Nonsampling errors are "mistakes" that cannot be measured. Examples of nonsampling errors include the following:

1. Using biased selection rules, such as selecting "representative samples" by subjectively locating sampling units or substituting sampling units that are "easier" to measure.
2. Using sampling units in which it is impossible to accurately count or estimate the attribute in question.
3. Sloppy field work.
4. Transcription and recording errors.
5. Incorrect or inconsistent species identification.
6. Using inexperienced, untrained and many different examiners.

To minimize nonsampling errors:

1. Design projects to minimize nonsampling errors. For example, if canopy cover estimates are needed, point intercept or line intercept techniques result in smaller nonsampling errors than the use of quadrats. For density data, select a quadrat size that doesn't contain too many individual plants, stems, etc., to count accurately.
2. When different personnel are used, conduct rigorous training and testing to ensure consistency in measurement and estimation.
3. Design field forms that are easy to use and not confusing to data transcribers. Double (or triple) check all data entered into computer programs to ensure the numbers are correct.
4. Provide examiners with sufficient training and experience in order to correctly and consistenly implement a monitoring

method. Have the same examiner(s) sample the same areas. If at all possible avoid high turnover in examiner(s) (i.e., volunteers).

5. Confidence Interval. In monitoring, the true population total (or any other true population parameter) will never be known. The best way to judge how well a sample estimates the true population total is by calculating a confidence interval. The confidence interval is a range of values that is expected to include the true population size (or any other parameter of interest, often an average) a given percentage of the time.

6. Quadrat Size and Shape. Quadrat size and shape can have a major influence on the precision of the estimate.

a. **Frequency**. Frequency is most typically measured in square quadrats. Because only presence or absence is measured, square quadrats are fine for this purpose. Of most concern in frequency measurement is the size of the quadrat. Good sensitivity to change is obtained for frequency values between 20 percent and 80 percent. Frequency values between 10 percent and 90 percent are still useful, but values outside this range should be used only to indicate species presence, not to detect change. Because frequency values are measured separately for each species, what constitutes an optimum size quadrat for one species may be less than optimum or even inappropriate for another. This problem is partially resolved by using nested plot quadrats of different sizes.

b. **Cover**. In general, quadrats are not recommended for estimating cover. Where they are used, the same types of considerations given below for density apply: long, thin quadrats will likely be better than circular, square, or shorter and wider rectangular quadrats. Each situation, however, should be analyzed separately. The amount of area in the quadrat is a concern with cover estimation. The larger the area, the more difficult it is to accurately estimate cover.

c. **Density**. Long, thin quadrats are better (often very much better) than circles, squares, or shorter and wider quadrats. How narrow the quadrats can be depends upon consideration of problems of edge effect, although problems of edge effect can be largely eliminated by developing consistent rules for determining whether to include or exclude plants that fall directly under quadrat edges. One recommendation is to count plants that are rooted directly under the top and left sides of the quadrat but not those directly rooted under the bottom and right quadrat sides. The amount of area within the quadrat is limited by the degree of accuracy with which one can count all the plants within each quadrat.

d. **Biomass**. For the same reason as given for density, long, thin quadrats are likely to be better than circular, square, or shorter and wider rectangular quadrats. Edge effect can result in significant measurement bias if the quadrats are too small. Since above*ground vegetation must be clipped in some quadrats, circular quadrats should be avoided because of the difficulty in cutting around the perimeter of the circle with hand shears and the likely measurement bias that would result.

7. Interspersion. One of the most important considerations of sampling is good interspersion of sampling units throughout the area to be sampled (the target population).

The basic goal should be to have sampling units as well interspersed as possible throughout the area of the target population. The practice of placing all of the sampling units, whether they be quadrats or points, along a single transect or even a few transects should be avoided, because it results in poor interspersion of sampling units and makes it unlikely that the sample will provide a representative sample of the target population. This is true even if the transect(s) is randomly located.

8. Pilot Projects. The purposes of pilot projects are to select the optimum size and/ or shape of the sampling unit for the project and to determine how much variability exists in the population being sampled. The latter information is necessary to determine the sample size necessary to meet specific management and sampling objectives.

a. **Initial Considerations**. Before beginning the actual pilot project, subjectively experiment with different sizes and shapes of sampling units. For example, if estimating density, subjectively place quadrats of a certain size and shape in areas with large numbers of the target plant species. (Note that it is not necessary to construct an actual frame for the quadrats used. It is sufficient to delineate quadrats using a combination of tape measures and meter (or yard) sticks. For example, a 5 m x 0.25 m quadrat can be constructed by selecting a 5 m interval along a meter tape, placing two I -meter sticks perpendicular to the tape at both ends of the interval (with their zero points at the tape), and laying another tape or rope across these two sticks at their 0. 2 5 m points. This then circumscribes a quadrat of the desired size and shape.) Then see how many plants fall into the quadrat and ascertain if this is too many to count. See what kind of problems there might be with edge effect: when individuals fall on or near one of the long edges of the quadrat, will it be difficult for examiners to make consistent calls as to whether these individuals are in or out of the quadrat? (Often, problems with edge effect can be largely overcome by making a rule that any plants that fall on the left or top edges of the quadrat are counted, whereas any plants that fall on the right or bottom edges of the quadrat are not counted.) See if there is a tendency to get more plants in rectangular quadrats when they are run one way as opposed to another. If so, then the quadrats should be run in the direction that hits the most plants. Otherwise it is likely that some quadrats will have few to no plants in them, while others will have many; this is highly undesirable. The goal should be to end up with similar numbers of plants in each of the quadrats, while still sampling at random.

If transects or lines are the sampling units, subjectively lay out lines of different lengths and in different directions. See if the lines cross most of the variability likely to be encountered with respect to the target plant species. If not, they may need to be longer. Don't make the lines so long, however, that it will be difficult to measure them, especially if there are a lot of lines involved. As with rectangular quadrats, it is desirable to have each of the lines encountering similar numbers and/or cover values of the target species, while still sampling at random.

b. **Efficiency of Sample Design**. Pilot sampling allows the examiner to compare the efficiency of various sampling designs. By dividing the sample standard deviation by the sample average, the coefficient of variation is obtained. Comparing coefficients of variation allows one to determine which of two or more sampling designs is most efficient (the lower the coefficient of variation, the greater the efficiency of the sampling design).

Conduct a pilot project by randomly positioning a number of sampling units of different sizes and shapes within the area to be sampled and then choosing the size and shape that yields the smallest coefficient of variation.

c. **Sequential Sampling**. The estimate of the standard deviation derived through pilot sampling is one of the values used to calculate sample size.

When conducting the pilot sampling, employ sequential sampling. Sequential sampling helps determine whether the examiner has taken a large enough pilot sample to properly evaluate different sampling designs and/or to use the standard deviation from the pilot sample to calculate sample size. The process is accomplished as follows:

Gather pilot sampling data using some arbitrarily selected sample size. Calculate the average and standard deviation for the first two quadrats, calculate it again after putting in the next quadrat value, and continue these iterative calculations after the addition of each quadrat value to the sample. This will generate a running average and standard deviation. Look at the four columns of numbers on the right of Figure 5 for an example of how to carry out this procedure.

Plot on graph paper (or use a computer program) the sample size versus the average and standard deviation. Look for curves smoothing out. The decision to stop sampling is a subjective one. There are no hard and fast rules.

A computer is valuable for creating sequential sampling graphs. Spreadsheet programs such as Lotus 1-2-3 allow for entering the data in a form that can later be analyzed while at the same time creating a sequential sampling graph of the running average and standard deviation. This further allows the examiner to look at several random sequences of the data before deciding on the number of sampling units to measure.

Use the sequential sampling method to determine what sample size not to use (don't use a sample size below the point where the running average and standard deviation have not stabilized). Plug the final average and standard deviation information into the appropriate sample size equation to actually determine the necessary sample size.

9. Sample size determination. An adequate sample is vital to the success of any monitoring effort. Adequacy relates to the ability of the observer to evaluate whether the management objective has been achieved. It makes little sense, for example, to set a management objective of increasing the density of a rare plant species by 20 percent when the monitoring design and sample size is unlikely to detect changes in density of less than 50 percent.

Formulas for calculating sample sizes differ depending on the sample design. Because these formulas are rather unwieldy, you may choose to use a computer program. There are several microcomputer programs that will calculate sample size, most of which are available for reasonable cost. Examples are the programs DESIGN (by SYSTAT), EXSAMPLE, N, Nsurv, PASS, and SOLO Power Analysis. Goldstein (1989) reviews 13 different computer programs that can calculate sample sizes. STPLAN Version 4.0, a DOS-based program developed by Brown et al. (1993). Documentation is included with the program. The program calculates sample sizes needed for all of the types of significance testing but does not calculate those required for estimating a single population average, total, or proportion. PC-SIZE: CONSULTANT is a shareware program that will calculate sample sizes for estimating an average (but not a proportion) and for all the types of significance tests. It was developed in 1990 by Gerard E. Dallal, who also developed the commercial program DESIGN discussed above. PC-SIZE: CONSULTANT appears to contain all of the algorithms included in DESIGN but at a fraction of the cost.

Alternatively, tables can be used to calculate sample size. For detecting change in averages, proportions, or totals between two time periods, the tables found in Cohen (1988) are highly recommended.

10. Graphical Display of Data. The use of graphs, both to initially explore the quality of the monitoring data collected and to display the results of the data analysis, is important to designing and implementing monitoring projects.

a. **Graphs to Examine Study Data**. Prior to Analysis The best of these graphs plot each data point. These graphs can help determine whether the data meet the assumptions of parametric statistics, or whether the data set contains outliers (data with values much lower or much higher than most of the rest of the data-as might occur if one made a mistake in measuring or recording). Normal probability plots and box plots are two of the most useful types for this purpose. Graphs can also assist in determining appropriate quadrat size.

b. **Graphs to Display the Results of Data Analysis**. Rather than displaying each data point, these graphs display summary statistics (i.e., averages, totals, or proportions). When these summary statistics are graphed, error bars must be used to display the precision of estimates. Because it is the true parameter (average, median, total, or proportion) that is of interest, confidence intervals should be used as error bars. Types of graphs include:

1. Bar charts with confidence intervals.
2. Graphs of summary statistics plotted as points, with error bars.
3. Box plots with "notches" for error bars.

C. Other Important Considerations

1. Sampling All Species. Although the key species concept is important in analyzing and evaluating management actions, other species should also be considered for sampling. Whenever possible, all species should be sampled, especially on the initial sampling. It is also important to record sampling data by individual species rather than by genera, form class, or other grouping. These data can be lumped later during the analysis if appropriate. Both of these approaches will provide greater flexibility in data analysis if objectives or key species change in the future.

2. Plant Species Identification. The plant species must be properly identified in order for the data to be useful in the designated management area evaluations. In some cases, it may be helpful to include pressed plant specimens, photographs, or other aids used for species identification in the project file. If data are collected prior to positive species identification, examiners should collect plant specimens for later verification.

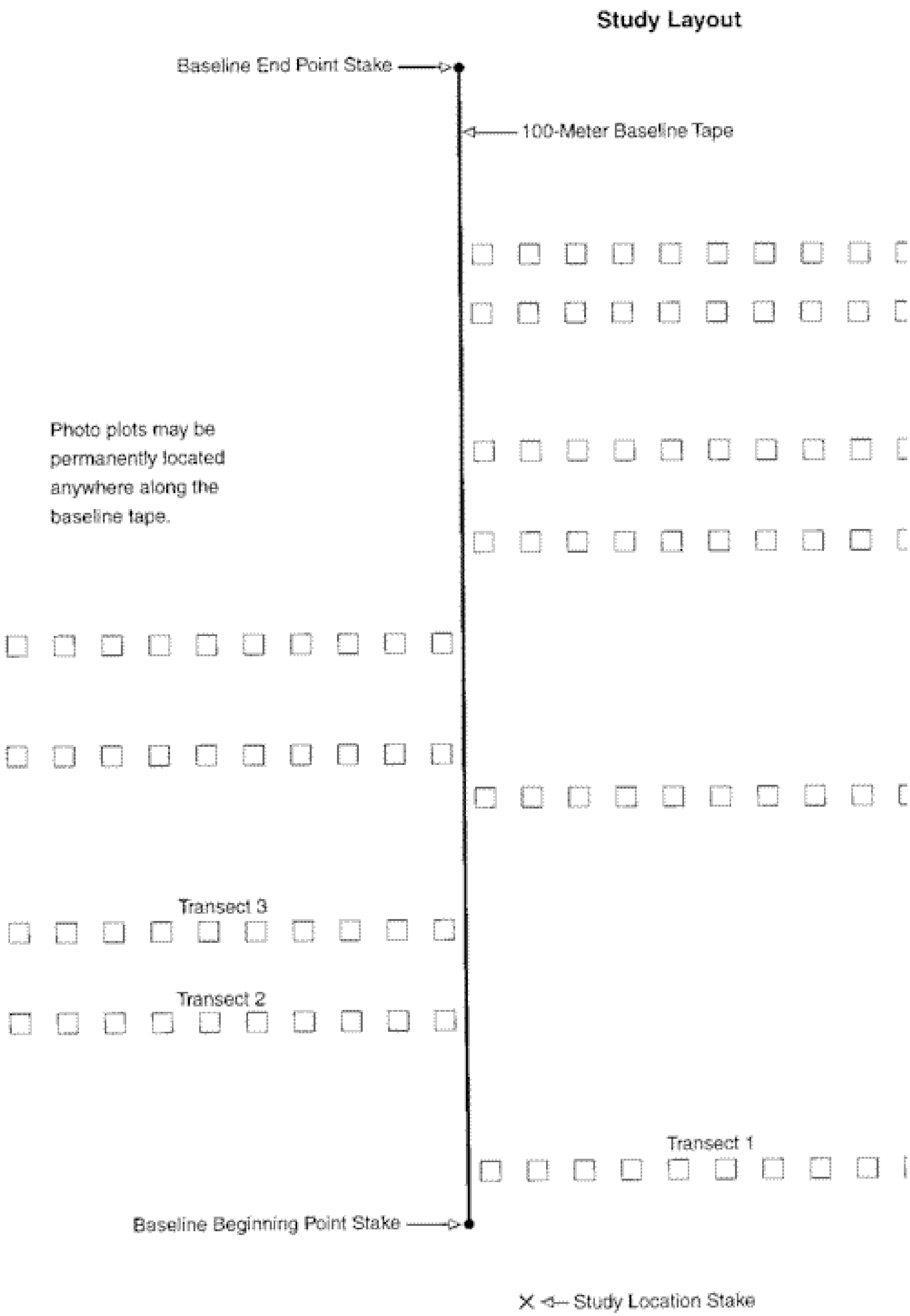
3. Training. The purpose of training is to provide resource specialists with the necessary skills for implementing projects and collecting reliable, unbiased, and consistent data. Examiners should understand data collection, documentation, analysis, interpretation, and evaluation procedures, including the need for uniformity, accuracy, and reliable monitoring data.

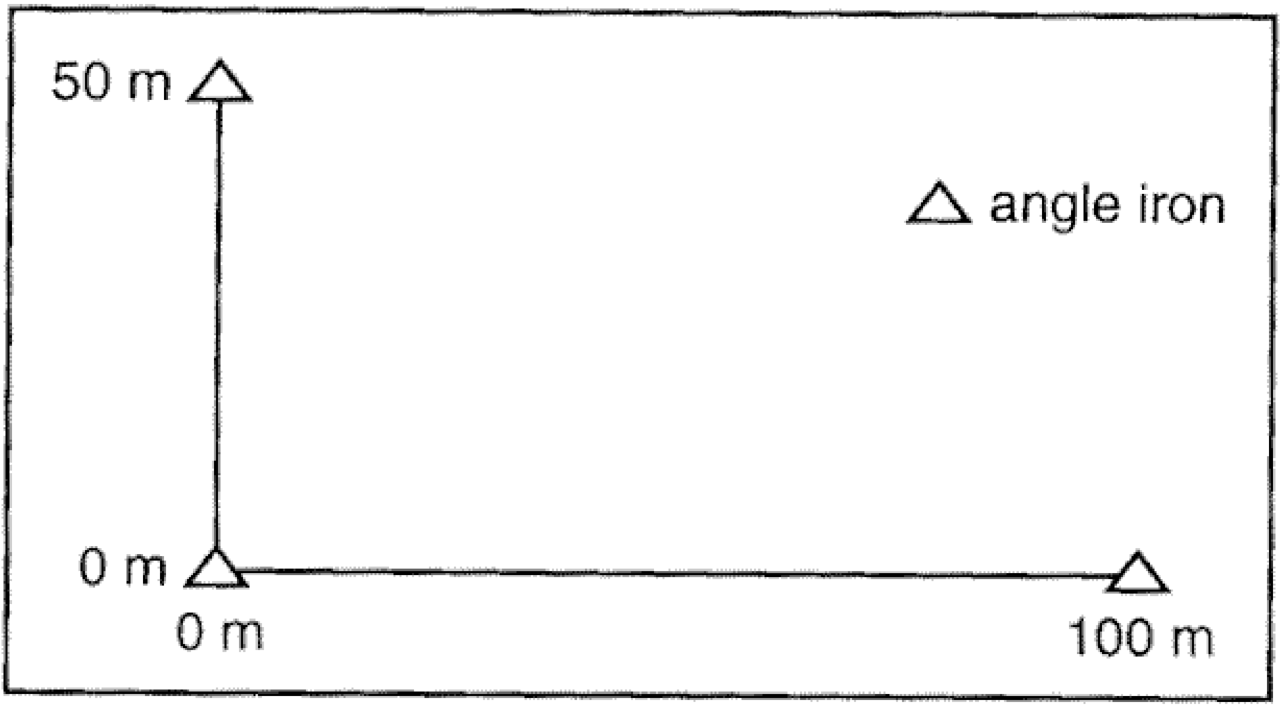
Training should occur in the field by qualified personnel to ensure that examiners are familiar with the equipment and supplies and that detailed procedural instructions are thoroughly demonstrated and understood.

As a follow-up to the training, data collected should be examined early in the project to ensure that the data are properly collected and recorded.

Periodic review and/or recalibration during the field season may be necessary for maintaining consistency among examiners because of progressive phenological changes. Review and recalibration during each field season are especially important where data collection methods require estimates rather than direct measurements.

This page was last modified 06/21/01


Study Layout
Baseline End Point Stake
100-Meter Baseline Tape
Photo plots may be permanently located anywhere along the baseline tape.
Transect 3
Transect 2
Transect 1
Baseline Beginning Point Stake
Study Location Stake


50 m
△ angle iron
0 m
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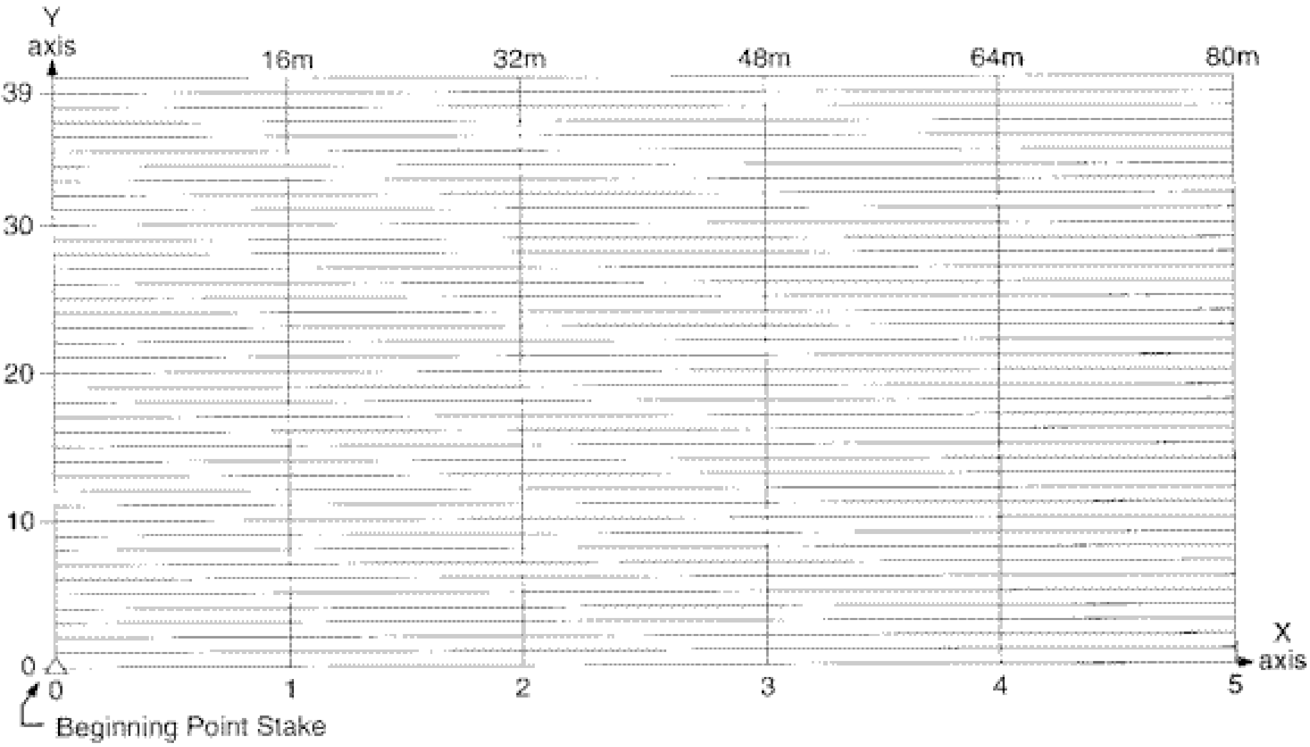
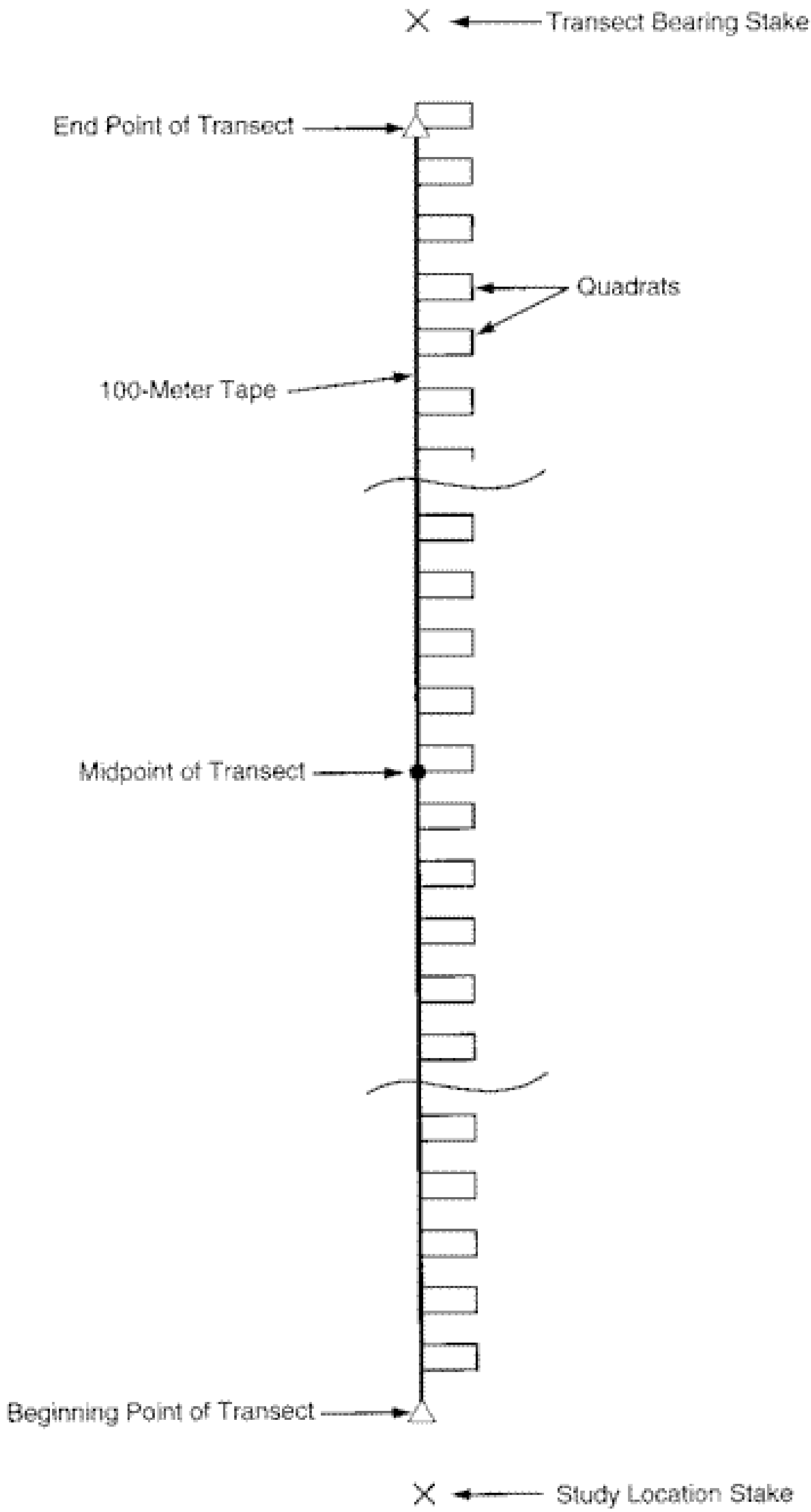
100 m



A 40 m x 80 m macroplot showing the 200 possible quadrats of size 1 m x 16 m that could be placed within it (assuming the long side of the quadrats is oriented along the x-axis).


Transect Bearing Stake
End Point of Transect
Quadrats
100-Meter Tape
Midpoint of Transect
Beginning Point of Transect
Study Location Stake

SAMPLING DESIGN

Excerpts Plates, WS.; Armor, C.; Booth, G.D.; Bryant, M.; Buffered, J.L.; Coupling, P.; Jensen, S.; Lienkaemper, G.W; Mensal, G.W; Monsoon, S.B.; Nelson; Roger L.; Seder, J.R.; Thy, J.S. 1987. Methods for evaluating riparian habitats with applications to management. U.S. Forest Service Intermountain Research Station, General Technical Report NIT-221, Ogden, Utah are provided for further understanding of sampling design. We have included this material in the Fuel and Fire Effects Reference Guide because it includes a clear discussion of how to calculate summary statistics and determine sample sizes for several sampling designs.

1. General Field Sampling

Information collection is necessary for inventory and monitoring activities associated with management programs. Success for the programs is dependent upon the acquisition and use of information that must be appropriate for planning processes and the design of site-specific management. Unfortunately, widespread problems have resulted in inadequate, improper, or excessive information. This is usually attributed to a poorly thought out approach to collecting information for specifically fulfilling resource management requirements.

Six basic steps should be followed for a field sampling program if useful information is to be obtained. Before sampling, justification for collecting the information (step 1) must be made. Considerations for establishing justifications include: (1) Is the information already available? (2) Is the acquisition of new information absolutely necessary for activities associated with resource planning and management activities? (3) Would it be possible to measure substitute condition to obtain essentially the same information at lower cost?

After specific information needs are defined, collection approaches must be determined (step 2). Considerations for this step must include evaluation of the suitability of a technique for achieving appropriate levels of accuracy and precision and the practicality of the technique based on ease of field application, costs, and other factors. Following step 2, pilot sampling (step 3) must be performed. Essentially, this step is a trial run designed to detect and correct problems that could seriously affect sampling. Additionally, this step is necessary for training of field crews and obtaining preliminary data for use in estimating the sample size for a predetermined level of statistical confidence. If problems are detected, which is usually the case (examples: sampling gear performs improperly, inadequate time was allocated for collecting and analyzing samples, more samples must be collected than originally planned), corrective measures must be taken. Step 3 is mandatory because serious flaws in the way sampling is conducted will adversely impact the quality of information that is collected.

When information is collected (step 4), it must be recorded accurately and assembled in a usable formation for analysis (step 5). When the results are processed for use in planning and management procedures (step 6), careful thought must be given to the best way to present it to resource specialists and administrators. If the information is not presented with clarity and in a useful form, effort and costs expended for the work will be wasted.

2. Concepts About Populations and Samples

The entire collection of items in which we are interested is called the population. For example, the population might be a 100-ft. section of the stream to be divided into 100 cross sections of 1 ft. each. If we take measurements on only 20 of these cross sections, the cross sections we measure constitute the sample. The whole purpose of using sampling is to obtain information about the entire population when it is not possible or feasible to measure every element in it. We hope the items in the sample will give us accurate information about the whole population.

Populations can be either finite (with a fixed, countable number of elements) or infinite (with an infinite number of elements). Some populations are technically finite but with so many elements we could not reasonably count them. Such populations are considered to be infinite.

To illustrate, consider the example mentioned above. The 100-ft. stretch of stream is the population. We have arbitrarily divided it into 100 cross sections of I ft. each. Does this mean we have 100 elements in our population? Not necessarily. If we are interested in some characteristic that requirements measurement over the entire 1-ft. cross section, then the population could be considered finite with 100 elements in it. On the other hand, if we were interested in a characteristic that requires measurement at only a point along the stream (such as stream width, measured at a transact), it would be incorrect to consider the population as consisting of only 100 elements. In this case, the population should be dealt with as infinite. The methods that follow will often involve the finite population correction (*fpc*). It is defined as:

$$fpc = (1 - n/N)$$

where:

N = number of elements in the whole population
n = number of elements in the sample.

Notice that if N is large (essentially infinite), the fpc approaches 1. In the methods described later, if the population is infinite, we can ignore the fpc (that is, consider it equal to 1). This is true because the fpc is always used as a multiplier and multiplying by I has no effect.

We use "error of estimation" to denote the distance by which our estimate misses the true population value we are attempt to estimate. Although we cannot know the true error of estimation, it would be useful to be quite certain that after our sampling and estimating are complete, we have an error of estimation that is no greater than some upper boundary, say B.

Common field sampling procedures are simple random sampling, stratified random sampling, and cluster sampling. The information presented here is expected to introduce field workers to some useful procedures; prior to application, a qualified statistician should be consulted.

3. Simple Random Sampling

A simple random sample (SRS) is, as its name implies, the sampling method that is simplest in concept. For its use, each element in the population (such as plots and transacts) must be identifiable as individuals. Sampling must be performed in such a way that every element in the population has the same probability of being in the sample.

Using simple random sampling often results in samples that (1) are widely dispersed, causing considerable travel expense, and (2) leave some areas totally unsampled. Therefore, the most successful use of SRS is in relatively small geographical areas where a degree of homogeneity is known to exist. Simple random sampling could be used in other circumstances, but it would tend to be inefficient and more costly.

Simple random sampling should probably be within ecological types instead of across multiple types. This precaution will tend to reduce the variability and increase the precision of habitat parameter estimates. The precaution is reasonable, for example, when one considers the high variation that occurs between riparian habitat in meadows compared to headwater-timbered areas in an allotment that is heavily grazed.

4. Stratified Random Sampling

If the population of interest falls naturally into several subdivisions, or strata, stratified random sampling is found to be substantially more efficient than simple random sampling. For example, if the number of shrubs is a management concern in a riparian zone that extends through several homogeneous vegetation types (such as sagebrush, sagebrush-grass, and ponderosa pine-Idaho fescue), this method of sampling is suitable. This procedures requires that the investigator clearly identify each stratum in advance of sampling. Then a simple random sample (SRS) is taken independently within each stratum.

In addition to being more efficient in estimating the overall population mean or total, stratified random sampling provides separate estimates for each stratum. This feature alone might be reason enough for using this method of SRS.

5. Cluster Sampling

Cluster sampling should not be confused with cluster analysis, which is a classification and taxonomic technique. Here, cluster sampling refers to a method of collecting a sample when the individual elements cannot be identified in advance. Instead we are only able to identify groups or clusters of these elements. A sample of the clusters is then obtained, and every element in each cluster is measured.

For example, we may wish to take measurements on individual trees but are only able to identify 1-acre plots. Each plot can contain a different number of trees, and the individual trees cannot be identified before taking the sample. Cluster sampling allows us to select a sample of clusters, instead of individual trees. We would then measure every tree within each cluster.

Cluster sampling is convenient and inexpensive with regard to travel costs. To gain maximum advantage of this method, elements within a cluster should be close to each other geographically.

If we compare cluster sampling with either simple random sampling or stratified random sampling, we find one major advantage of the cluster method: the cost per element sampled is lower than for the other two methods. Unfortunately, two disadvantages of cluster sampling are: (1) the variance among elements sampled tends to be higher, and (2) the computations required to analyze the results of the sample are most extensive. Therefore, cluster sampling is preferable to the other methods if the cost benefits exceed the disadvantages.

If we have only a few clusters, each quite large, we minimize our costs-especially of travel. However, samples with only a few clusters produce estimates with low precision (that is, high variance). On the other hand, if we increase the number of clusters (making each cluster smaller), the variance is reduced while the cost is increased. The user must find a compromise.

Whether sampling 40 clusters of 0.5 acre each is better than 20 clusters of a full acre each is not clear, although approximately the same number of trees may be measured with either sample. There would be a larger number of the smaller clusters, and therefore they would be dispersed more evenly over the population. The estimates produced would have lower variability than those from fewer but larger clusters. However, the sample would have to travel to twice as many sites, thus increasing costs. Knowledge of the variability and costs involved would be the key to planning such a study effectively.

6. Two-Stage Sampling

Suppose we have clusters with so many elements in them that it is prohibitive to measure all elements in the cluster. It is natural to think of sampling elements within each cluster - that is, to measure only part of the elements within each cluster. This situation is a common one and is referred to as two-stage sampling.

Another common use of two-stage sampling is when it is apparent that even though there are many elements within a cluster, all elements are so nearly the same that to sample all of them would provide little additional information. The reasonable thing to do might be to measure only a part of the elements available within the cluster.

Two-stage sampling introduces a high degree of flexibility in defining clusters and sampling within them. The give and take between the number of clusters and the number of elements to be sampled within each cluster has been studied in some detail. Unfortunately, the results are complicated and beyond the scope of this publication. Interested readers are referred to one of the more extensive books on sampling.

7. Monitoring

The purpose of monitoring is to obtain information for use in evaluating responses of land management practices. Specific steps must be followed if meaningful results are to be obtained from a monitoring study. Step 1 is the documentation of baseline condition, management potential, and problems attributed to the mix of land use practices adversely affecting a riparian area. Management potential is the level of riparian habitat quality that could be achieved through application of improved management. Potential will vary between sites because of several variables, including rainfall patterns, landform, and history of use. If potential is evaluated to be higher than the response capability of a site, and an objective is made to achieve better conditions than are possible, a management failure will obviously occur. This emphasizes the importance of developing objectives that are compatible with site potential.

Documentation of problems from all land use practices that affect a site requires a thorough analysis. For example, if the objective is to improve habitat to increase numbers of trout, it is possible that complex problems must be solved or controlled before trout will benefit.

Before completing the objectives for riparian habitat management (step 2) holistic planning by an interdisciplinary group will be necessary because most sites will be subjected to multiple-use management. Therefore, riparian habitat objectives will have to be compatible with those of the overall multiple-use plan. If dominant-use management is to be applied to solely benefit a riparian area, it is advisable to involve individuals in other disciplines to assess potential for response to management. Depending on site-specific problems, the disciplines could include hydrology, plant ecology, and perhaps engineering if structural physical changes (such as rechannelization or installation of stream improvements devices) are considered. When objectives are specified, they must be stated in quantifiable and measurable terms; this is of paramount importance. An example of an objective could be to increase the density of shrubs from 25 to 50 percent. This specifically requires that existing conditions be documented for comparison with future management results.

The design of site-specific management plans for achieving objectives (step 3) requires multiple-use planning and conflict resolution. For example, suppose that timber harvesting, recreation, and mining are contributing to a degraded riparian habitat. It will be difficult, if not impossible, to design a management plan strictly for application in the area to solve problems caused by outside influences. Key considerations for a properly designed monitoring program (step 4) include the following:

- Measurement of response to management is possible to determine through hypothesis testing if objects are met. This prerequisite depends upon a clearly stated hypothesis (for example, H_a: shrub density increased 100 percent vs. H_o: shrub density increased <100 percent) that tracks with a management objective, and the variable must be responsive to management that will be applied. Additionally, measurement of the response with appropriate accuracy and precision must be feasible. Designation of variables that are difficult to measure and ones for which good measurement techniques have not been perfected should be avoided.
- Control areas that will not receive management treatments must be included in the study. One precaution that must be taken in selecting control and treatment sites is that they must have the same premanagement characteristics and the same potential for response to management. This precaution is necessary if changes attributable to management are to be detectable. For example, if the objective is to improve overhanging stream-side cover by 50 percent in a meadow, a control must be established in a similar meadow, not in an area with different landform features and response capabilities. The recommended approach for selecting control and treatment sites for comparison is to make the selections randomly in areas with similar premanagement conditions.
- Resources must be available for monitoring through an adequate period to permit management responses to occur. This requirement is frequently neglected. If it is uncertain whether a monitoring program can be completed with adherence to the plan, the program should not be initiated.

- Management must be consistent with the original plan throughout the study. Noncompliance with this condition is one of the most common problems thwarting studies. The problem occurs when changes are made in management, preventing accurate interpretations of data. An example of the problem could be when the establishment of easier access by fishermen to study sites in a stream has resulted in depletion of fish in treatment and control sites, masking influences of improved habitat conditions. Another example that happens frequently is the trespass of livestock and subsequent overgrazing and habitat change in control sites.
- Confounding factors that can adversely affect the study must be controlled. These factors are defined as unplanned events or influences that adversely affect results of a study. Factors in this category include institutional influences (such as when an agency changes emphasis away from monitoring and a study is stopped), political pressures (such as when a user group uses influence to stop a study because potential results are disliked), equipment failure problems, changes in personnel conducting the study and inability to find suitable replacements, and biological effects (such as when natural variation is excessive in time and space, and responses to management are masked). Although it is impossible to guarantee that confounding problems will not occur, individuals involved with monitoring should consider them in advance to eliminate as many as possible.
- Statistical tests to analyze information are designated when the monitoring program is designed and assumptions for proper use of the tests are met. Unfortunately, there has been a tendency for the advance consideration of statistical tests to be neglected, resulting in the collection of data and the expectation that a statistician "can make something out of it" after completion of field work. When this happens, the result is usually a disappointing conclusion that the study was useless. To prevent problems, individuals involved with designing monitoring programs should always obtain assistance from a statistician during the design phase. This will help avoid serious problems that cannot be corrected. Essentially the pilot study (step 5) for a monitoring project is conducted for the same reasons discussed earlier. To help ensure that meaningful statistical tests are feasible.

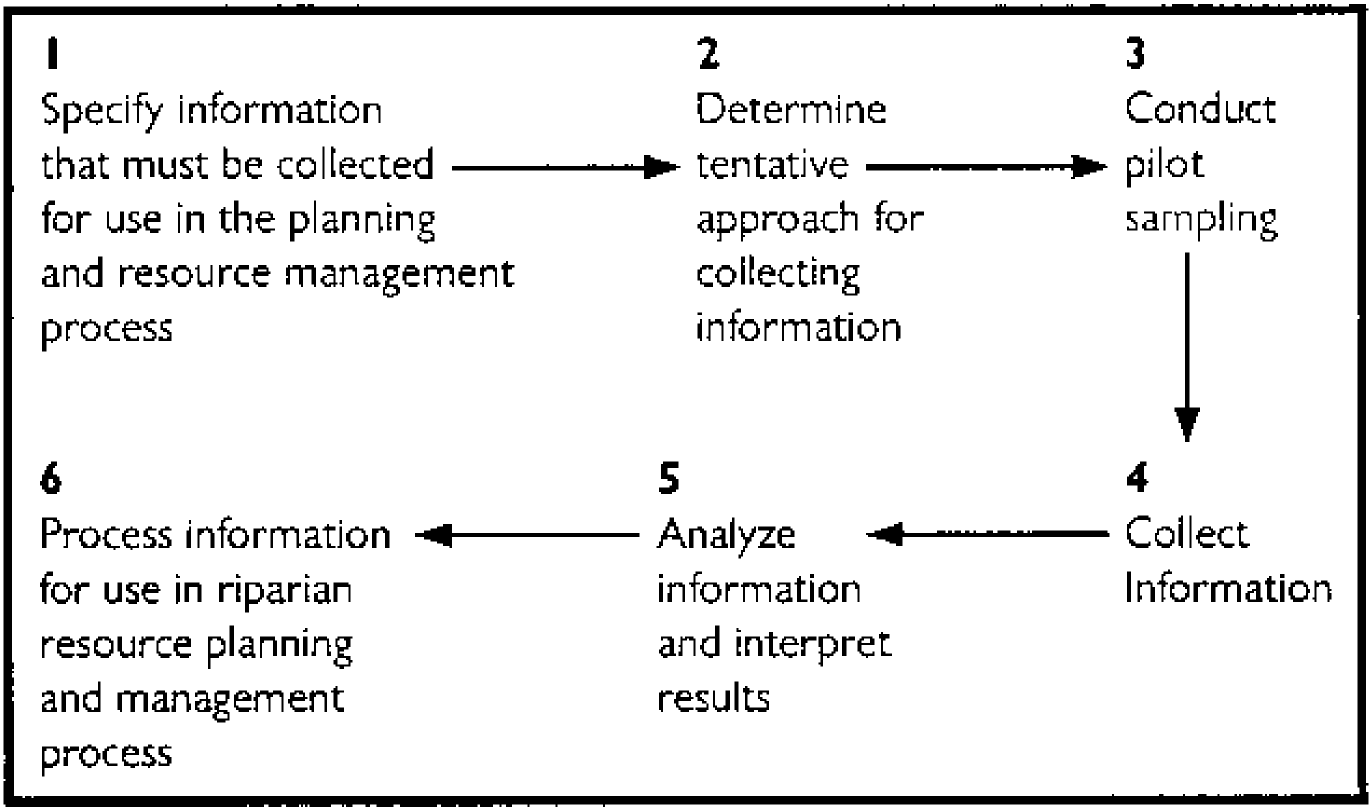
Assistance should be obtained from a statistician for this phase to refine approaches for the study. Once the pilot study is completed, assuming that appropriate premanagement data for control and treatment sites have been collected, management can be applied and monitoring (step 6) can proceed with strict adherence to the design specifications. If appropriate premanagement data have not been collected, this requirement must be fulfilled before management is applied. Failure to obtain data from preconditions and postconditions will preclude evaluation if management resulted in the achievement of stipulated objectives. Special considerations for step 6 must include: (1) maintenance of accuracy and precision in collecting data, (2) the expending of equal levels of effort and adherence to the same technical standards in control and treatment sites to prevent bias from influencing results of the study, and (3) the recording and processing of data suitable for retrieval and use in statistical analyses.

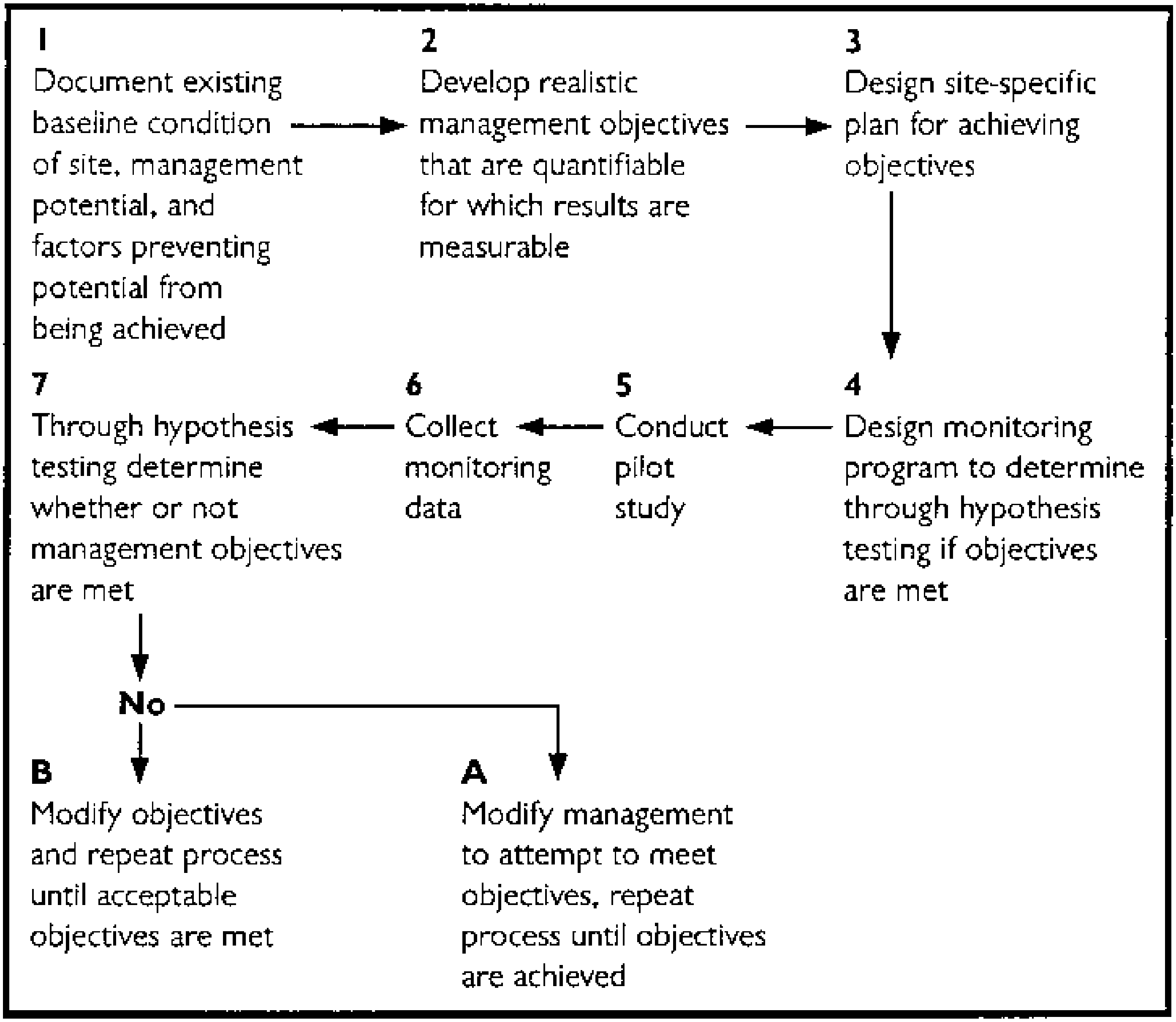
Statistical tests are used in step 7 to evaluate with a predetermined level of statistical confidence whether objectives were met. This level might not have to be as high (say, 95 or 99 percent) as would be expected for research, but the price for a lower level is an increased chance for a type I error (claiming a difference when it does not exist). When tests are performed, the determined confidence level must not be arbitrarily altered (say, from 95 to 85 percent) if results do not conform with preconceived perceptions.

Common errors to avoid when using statistical tests include inaccurate data entry, errors in rounding numbers, use of incorrect degrees of freedom, and incorrectly reading statistical table (such as tables of t and F values).

Based on results of hypothesis testing, it is possible to conclude with a stipulated level of statistical confidence whether objectives are met. If they are not met, there are two options: modify objectives and repeat the process until they are eventually met, or modify management and repeat the process until success is achieved.

One concept that must be emphasized is that monitoring should not result in a strict "pass" or "fail" conclusion. There cannot be a failure if, in the future, negative results contribute to avoidance of management practices that do not work. Therefore, it is equally important to document unsuitable practices to avoid if the art of riparian resource management is to progress.


1
Specify information that must be collected for use in the planning and resource management process
2
Determine tentative approach for collecting information
3
Conduct pilot sampling
4
Collect Information
5
Analyze information and interpret results
6
Process information for use in riparian resource planning and management process


1
Document existing baseline condition of site, management potential, and factors preventing potential from being achieved
2
Develop realistic management objectives that are quantifiable for which results are measurable
3
Design site-specific plan for achieving objectives
4
Design monitoring program to determine through hypothesis testing if objectives are met
5
Conduct pilot study
6
Collect monitoring data
7
Through hypothesis testing determine whether or not management objectives are met
No
B
Modify objectives and repeat process until acceptable objectives are met
A
Modify management to attempt to meet objectives, repeat process until objectives are achieved

LOCATING RANDOM SAMPLE POINTS, LINE TRANSECTS, INDIVIDUAL PLANTS, AND GROUPS OF PLANTS

RANDOM POINTS

1. Grid

Two lines are laid out perpendicular to each other. They should run the length and width of the site, and are usually most easily located at the sides of the plot. Each line is measured. Enough precision (decimal places) should be used so that if you ignore the decimal point, the measurement for each line is between 50 and 1000 (e.g., 18.1 and 92). The numbers of digits in these measurements of each line are counted (e.g., 3 and 2). This number of random digits in the length is selected from a random number table. If the random number selected is larger than the length, other sets of random digits are taken until one is selected that is equal to or smaller than the length. This process is repeated for the width. Each set of random digits is used as coordinates to locate the random point.

For large sites, it is best to draw the lines on a map and locate all the random points before leaving the office. The field crew can then start at one corner and sample each point in a systematic pattern to avoid unnecessary walking.

This technique is preferred in dense vegetation or where the vegetation is obviously different near the margins than in the center. It selects truly random points, so it is suitable for high accuracy inventories. It is better than a line transect in plots that are not long and narrow. It can be easier to apply than the dropped pointer if few obvious landmarks are present.

2. Thrown Marker

The crew walks to a convenient point near the center of the site. One member closes his eyes, spins around several times, then tosses a marker (e.g., a rock) over his shoulder. The random point is where the marker lands. The next random point is selected using the same process while standing at the first random point. If the marker lands outside the site, the process should be repeated using the last random point inside the site.

Note that this approach actually identifies points in a haphazard manner. The deviation from the randomness has a tendency to over sample the center of the site. Consequently, it is not suitable for high accuracy inventories. It can be difficult to apply if the vegetation is dense enough to make it hard to find the marker.

3. Line Transect

A line transect is laid out using one of the techniques described below. Pairs of random digits are selected from a random numbers table. An observer moves along the line a distance corresponding to the pair of random digits to locate the random point. The next point can be located by repeating the process starting from the point just located.

This technique is best applied using a meter tape as the line. It is preferred in long narrow sites where the vegetation is open enough to permit walking in a straight line.

4. Dropped Pointer

A pencil is held point down over a map or photo with one's eyes closed. It is then dropped. The mark left by the point is used. Note that this approach selects points haphazardly and may oversample some portion of the study area. It is most applicable in plots with many good landmarks, such as open woodland.

LINE TRANSECTS

1. Starting Point

The Grid or Thrown Marker techniques (above) can be used for establishing random points. Alternatively, a baseline can be established along one side of the site. Starting points for line transects can be selected at random or regular intervals along the baseline. Multiple transects can be run from the baseline. If this is done, it is best to run them all parallel to one another.

2. Direction

A. **Spinning "Pointer"**. This technique involves spinning a "pointer" until it stops. The most convenient "pointer" is a pencil. One tosses the pencil up in the air so it is spinning in a horizontal plane (like a baton). After the pencil comes to rest, its direction is used. This technique can be somewhat biased, and should not be used in high accuracy inventories.

B. **Random angle**, A 3-digit random number less than 360 is selected from a random numbers table. This is used as the bearing on a compass., This technique takes longer to use than the spinning pointer, but is truly random. Hence, it is preferred for high accuracy inventories.

C. **Laying out the line**. This is most conveniently done using one edge of a stretched tape measure as the line. One crew member stands at the start of the transect and holds the free end of the tape. The other member moves off with the bulk of the tape in the direction selected. The moving member should select a distant landmark in the appropriate direction. He should then select another landmark at about 5 m distance (or the first barrier, if closer). Next, he should walk toward the close landmark. When it is reached, he should stop and select another close landmark in line with the distant one (for barriers, see below). The person holding the end of the tape should direct corrections if the walking person deviates out of line. When the end is reached, the line should be raised above the surface and stretched, if possible, before laying it down.

For highest accuracy, the tape should be anchored in place straight and stretched. The free end of the tape (or a loop of cord attached to it) can sometimes be held adequately by pushing a small stick through the loop. The reel case's weight will sometimes hold it well enough. Often, however, both ends should be tied to plants or stakes driven into the ground.

3. Barriers

If the line transect passes out of the site, or crosses an impenetrable barrier, it should be terminated at that point. Either a new starting point or the termination point can be used to lay out the next transect. If the termination point is used, a new direction can be selected using the Spinning Pointer or Random Angle technique (above), which will avoid the boundary or barrier. The tape can be put through a shrub using a stick as a "needle."

INDIVIDUAL PLANTS

1. Nearest Neighbor

Select a random point using one of the techniques described above. The plant closest to this point is used. This technique is usually preferred in inventories of multiple variables. It can be biased if a haphazard method is used to select the point. Often the density of plants is patchy, and plant characteristics, e.g., size, are correlated with density. Using this technique in this situation will give a biased sample because sampling is more likely to select a plant in the low density areas. In this case, the following technique may be used. Alternatively, high and low density areas can be sampled separately.

2. Assigned Label

Identify and number every plant of the type to be sampled in the site. Draw a group of random digits (from a random numbers table) that lie within this range (see the Grid technique discussion above) to identify the plant to be used. This technique is preferred in plots with few plants to be sampled.

GROUP OF PLANT

1. Quadrat

Determine a quadrat size that will encompass approximately the number of plants desired in the group. Next, decide on a convenient shape. If this shape is not a long narrow strip, locate a random point (see above). This is the center of a round quadrat or a corner of a square or rectangular one. If the quadrat is not round, select a random direction (see line transect). This determines where a side of the quadrat goes. The side to be used should be determined ahead of time. All plants lying inside the quadrat are used.

If a strip or belt quadrat is used, lay out a transect line. Next, determine the width to be used. All plants falling within this width from the transect line (usually on one side only) are used. This technique is preferred if a quadrat or line transect is to be laid out for sampling other variables.

2. Nearest Neighbors

Use the Nearest Neighbor technique under above, except determine the size of group desired. One then selects, successively, the nearest plants to the random point until the desired group size is reached. This technique is preferred if random points are being used for sampling other variables. It is also convenient if the plant density is low.

SAMPLE SIZE EQUATIONS

Five different sample size equations are presented in this appendix for the following situations:

Equation #I: Determining the necessary sample size for estimating a single population mean or a single population total with a specified level of precision.

Equation #2: Determining the necessary sample size for detecting differences between two means with temporary sampling units.

Equation #3: Determining the necessary sample size for detecting differences between two means when using paired or permanent sampling units.

Equation #4: Determining the necessary sample size for estimating a single population proportion with a specified level of precision.

Equation #5: Determining the necessary sample size for detecting differences between two proportions with temporary sampling units.

Each separate section is designed to stand alone from the others. Each section includes the sample size equation, a description of each term in the equation, a table of appropriate coefficients, and a worked out example including a complete management objective.

The examples included all refer to monitoring with a quadrat-based sampling procedure. The equations and calculations also work with other kinds of monitoring data such as measurements of plant height, number of flowers, or measures of cover.

For the equations that deal with comparing different sample means, all comparisons shown are for two-tail tests. If a one-tail test is desired, double the false-change (Type I) error rate (æ) and look up the new doubled-æ value in the table of coefficients (e.g., use æ = 0.20 instead of æ = 0.10 for a one-tailed test with a false-change (Type 1 error rate of æ = 0.10).

The coefficients used in all of the equations are from a standard normal distribution ($Z_{æ}$ and $Z_{ß}$) instead of the *t*-distribution ($t_{æ}$, and $t_{ß}$). These two distributions are nearly identical at large sample sizes but at small sample sizes (n < 30) the *Z* coefficients will slightly underestimate the number of samples needed. The correction procedure described for Equation #1 (using the sample size correction table) already adjusts the sample size using the appropriate *t*-value. For the other equations, $t_{æ}$ and $t_{ß}$ values can be obtained from a *t*-table and used in place of the $Z_{æ}$ and $Z_{ß}$ coefficients that are included with the sample size equations. The appropriate $t_{æ}$-coefficient for the false-change (Type I) error rate can be taken directly from the æ(2) column of a t-table at the appropriate degrees of freedom (*v*). For example, for a false-change error rate of 0.10 use the æ(2) = 0.10 column. The appropriate $t_{ß}$ coefficient for a specified missed-change error level can be looked up by calculating 2(1-power) and looking up that value in the appropriate æ(2) column. For example, for a power of 0.90, the calculations for $t_{ß}$ would be 2(1-.90) = 0.20. Use the æ(2) = 0.20 column at the appropriate degrees of freedom (*v*) to obtain the appropriate *t*-value.

SAMPLE SIZE EQUATION #1

Determining the necessary sample size for estimating a single population mean or a population total with a specified level of precision.

Estimating a sample *mean vs. total population size*. The sample size needed to estimate confidence intervals that are within a given percentage of the estimated *total population size* is the same as the sample size needed to estimate confidence intervals that are within that percentage of the estimated *mean value*. The instructions below assume you are working with a sample mean.

Determining sample size for a single population mean or a single population total is a two- or three-step process.

(1) The first step is to use the equation provided below to calculate an uncorrected sample size estimate.

(2) The second step is to consult the Sample Size Correction Table appearing on pages 5-6 of these instructions to come up with the corrected sample size estimate. The use of the correction table is necessary because the equation below under-estimates the number of samples that will be needed to meet the specified level of precision. The use of the table to correct the underestimated sample size is simpler than using a more complex equation that does not require correction.

(3) The third step is to multiply the corrected sample size estimate by the finite population correction factor if more than 5% of the population area is being sampled.

1. Calculate an initial sample size using the following equation:

$$n = (Z_{æ})^2 (s)^2 / (B)^2$$

Where:

n = The uncorrected sample size estimate.
$Z_{æ}$ = The standard normal coefficient from the table below.
s =The standard deviation.
B = The desired precision level expressed as half of the maximum acceptable confidence interval width. This needs to be specified in absolute terms rather than as a percentage. For example, if you wanted your confidence interval width to be within 30% of your sample mean and your sample mean = 10 plants/quadrat then B = (0.30 x 10) = 3.0.

Table of standard normal deviates ($Z_{æ}$) for various confidence levels

Confidence level	Alpha (æ) level	($Z_{æ}$)
80%	0.20	1.28
90%	0.10	1.64
95%	0.05	1.96

99%	0.01	2.58

2. To obtain the adjusted sample size estimate, consult the correction table of these instructions.

n = the uncorrected sample size value from the sample size equation.
n* = the corrected sample size value.

3. Additional correction for sampling finite populations

The above formula assumes that the population is very large compared to the proportion of the population that is sampled. If you are sampling more than 5% of the whole population then you should apply a correction to the sample size estimate that incorporates the finite population correction factor (FPC). This will reduce the sample size.

The formula for correcting the sample size estimate with the FPC for confidence intervals is:

$$n' = n^* / (1+(n^*/N))$$

Where:

n' = The new FPC-corrected sample size.
n^* = The corrected sample size from the sample size correction table.
N = The total number of possible quadrat locations in the population. To calculate N, determine the total area of the population and divide by the size of one quadrat.

Example:

Management objective: Restore the population of species Y in population Z to a density of at least 30 plants/quadrat by the year 2001

Sampling objective: Obtain estimates of the mean density and population size of 95% confidence intervals within 20% of the estimated true value.

Results of pilot sampling:

Mean (x) = 25 plants/quadrat.
Standard deviation (s) = 7 plants.

Given: The desired **confidence level** is 95% so the appropriate $Z_{æ}$ from the table above = 1.96. The desired **confidence interval width** is 20% (0.20) of the estimated true value. Since the estimated true value is 25 plants/quadrat, the desired confidence interval (**B**) = 25 x 0.20 = 5 plants/quadrat.

Calculate an unadjusted estimate of the sample size needed by using the sample size formula:

$$n = (Z_{æ})^2(s)^2 / (B)^2 \quad n = (1.96)^2(7)^2 / (5)^2 = 7.5$$

Round 7.5 plots up to 8 plots for the unadjusted sample size.

To adjust this preliminary estimate, go to the sample size correction table and find n = 8 and the corresponding n* value in the 95% confidence level portion of the table. For n = 8, the corresponding n* value = 15.

The corrected estimated sample size needed to be 95% confident that the estimate of the population mean is within 20% (+/- 5 plants) of the true mean = **15 quadrats**.

Additional correction for sampling finite populations: The above formula assumes that the population is very large compared to the proportion of the population that is sampled. If you are sampling more than 5% of the whole population area then you should apply a correction to the sample size estimate that incorporates the finite population correction factor (FPC). This will reduce the sample size. The formula for correcting the sample size estimate is as follows:

$n' = n^* / (1+(n^*/N))$

Where:

n' = The new sample size based upon inclusion of the finite population correction factor.
n = The corrected sample size from the sample size correction table.
N = The total number of possible quadrat locations in the population. To calculate N, determine the total area of the population and divide by the size of the sampling unit.

Example:

If the pilot data described above was gathered using a 1m x 10m (10 m^2) quadrat and the total population being sampled was located within a 20m x 50m macroplot (1000 m^2) then N = $1000m^2/10m^2$ = 100. The corrected sample size would then be:

$n' = n^* / (1+(n^*/N))$ $n' = 15 / (1+(15/100)) = 13.0$

The new, FPC-corrected, estimated sample size to be 95% confident that the estimate of the population mean is within 20% (+/- 5 plants) of the true mean = 13 quadrats.

SAMPLE SIZE EQUATION #2:

Determining the necessary sample size for detecting differences between two means with temporary sampling units.

$n = 2(s)^2(Z_{æ}+Z_{ß})^2 / (MDC)^2$

Where:

n = The uncorrected sample size estimate.
s = sample standard deviation.
$Z_{æ}$ = Z-coefficient for the false-change (Type 1) error rate from the table below.
$Z_{ß}$ = Z-coefficient for the missed-change (Type II) error rate from the table below.

MDC = Minimum detectable change size. This needs to be specified in absolute terms rather than as a percentage. For example, if you wanted to detect a 20% change in the sample mean from one year to the next and your first year sample mean = 10 plants/quadrat then MDC = (0.20 x 10) = 2 plants/quadrat.

Table of standard normal deviates for $Z_{æ}$		Table of standard normal deviates for $Z_{ß}$		
False-change (Type I) error rate (æ)	$Z_{æ}$	Missed-change (Type II) error rate (ß)	Power	$Z_{ß}$
0.40	0.84	0.40	0.60	0.25
0.20	1.28	0.20	0.80	0.84
0.10	1.64	0.10	0.90	1.28
0.05	1.96	0.05	0.95	1.64
0.01	2.58	0.01	0.99	2.33

Example:

Management objective: Increase the dinsity of species F at Sity Y by 20% between 1999 and 2004.

Sampling objective: I want to be 90% certain of detecting a 20% in mean plant density and I am willing to accept a 10% chance that I will make a false-change error (conclude that a change took place when it really did not).

Results from pilot sampling:

Mean (x) = 25 plants/quadrat
Standard deviation (s) = 7 plants.

Given: The acceptable **False-change error rate (æ) = 0.10** so the appropriate $Z_{æ}$ from the table = 1.64.

The desired Power is 90% (0.90) so the **Missed-change error rate (ß) = 0.10** and the appropriate $Z_{ß}$, coefficient from the table = 1.28.

The **Minimum Detectable Change (*MDC*)** is 20% of the 1993 value or (.20)(25) = 5 plants/quadrat.

Calculate the estimated necessary sample size using the equation provided above:

$n = 2(s)^2(Z_{æ}+Z_{ß})^2 / (MDC)^2 \qquad n = 2(7)^2(1.64+1.28)^2 / (5)^2 = 33.5$

Round up 33.4 to 34 plots.

Final estimated sample size needed to be 90% confident of detecting a change of 5 plants between 1993 and 1994 with a false-change error rate of 0.10 = **34 quadrats**. The sample size correction table is not needed for estimating sample sizes for detecting differences between two population means.

Correction for sampling finite populations: The above formula assumes that the population is very large compared to the proportion of the population that is sampled. If you are sampling more than 5% of the whole population area then you should apply a correction to the sample size estimate that incorporates the finite population correction factor (FPC). This will reduce the sample size. The formula for correcting the sample size estimate is as follows:

$n' = n^* / (1+(n^*/N))$

Where:

n' = The new sample size based upon inclusion of the finite population correction factor.
n = The corrected sample size from the sample size correction table.
N = The total number of possible quadrat locations in the population. To calculate N, determine the total area of the population and divide by the size of the sampling unit.

Example:

If the pilot data described above was gathered using a 1m x 10m (10 m^2) quadrat and the total population being sampled was located within a 20m x 50m macroplot (1000 m^2) then N = $1000m^2/10m^2$ = 100. The corrected sample size would then be:

$n' = n^* / (1+(n^*/N))$ $n' = 34 / (1+(34/100)) = 25.3$

Round up 25.3 to 26.

The new, FPC-corrected estimated sample size needed to be 90% certain of detecting a change of 5 plants between 1993 and 1994 with a false-change error rate of 0.10 = **26 quadrats**.

Note on the statistical analysis for two sample tests from finite populations. If you have sampled more than 5% of an entire population then you should also apply the finite population correction factor to the results of the statistical test. This procedure involves dividing the test statistic by the square root of the finite population factor (1-n/N). For example, if your t-statistic from a particular test turned out to be 1.645 and you sampled n = 26 quadrats out of a total N=100 possible quadrats, then your correction procedure would look like the following:

$t' = t / \sqrt{1-(n/N)}$ $t' = 1.645 / \sqrt{1-(26/100)} = 1.912$

Where:

t = The t-statistic from a t-test.
t' = The corrected t-statistic using the FPC.
n = The sample size from the equation above.
N = The total number of possible quadrat locations in the population. To calculate N, determine the total area of the population and divide by the size of each individual sampling unit.

You would need to look up the *p*-value of *t'* = 1.912 in a t-table at the appropriate degrees of freedom to obtain the correct *p*-value for this statistical test.

SAMPLE SIZE EQUATION #3:

Determining the necessary sample size for detecting differences between two means when using paired or permanent sampling units.

When paired sampling units are being compared or when data from permanent quadrats are being compared between two time periods, then sample size determination requires a different procedure than if samples are independent of one another. The equation for determining the number of samples necessary to detect some "true" difference between two sample means is:

$n = (s)^2(Z_{æ}+Z_{ß})^2 / (MDC)^2$

Where:

> s = sample standard deviation.
> $Z_{æ}$ = Z-coefficient for the false-change (Type I) error rate from the table below.
> $Z_{ß}$ = Z-coefficient for the missed-change (Type II) error rate from the table below.
> *MDC* = Minimum detectable change size. This needs to be specified in absolute terms rather than as a percentage. For example, if you wanted to detect a 20% change in the sample mean from one year to the next and your first year sample mean = 10 plants/quadrat then MDC = (0.20 x 10) = 2 plants/quadrat.

Table of standard normal deviates for $Z_{æ}$		Table of standard normal deviates for $Z_{ß}$		
False-change (Type I) error rate (æ)	$Z_{æ}$	Missed-change (Type II) error rate (ß)	Power	$Z_{ß}$
0.40	0.84	0.40	0.60	0.25
0.20	1.28	0.20	0.80	0.84
0.10	1.64	0.10	0.90	1.28
0.05	1.96	0.05	0.95	1.64
0.01	2.58	0.01	0.99	2.33

If the objective is to track changes over time with permanent sampling units and only a single year of data is available, then you will not have a standard deviation of differences between the paired samples. If you have an estimate of the likely degree of correlation between the two years of data, and you assume that the among sampling units standard deviation is going to be the same in the second time period, then you can use the equation below to estimate the standard deviation of differences.

> $s_{diff} = (s_1)\left(\sqrt{2(1-corr_{diff})}\right)$

Where:

> s_{diff} = Estimated standard deviation of the differences between paired samples.
> s_1 = Sample standard deviation among sampling units at the first time period.
> $corr_{diff}$ = Correlation coefficient between sampling unit values in the first time period and sampling unit values in the second time period.

Example #1:

Management Objective: Achieve at least a 20% higher density of species F at Site Y in unburned areas compared to burned areas in 1999.

Sampling objective: I want to be able to detect a 90% difference in mean plant density in unburned areas and adjacent burned areas. I want to be 90% certain of detecting that difference, if it occurs, and I am willing to accept a 10% chance of detecting that difference, if it occurs, and I am willing to accept a 10% change that I will make a false-change error (conclude that a difference exists when it really did not).

Results from pilot sampling: Five paired quadrats were sampled where one member of the pair was excluded from burning and the other member of the pair was burned.

Quadrat number	# of plants/quadrat		Difference between burned and unburned	
	burned	unburned		
1	2	3	1	
2	5	8	3	
3	4	9	5	
4	7	12	5	
5	3	7	4	
	x =4.20 s =1.92	x =7.80 s =3.27		
Summary statistics for the differences between the two sets of quadrats			x =3.60	s =1.67

Given: The sampling objective specified a desired minimum detectable difference (i.e., equivalent to the MDC) of 20%. Taking the larger of the two mean values and multiplying by 20% leads to: (7.80) x (0.20) = **MDC = 1.56** plants quadrat.

The appropriate **standard deviation** to use is **1.67**, the standard deviation of the differences between the pairs.

The acceptable **False-change error rate (æ) = 0.10** so the appropriate $Z_{æ}$ from the table = 1.64.

The desired Power is 90% (0.90) so the **Missed-change error rate (ß) = 0.10** and the appropriate $Z_{ß}$ coefficient from the table = 1.28.

Calculate the estimated necessary sample size using the equation provided above:

$$n = (s)^2(Z_{æ}+Z_{ß})^2 / (MDC)^2 \quad n = (1.67)^2(1.64+1.28)^2 / (1.56)^2 = 9.7$$

Round up 9.7 to 10 plots.

Final estimated sample size needed to be 90% certain of detecting a true difference of 1.56

plants/quadrat between the burned and unburned quadrats with a false-change error rate of 0.10 = **10 quadrats**.

Example #2:

Management objective: Increase the density of species F at Site Q by 20% between 1999 and 2002.

Sampling objective: I want to be able to detect a 20% difference in mean plant density of species F at Site Q between 1999 and 2001. I want to be 90% certain of detecting that change, if it occurs, and I am willing to accept a 10% chance that I will make a false-change error (conclude that a difference exists when it really did not).

The procedure for determining the necessary sample size for this example would be very similar to the previous example. Just replace "burned" and "unburned" in the data table with "1999" and "2002" and the rest of the calculations would be the same. Because the sample size determination procedure needs the standard deviation of the difference between two samples, you will not have the necessary standard deviation term to plug into the equation until you have two years of data. The standard deviation of the difference can be estimated in the first year if some estimate of the correlation coefficient between sampling unit values in the first time period and the sampling unit values in the second time period is available (see the s_{diff} equation above).

Correction for sampling finite populations: The above formula assumes that the population is very large compared to the proportion of the population that is sampled. If you are sampling more than 5% of the whole population area then you should apply a correction to the sample size estimate that incorporates the finite population correction factor (FPC). This will reduce the sample size. The formula for correcting the sample size estimate is as follows:

$$n' = n^* / (1+(n^*/N))$$

Where:

n' = The new sample size based upon inclusion of the finite population correction factor.
n = The corrected sample size from the sample size correction table.
N = The total number of possible quadrat locations in the population. To calculate N, determine the total area of the population and divide by the size of the sampling unit.

Example:

If the pilot data described above was gathered using a 1m x 10m (10 m^2) quadrat and the total population being sampled was located within a 10m x 50m macroplot (500 m^2) then N = 500m^2/10m^2 = 50. The corrected sample size would then be:

$$n' = n^* / (1+(n^*/N)) \quad n' = 10 / (1+(10/500)) = 8.3$$

Round up 8.3 to 9.

The new, FPC-corrected estimated sample size needed to be 90% confident of detecting a true difference of 1.56 plants/quadrat between the burned and unburned quadrats with a false-change error rate of 0.10 = **9 quadrats**.

Note on the statistical analysis for two sample tests from finite populations. If you have sampled more than 5% of an entire population then you should also apply the finite population correction factor to the results of the statistical test. This procedure involves dividing the test statistic by the square root of (1-n/N). For example, if your t-statistic from a particular test turned out to be 1.782 and you sampled n=9 quadrats out of a total N=50 possible quadrats, then your correction procedure would look like the following:

$t' = t / \sqrt{1-(n/N)}$ $t' = 1.782 / \sqrt{1-(9/50)} = 1.968$

Where:

t = The t-statistic from a t-test.
t' = The corrected t-statistic using the FPC.
n = The sample size from the equation above.
N = The total number of possible quadrat locations in the population. To calculate N, determine the total area of the population and divide by the size of each individual sampling unit.

You would need to look up the *p*-value of *t*' = 1.968 in a t-table at the appropriate degrees of freedom to obtain the correct *p*-value for this statistical test.

SAMPLE SIZE EQUATION #4:

Determining the necessary sample size for estimating a single population proportion with a specified level of precision.

The equation for determining the sample size for estimating a single proportion is:

$n = (Z_{æ})^2(p)(q) / d^2$

Where:

n = Estimated necessary sample size.
$Z_{æ}$ = The coefficient from the table of standard normal deviates below.
p = The value of the proportion as a decimal percent (e.g., 0.45).
q = 1-*p*
d = The desired precision level expressed as half of the maximum acceptable confidence interval width. This is also expressed as a decimal percent (e.g., 0.15) and this represents an *absolute* rather than a *relative* value. For example, if your proportion value is 30% and you want a precision level of ± l0% this means you are targeting an interval width from 20% to 40%. Use 0.10 for the d-value and *not* 0.30 x 0.10 = 0.03.

Table of standard normal deviates ($Z_{æ}$) for various confidence levels

Confidence level	Alpha (æ) level	($Z_{æ}$)
80%	0.20	1.28
90%	0.10	1.64
95%	0.05	1.96
99%	0.01	2.58

Example:

Management objective: Maintain at least a 40% frequency (in 1m2 quadrats) of species Y in population Z over the next 5 years.

Sampling objective: Estimate percent frequency with 95% confidence intervals no wider than ± 10% of the estimated true value.

Results of pilot sampling: The proportion of quadrats with species *Z* is estimated to be *p* = 65% (0.65). Because *q* = (1-p), *q* = (1-.65) = 0.35.

Given: The desired **confidence level** is 95% so the appropriate $Z_{æ}$ from the table above = 1.96. The desired **confidence interval width (d)** is specified as 10% (0.10).

Using the equation provided above:

$$n = (Z_{æ})^2(p)(q) / d^2 \qquad n = (1.96)^2(0.65)(0.35) / 0.10^2 = 87.4$$

Round up 87.4 to 88.

The estimated sample size needed to be 95% confident that the estimate of the population percent frequency is within 10% (+/- 0.10) of the true percent frequency = 88 quadrats.

This sample size formula works well as long as the proportion is more than 0.20 and less than 0.80. If you suspect the population proportion is less than 0.20 or greater than 0.80, use 2.20 or 0.8, respectively, as a conservative estimate of the proportion.

Correction for sampling finite populations: The above formula assumes that the population is very large compared to the proportion of the population that is sampled. If you are sampling more than 5% of the whole population area then you should apply a correction to the sample size estimate that incorporates the finite population correction factor (FPC). This will reduce the sample size. The formula for correcting the sample size estimate is as follows:

$$n' = n^* / (1+(n^*/N))$$

Where:

n' = The new sample size based upon inclusion of the finite population correction factor.
n = The corrected sample size from the sample size correction table.
N = The total number of possible quadrat locations in the population. To calculate N, determine the total area of the population and divide by the size of the sampling unit.

Example:

If the pilot data described above was gathered using a 1m x 1m (1 m^2) quadrat and the total population being sampled was located within a 25m x 25m macroplot (625 m^2) then N = $625m^2/1m^2$ = 625. The corrected sample size would then be:

$n' = n^* / (1+(n^*/N))$ n' = 88 / (1+(88/625)) = 77.1

Round up 77.1 to 78.

The new, FPC-corrected, estimated sample size needed to be 95% confident that the estimate of the population percent frequency is within 10% (± 0.10) of the true percent frequency = 78 quadrats.

SAMPLE SIZE EQUATION #5:

Determining the necessary sample size for detecting differences between two proportions with temporary sampling units.

$$n = (Z_{æ}+Z_{ß})^2(p_1q_1+p_2q_2) / (p_2-p_1)$$

Where:

n = Estimated necessary sample size.
$Z_{æ}$ = Z-coefficient for the false-change (Type I) error rate from the table below.
$Z_{ß}$ = Z-coefficient for the missed-change (Type II) error rate from the table below.
p_1 = The value of the proportion for the first sample as a decimal (e.g., 0.65).
q_1 = 1 - p1.
p_2 = The value of the proportion for the second sample as a decimal (e.g., 0.45).
q_2 = 1 - p2.

Table of standard normal deviates for $Z_{æ}$		Table of standard normal deviates for $Z_{ß}$		
False-change (Type I) error rate (æ)	$Z_{æ}$	Missed-change (Type II) error rate (ß)	Power	$Z_{ß}$
0.40	0.84	0.40	0.60	0.25

0.20	1.28	0.20	0.80	0.84
0.10	1.64	0.10	0.90	1.28
0.05	1.96	0.05	0.95	1.64
0.01	2.58	0.01	0.99	2.33

Example:

Management objective: Decrease the frequency of invasive weed F at Site G by 20% between 1999 and 2001.

Sampling objective: I want to be 90% certain of detecting an absolute change of 20% frequency and I am willing to accept a l0% chance that I will make a false-change error (conclude that a change took place when it really did not).

Note that the magnitude of change for detecting change over time for proportion data is expressed in absolute terms rather than in relative terms (relative terms where used in earlier examples that dealt with sample means values). The reason absolute terms are used instead of relative terms relates to the type of data being gathered (percent frequency is already expressed as a relative measure). Think of taking your population area and dividing it into a grid where the size of each grid cell equals your quadrat size. When you estimate a percent frequency, you are estimating the proportion of these grid cells occupied by a particular species. If 45% of all the grid cells in the population are occupied by a particular species then you hope that your sample values will be close to 45%. If over time the population changes so that now 65% of all the grid cells are occupied, then the true percent frequency has changed from 45% to 65%, representing a 20% absolute change.

Results from pilot sampling: The proportion of quadrats with species Z in 1999 is estimated to be p_1 = 65% **(0.65)**.

Because $q_1 = (1-p_1)$, $q_1 = (1-.65) = 0.35$.

Because we are interested in detecting a 20% shift in percent frequency, we will assign $p_2 = 0.45$. This represents a shift of 20% frequency from 1999 to 2001. A decline was selected instead of an increase (e.g., from 65% frequency to 85% frequency) because sample size requirements are higher at the mid-range of frequency values (i.e., closer to 50%) than they are closer to 0 or 100. Sticking closer to the mid-range gives us a more conservative sample size estimate.

Because $q_1 = (1-q_2)$, $q_1 =(1-0.45) = 0.55$.

Given: The acceptable **False-change error rate (æ) = 0.10** so the appropriate $Z_{æ}$ from the table = 1.64.

The desired **Power is 90% (0.90)** so the **Missed-change error rate (p) = 0. 10** and the appropriate $Z_{ß}$ coefficient from the table = 1.28.

Using the equation provided above:

$$n = (Z_{æ}+Z_{ß})^2(p_1q_1+p_2q_2) / (p_2-p_1)$$

$n = (1.64+1.28)^2((0.65)(0.35)+(0.45)(0.55)) / (0.45-0.65)^2 = 101.3$

Round up 101.3 to 102.

The estimated sample size needed to be 90% sure of detecting a shift of 20% frequency with a starting frequency of 65% and a false-change error rate of 0.10 = 102 quadrats.

Correction for sampling finite populations: The above formula assumes that the population is very large compared to the proportion of the population that is sampled. If you are sampling more than 5% of the whole population area then you should apply a correction to the sample size estimate that incorporates the finite population correction factor (FPC). This will reduce the sample size. The formula for correcting the sample size estimate is as follows:

$n' = n^* / (1+(n^*/N))$

Where:

n' = The new sample size based upon inclusion of the finite population correction factor.
n = The corrected sample size from the sample size correction table.
N = The total number of possible quadrat locations in the population. To calculate N, determine the total area of the population and divide by the size of the sampling unit.

Example:

If the pilot data described above was gathered using a 1m x 1m ($1m^2$) quadrat and the total population being sampled was located within a 10m x 30m macroplot (300 m^2) then N = $300m^2/1m^2$ = 300. The corrected sample size would then be:

$n' = n^* / (1+(n^*/N))$ $n' = 102 / (1+(102/300)) = 76.1$

Round up 76.1 to 77.

The new, FPC-corrected estimated sample size needed to be 90% sure of detecting an absolute shift of 20% frequency with a starting frequency of 65% and a false-change error rate o 0.10 - **77 quadrats**.

Note on the statistical analysis for two sample tests from finite populations. If you have sampled more than 50% of an entire population then you should also apply the finite population correction factor to the results of the statistical test. For proportioning data this procedure involves dividing the test statistic by (1-n.N). For example, if your X^2 -statistic from a particular test turned out to be 2.706 and you sampled n-77 quadrats out of a total N=300 possible quadrats, then your correction procedure would look like the following:

$X^{2'} = X^2 / 1-(n/N)$ $X^{2'} = 2.706 / 1-(77/300) = 3.640$

Where:

X^2 = The X^2 - statistic from a X^2 - statistic -test.
$X^{2'}$ = The corrected X^2 - statistic using the FPC.
n = The sample size from the equation above.
N = The total number of possible quadrat location in the population. To calculate N,

determine the total area of the population and divide by the size of each individual sampling unit.

You would need to look up the *p*-value of $X^{2'}$ = 3.640 in a X^2 -table for the appropriate degrees of freedom to obtain the corrected *p*-value for this statistical test.

Sample Size Correction Table for Single Parameter Estimates

Sample size correction table for adjusting "point-in-time" parameter estimates. n = the uncorrected sample size value from the sample size equation. n* = the corrected sample size value. This table was created using the algorithm reported by Kupper and Haffier (1989) for a one-sample tolerance probability of 0.90. For more information consult Kupper, L.L. and K.B. Hafner. 1989. How appropriate are popular sample size formulas? The American Statistician (43):101-105.

80% Confidence Level						90% Confidence Level						95% Confidence Level						99% Confidence Level					
n	n*	n	n*	n	n*	n	n*	n	n*	n	n*	n	n*	n	n*	n	n*	n	n*	n	n*	n	n*
1	5	51	65	101	120	1	5	51	65	101	120	1	5	51	66	101	121	1	6	51	67	101	122
2	6	52	66	102	121	2	6	52	66	102	122	2	7	52	67	102	122	2	8	52	68	102	123
3	7	53	67	103	122	3	8	53	67	103	123	3	8	53	68	103	123	3	9	53	69	103	124
4	9	54	68	104	123	4	9	54	69	104	124	4	10	54	69	104	124	4	11	54	70	104	125
5	10	55	69	105	124	5	11	55	70	105	125	5	11	55	70	105	125	5	12	55	72	105	126
6	11	56	70	106	125	6	12	56	71	106	126	6	12	56	71	106	126	6	14	56	73	106	128
7	13	57	71	107	126	7	13	57	72	107	127	7	14	57	72	107	128	7	15	57	74	107	129
8	14	58	73	108	128	8	15	58	73	108	128	8	15	58	74	108	129	8	16	58	75	108	130
9	15	59	74	109	129	9	16	59	74	109	129	9	16	59	75	109	130	9	18	59	76	109	131
10	17	60	75	110	130	10	17	60	75	110	130	10	18	60	76	110	131	10	19	60	77	110	132
11	18	61	76	111	131	11	18	61	76	111	131	11	19	61	77	111	132	11	20	61	78	111	133
12	19	62	77	112	132	12	20	62	78	112	132	12	20	62	78	112	133	12	22	62	79	112	134
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17	25	67	83	117	137	17	26	67	83	117	137	17	26	67	84	117	138	17	28	67	85	117	140
18	27	68	84	118	138	18	27	68	84	118	138	18	28	68	85	118	139	18	29	68	86	118	141
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21	30	71	87	121	142	21	31	71	88	121	142	21	31	71	88	121	143	21	32	71	89	121	144
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23	33	73	89	123	144	23	33	73	90	123	144	23	34	73	90	123	145	23	35	73	92	123	146

24	34	74	90	124	145	24	34	74	91	124	145	24	35	74	91	124	146	24	36	74	93	124	147
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32	43	82	99	132	154	32	44	82	100	132	154	32	44	82	100	132	155	32	45	82	101	132	156
33	44	83	100	133	155	33	45	83	101	133	155	33	45	83	101	133	156	33	46	83	103	133	157
34	45	84	101	134	156	34	46	84	102	134	156	34	46	84	102	134	157	34	48	84	104	134	158
35	47	85	102	135	157	35	47	85	103	135	157	35	48	85	103	135	158	35	49	85	105	135	159
36	48	86	104	136	158	36	48	86	104	136	158	36	49	86	104	136	159	36	50	86	106	136	160
37	49	87	105	137	159	37	49	87	105	137	159	37	50	87	105	137	160	37	51	87	107	137	161
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41	53	91	109	141	163	41	54	91	110	141	164	41	54	91	110	141	164	41	56	91	111	141	166
42	55	92	110	142	164	42	55	92	111	142	165	42	56	92	111	142	165	42	57	92	112	142	167
43	56	93	111	143	165	43	56	93	112	143	166	43	57	93	112	143	166	43	58	93	114	143	168
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48	61	98	117	148	171	48	62	98	117	148	171	48	62	98	118	148	172	48	64	98	119	148	173
49	62	99	118	149	172	49	63	99	118	149	172	49	63	99	119	149	173	49	65	99	120	149	174
50	64	100	119	150	173	50	64	100	119	150	173	50	65	100	120	150	174	50	66	100	121	150	175

ACCURACY, BIAS, AND PRECISION

Criteria by which estimators are judged are accuracy, bias, and precision. Accuracy is defined as "exact conformity to truth," or "freedom from error." It is virtually impossible to determine accuracy because the true value being estimated with sampling and measurement methods is rarely known; thus, the investigator must carefully design his sampling program and use certain statistical tools to evaluate his data before making any inferences from his data.

Bias is error introduced into sampling that causes estimates of parameters to be inaccurate. If a sampling experiment were repeated many times and each time an estimate computed, the average of these estimates will be near the value of the parameters if bias is small. Bias can be introduced into estimates if sample sites are not randomly selected or from systematic errors during measurement. For example, measurements would be biased if the meter were incorrectly calibrated, and length measurements would be biased if the tape were not tightly stretched.

Precision is the repeatability of measurements. Poor, sloppy techniques can cause low precision. Vague reference points and variables also make precision difficult to achieve.

Target shooting is an analogy often used to illustrate the concepts of accuracy, bias, and precision. The bulls eye is the true population parameter the investigator is attempting to estimate with his sampling, which is shown by the shot pattern on the target. An unbiased, precise pattern is tightly clustered around the bullseye. A precise but biased pattern is still tightly clustered but is not near the true value, or bullseye. An unbiased but imprecise pattern is spread out around the bullseye; and an unbiased, imprecise pattern not only is spread out but also the center is not near the bullseye.

U.S. Fish & Wildlife Service

Fuel and Fire Effects Monitoring Guide

Fire Works!

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WHAT'S NEW

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Populations

COMPLETING MONITORING AND REPORTING RESULTS

A successful monitoring project is characterized by two traits. First, it is implemented as planned in spite of personnel changes, changes in funding, and changes in priorities. Successful implementation depends on good design and good communication and documentation over the life of the project. Second, the information from a successful monitoring program is applied, resulting in management changes or validation of existing management. A monitoring project that simply provides additional insights into the natural history of a species, or that languishes in a file read only by the specialist, does not meet the intent of monitoring. Successful application of monitoring results requires reporting them in a form accessible to all interested parties.

Monitoring projects that are implemented and applied will complete the adaptive management cycle. Successful monitoring affects management, either by suggesting a change or validating the continuation of current management.

1. Assessing results at the end of the pilot period Pilot studies are advocated to avoid the expense and waste of a monitoring project that yields inconclusive results. After the pilot period you should consider several issues before continuing the monitoring project:

A. **Can the monitoring design be implemented as planned?** The pilot period should answer several questions about field design and implementation: If sampling units are permanent, can they be relocated? Are sampling units reasonably sized for the number of plants or do quadrats contain hundreds of individuals? Is it difficult to accurately position a tape because of dense growth? Are the investigator impacts from monitoring acceptable? Is the skill level of field personnel adequate for the field work, or is additional training needed?

Projects rarely work as smoothly in the field as anticipated in the office.

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CREDITS

Nearly all monitoring projects require some modification for effective field implementation. Occasionally you may find that the planned method does not work at all, and a major overhaul of the monitoring project is required.

B. **Are the costs of monitoring within estimates?** The pilot period is important as a reality check on required resources: Does the monitoring take much longer than planned? Will the data entry, analysis, and reporting work take more time than allocated?

If the monitoring project as designed requires more resources than originally planned, either management must devote more resources to the project, or you will need to redesign the monitoring to be within budget.

C. **Do the assumptions of the ecological model still seem valid?** Your understanding of the biology and ecology of a species may improve as you spend time on the site collecting data. Does new information suggest another vegetation attribute would be more sensitive or easier to measure (cover instead of density, for example)? Is the change you've targeted to monitor biologically significant, or is the natural annual variability due to weather conditions so extreme that it masks the target change? Does the frequency of monitoring still seem appropriate?

D. **For sampling situations, does the monitoring meet the standards for precision and power that were set in the sampling objective?** After analyzing the pilot data, you may discover that you need many more sampling units than you planned to achieve the standards for precision, confidence, and power that you set in your sampling objective. You have six alternatives:

(1) Reconsider the design. The pilot study should improve your understanding of the population's spatial distribution. Will a different quadrat shape or size improve the efficiency and allow you to meet the sampling objective within the resources available for monitoring?

(2) Re-assess the scale. Consider sampling only one or a few macroplots, rather than sampling the entire plant population.

(3) Lobby for additional resources to be devoted to this monitoring project. Power curves may help to graphically illustrate the tradeoffs of precision, power, and sampling costs for managers.

(4) Accept lower precision. It may be prohibitively expensive, for

example, to be 90% confident of being within 10% of the estimated true mean, but it may be possible to be 90% confident of being within 20% of the true mean using available monitoring resources.

(5) Accept higher error rates. You may not, with the current design and expenditure of monitoring resources, be 90% certain of detecting a specified change, but you may be 80% certain. You may have to accept a 20% chance that you will make a false-change error, rather than the 10% level you set in your sampling objective. You may not be within I0% of the estimated true mean with a 95% confidence level, but your current design may allow you to be 90% confident. Look at the results from your pilot study, and consider whether the significance levels that can be achieved with the current design are acceptable, even though the levels may be less stringent than you originally set in your sampling objective.

(6) Start over. Acknowledge that you cannot monitor the sampling objective with reasonable precision or power within the budgetary constraints of the project.

D. **Reporting results from a pilot project** The results from the pilot period should be reported even if your design and project require significant revision. Your audiences for this report would include all those who reviewed your initial project proposal or monitoring plan. A report to managers is especially important to describe the recommended changes in design. Your report is also important to your successor and possibly other ecologists, botanists or biologists who work with similar situations or species. Reporting failures of techniques will help others avoid similar mistakes.

2. Assessing results after the pilot period

Three possible conclusions result from a monitoring study: (1) objectives are (being) met; (2) objectives are not (being) met; (3) the data are inconclusive. The pilot period should eliminate the problem of inconclusive results caused by poor design, but such results can occur even with excellent design.

A. **Objectives are met** Two management responses should result for objectives that have been met. First, the objective should be reevaluated and changed based on any new knowledge about a species and population. Second, both management and monitoring should be continued, although the latter perhaps less frequently or intensely.

It is important that monitoring does not cease when objectives have been met. Measured success may not be related to management, but simply a lucky correlation of an increasing population size or condition with the management period, caused by unknown factors. Fluctuations in population size caused by weather can give the appearance of success, especially with short-lived species. You should never assume that the resource is secured for the long-term. You may scale back the frequency and intensity of monitoring in a population that appears stable or increasing, but do not consider the job done and ignore the population or species permanently. Current management may in fact be detrimental, but its negative effects masked by fluctuations related to weather. In addition, site conditions change (i.e., weeds invade, native ungulate populations increase, livestock use patterns change with the construction of a fence or water trough, recreational pressure increases, etc.). All these things and more may pose new threats.

B. **Objectives are not met** According to the adaptive management approach, failure to meet an objective should result in the change in management that was identified as the management response during the objective development phase. Rarely, however, is resource management that simple. We need to remember that the inertia that resists changing management is very difficult to overcome. Managers will generally continue implementing existing management, the path of least resistance, unless monitoring or some other overriding reason clearly indicates a change.

Unfortunately, the data from most monitoring will not conclusively identify causes of failure to meet objectives or the corresponding corrective action. The biologist monitoring the population may feel confident of the cause, but decision-makers may be uncomfortable making changes in management, especially unpopular ones, which have a basis only in the biologist's professional opinion.

Thus, the most common response in land management agencies is to first reevaluate the objective. Was the amount of change too optimistic and biologically unlikely? Was the rate of change too optimistic? While such assessment is necessary, it can result in changing the objective rather than implementing necessary management changes.

This scenario is extremely common, but may often be avoided by two techniques. The first is to articulate the management response along with the management objective. This clearly states the response to monitoring results before monitoring is even started. It represents a commitment by the agency to stand by its monitoring results and use them to adapt management. The second technique is to reach consensus among all interested parties concerning the monitoring and the management response before monitoring data are collected.

3. Reporting results and recommending changes

A. **Periodic summaries** You should analyze results of monitoring each year (or each year data are collected) and report them in a short summary. Analyzing data as soon as they are collected has several important benefits. The most important is that analysis is completed while the field work is still fresh in your mind. Questions always arise during analysis, and the sooner analysis takes place after the field work the more likely you can answer those questions. You may also find after analysis that you would like supplementary information, but it may not be possible to collect this in the middle of the winter, or five years after the monitoring data were collected. You will have lost a valuable opportunity. Analysis after each data collection episode also means that you will assess the monitoring approach periodically. Although many problems will surface during the pilot period, some may not until after a few years of data collection. Periodic assessment insures a long-term monitoring project against problems of inadequate precision and power, and problems of interpretation.

B. **Final monitoring reports** At the end of the specified monitoring period, or when objectives are reached, you should summarize the results in a formal monitoring report (Box 1). Much of the information needed for the report can be lifted directly from the monitoring plan, although deviations from the proposed approach and the reasons for them will need to be described. The final report should be a complete document so it can function as a communication tool, so you should include all pertinent elements from the monitoring plan. You can either cut and paste electronically from the monitoring report, or simply append the report to existing copies of the monitoring plan. The preparation of the report should not be a major task. If you've been completing annual data analysis and internal reporting (as you should), summarizing the entire monitoring project should be straightforward.

Completing the monitoring project with a final formal report is important. This report provides a complete document that describes the monitoring and its results for distribution to interested parties. It provides a complete summary of the monitoring activity for successors, avoiding needless repetition or misunderstanding of the work of the predecessor. Finally, a professional summary lends credibility to the recommended management changes by presenting all of the evidence in a single document.

Suggested monitoring report format:

- Introduction.
- Description of ecological model.
- Management objective.
- Monitoring design.
- Data sheet example.
- Management implications of potential results.
- Summary of results: Include tables and figures communicating the results as well as general natural history observations.
- Interpretation of results. Describe potential causes for the results observed, sources of uncertainty in the data, and implications of the results for the resource.
- Assessment of the monitoring project. Describe time and resource requirements, efficiency of the methods, and suggestions for improvement.
- Management recommendations.
    - Change in management. Recommended changes based on results and the management implications.
    - Change in monitoring. Analysis of costs vs. information gain, effectiveness of current monitoring system, and recommended changes in monitoring.
- References. Includes gray literature and personal communications.
- Reviewers. List those who have reviewed drafts of the report.

C. **Reporting results-other vehicles** If the results would be interesting to others, consider sharing those results through a technical paper or symposium proceedings. Much of the preparation work for a presentation has already been done with the completion of the monitoring plan and monitoring report documents. Sharing the results has three important benefits: (1) it increases the audience, possibly helping more people and improving other monitoring projects (similar problems, similar species, etc.); (2) it increases the professional credibility of the agency; and (3) it contributes to your professional growth.

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U.S. Fish & Wildlife Service

Fuel and Fire Effects Monitoring Guide

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Reporting Results

MONITORING ATTRIBUTES

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Plant Mortality
Frequency
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Wildlife Populations
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Populations

FUEL INVENTORY

1. Introduction

This section describes procedures for inventorying weight of forest floor duff, forest floor litter, herbaceous vegetation, shrubs, small conifers, and downed woody material. The procedures furnish estimates for live and dead vegetation by diameter classes. The inventory methods have application to several facets of forest and range management and to research investigations.

The procedures were initially developed to provide estimates of fuel loading (weight per unit area) as part of an effort to appraise fire behavior potential for planning fire, strategies in wilderness areas. Although the methodology emphasizes forest fuels, estimates of above ground biomass of herbaceous vegetation, shrubs, and small conifers may be useful for purposes other than fuel appraisal. The procedures were used by numerous field crews for several years. This experience aided considerably in developing the step-by-step procedures reported here.

The inventory procedures are useful for determining biomass of any vegetation up to about 10 ft (3 m) in height. The entire set of procedures or a part of them can be applied to estimate all or any one of the vegetative components.

The procedures apply most accurately in the Interior West. The techniques for estimating biomass of herbaceous vegetation, litter, and downed woody material, however, apply anywhere. The shrub techniques apply most accurately to shrubs in the Northern Rocky Mountains. Considering sampling efficiency as attainment of desired precision by the most practical means, the most efficient methods of sampling vegetation vary by plant species and purpose. Different techniques are required to most efficiently sample all vegetation. Thus, the single set of procedures assembled here may not be the most efficient for some situations. Nevertheless, the procedures are

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appropriate for sampling each category of vegetation and can be widely applied with a minimum of training and experience.

The inventory procedures specify sampling of branch and stemwood under 3 inches in diameter by diameter classes of 0 to 0.25 inches (O to 0.6 cm), 0.26 to 1.0 inches (0.6 to 2.5 cm), and 1.0 to 3.0 inches (2.5 to 7.6 cm). The size classes correspond in increasing size to 1-, 10-, and 100-hour average moisture timelag classes for many woody materials. The size classes are used as moisture timelag standards in the U.S. National Fire-Danger Rating System. A moisture timelag is the amount of time for a substance to lose or gain approximately two-thirds of the moisture above or below its equilibrium moisture content. Appraisal of forest fuels is greatly facilitated when data on biomass are assimilated by these size classes.

Fuel depth was originally included in the procedures but was removed because interpretation of fuel depth was complex and required trained people to evaluate the reasonableness of depth observations. Although Albini (1975) developed an algorithm that was largely successful in processing fuel depth data for input to Rothermel's fire spread model, spurious depth measurements coupled with the fact that fire behavior predictions were highly sensitive to depth, continued to cause erratic predictions. In predicting fire behavior using Rothermel's model, depth together with loading is required to determine fuel bulk density. Recent research indicates that characterization of bulk density for understory vegetation and fuel groups may eliminate the need for measurement of fuel depth in inventorying fuel for practical applications.

To assure reasonable fire behavior predictions, inventoried fuel loadings should be interpreted by fire behavior modeling specialists for proper input to Rothermel's model. Estimates of certain fuel components such as downed woody material and duff can be used without interpretation in operating Albini's (1976) burnout model. This model is incorporated in a computer program called HAZARD, which appraises slash fuels. As the technology in fire behavior modeling grows, other direct applications of fuel inventory may arise.

2. Procedures

The procedures in this section are an assembly of sampling techniques that provide estimates of the following variables:

- Biomass and fuel loading on an ovendry basis of:
    - Downed woody material
    - Forest floor litter and duff
    - Herbaceous vegetation
    - Shrubs
    - Conifers less than 10 ft (2 m) in height.
- Depth of duff and height of shrubs and small trees.
- Percentage cover of herbaceous vegetation and shrubs.
- Percentage of dead in herbaceous vegetation and shrubs.
- Percentage cover of forest floor litter.
- Number of small trees per acre by species.
- Stand age.

In addition, provision is made for recording and summarizing slope, elevation, aspect, cover type, and habitat type. The field procedures involve counting shrub and small tree stems and intersected pieces of downed woody material; measuring diameters, depth, and height of vegetation; ocularly estimating percentage of cover and percentage of dead vegetation; and extracting increment cores for determining tree age. All the procedures may be followed to furnish estimates of all vegetation, or a subset of the procedures may be used to furnish an estimate of any single variable such as duff depth or shrub biomass.

These procedures permit estimation of total biomass and fuel loading of forest floor and under-story vegetation. The estimates are appropriate for intensive land management and studies involving biomass and forest fuels.

3. Cost

For an average amount of vegetation, about 15 minutes per sample point are required to complete measurements. Counting shrubs and clipping herbaceous vegetation and litter require the most time.

4. Deciding When to Sample

The time of year when vegetation, especially grasses and forbs, is sampled has a large influence on results. Grasses and forbs may not be fully developed during late spring or early summer. Sampling at that time will result in low estimates. During late summer, some annuals may have cured and deteriorated to such an extent that their biomass cannot be accurately estimated. The time of year when sampling is done must agree with the purpose of inventory. For appraising fuels, sampling during the normal fire season, such as late July and August in the western United States, is recommended. For comparing fuel loading, sampling during the same time of year is required.

5. Study Design

Fuel inventory techniques can be incorporated into a general inventory study design or a specific fuel inventory study design can be used.

6. Choice of Techniques

An efficient inventory of all fuel and understory vegetation requires several techniques because of the varied physical attributes of vegetation. Forest vegetation is comprised of living and dead plants, both standing and downed. Plants range in size from small grasses and forbs to large shrubs and trees. Pieces of vegetation considered as fuel particles range in size from small leaves, needles, and twigs to large branches and tree boles. Vegetation and fuels having similar physical characteristics, which can be appropriately sampled using the same technique, can be grouped as follows:

- Standing trees - Tree counts
- Shrubs - Stem counts
- Herbaceous vegetation (grasses and forbs) - Relative-weight estimate
- Forest floor litter (01 horizon) - Relative-weight estimate
- Forest floor duff (02 horizon) - Depth measurement
- Downed woody material - Planar intersect

7. Credit

Procedures taken from: Brown, J. K., R. D. Oberheu, and C. M. Johnston. 1982. Handbook for inventorying surface fuels and biomass in the Interior West. USDA Forest Service General Technical Report INT-129, 48p.

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FUEL MONITORING SAMPLING DESIGN

1. Number of Sample Points

For any area where estimates are desired, at least 15 to 20 sample points should be located. This sampling intensity will often yield estimates having standard errors within 20 percent of the mean estimates. Areas larger than approximately 50 acres containing a high diversity in amount and distribution of fuel and vegetation, should be sampled with more than 20 points to achieve standard errors within 20 percent of mean estimates.

Changing the size of plots also influences the desired number of sample points. For sampling downed woody material, these procedures accommodate a variable length sampling plane. Choose sampling plane lengths from the following tabulation:

Downed Material	Diameter of Debris (inches)		
	0-1	1-3	>3
	Sampling plane (feet)		
Nonslash (naturally fallen material)	6	10-12	35-50
Discontinuous light slash	6	10-12	35-50
Continuos heavy slash	3	6	15-25

If material larger than 3 inches (7.6 cm) in diameter is scanty or unevenly distributed, the longer sampling planes in the tabulation should be used.

For fuel and vegetation other than downed woody material, plot sizes could be changed.

The amount and distribution of vegetation, especially downed woody material, varies greatly among and within stands. Thus, these sampling recommendations should be considered approximate because a greater or fewer number of sample points may be required to furnish adequate precision for any given area.

Number of sample points can be calculated for any chosen percent error from:

$n = (cv / \text{percent error})^2$

Where:
n = number of samples
cv = (standard deviation / mean) * 100
percent error = (standard error of mean / mean) * 100

This figure applies to loadings ranging from light to heavy. Cover types appeared to slightly influence coefficients of variation. For example, for a given percent error, fewer sample points are required to estimate litter in ponderosa pine and Douglas-fir than in the grand fir and spruce-fir types. This seems reasonable because litter is more uniform in ponderosa pine and Douglas-fir stands. For the most part, however, differences among cover types provided little guidance on sampling intensities. Advance knowledge about the uniformity of fuels should be more useful in deciding upon sampling intensities the covertype. Coefficients of variation for shrubs vary considerably from stand to stand.

2. Locating Sample Points

After determining sampling area, such as a stand, delineate or describe its boundaries. Definition of the area and its boundaries should satisfy a sampling design based on a clear objective for the sampling. Sample points may be systematically or randomly located; however, systematic placement is usually the most practical. Two methods are:

A. Locate plots at a fixed interval along transects that lace regularly across a sample area (uniform sampling grid). For example, on a sample area, mark off parallel transects that are 5 to 10 chains (100 to 200 m) apart. Then, along the transects, locate plots at 1- to 5-chain (20- to 100-m) intervals.

B. Locate plots at a fixed interval along a transect that runs diagonally through the sample area. To minimize bias, have the transect cross areas where changes in fuels or biomass are suspected. Before entering the sample area, determine a transect azimuth and distance between plots. Distance between plots can be paced by foot or sampling rod. If variations in biomass across an area are obvious and significant, it may be desirable to divide the area into recognizable strata and sample each stratum separately.

Hints for conducting fieldwork:

1. Steep slopes and heavy brush will slow procedures from 5 to 10 minutes per sample point. Keep this in mind when laying out the day's work.
2. In bogs and moist areas, it can be difficult to distinguish the division between duff and mineral soil. It may be desirable to establish a lower limit as 12 inches. Below this, duff should not be measured.
3. Before going to the field, label bags for collecting herbs and litter.
4. Keep herb and litter samples in porous containers to prevent mildew. If the weather permits, hang samples where they can air-dry.
5. Approach sample point centers cautiously to avoid disturbing vegetation. At each point, lay out the sampling plane and subplots before doing any sampling. This will minimize disturbance of vegetation to be sampled.
6. In areas with abundant herbaceous vegetation, take larger bags for collecting samples.
7. Fill out the forms in pencil with dark lead. Mistakes can be easily erased.
8. Take care to enter data and label sacks clearly. Make sure all the recording is completed in the field at each plot while it is still fresh in your mind.

3. Plot Layout

The plot layout at a sample point consists of a randomly positioned line transect for downed woody material and duff, a 1/300-acre plot for trees, two 1/4-milacre plots for shrubs, and four

0.98 by 1.97-ft (30 by 60-cm) plots for herbaceous material and litter .

Downed woody material, litter, herbaceous vegetation, shrubs, and small trees are measured on plots laid out parallel to the slope. Thus, calculations of loading on a horizontal acre basis require slope correction. Duff depth is measured vertically so that slope adjustment is unnecessary for calculating loading.

A. Mark the sampling point With a chaining pin (No. 9 wire or similar item). Avoid disturbing material around the point so that measurements can be accurately made.

B. Randomly determine direction of the sampling plane in one of two ways:

(1) Toss a die to indicate one of six 30º angles between 0º and 150º. The 0º heading is the direction of travel. Turn a fixed direction, such as clockwise, to position the sampling plane.

(2) Orient the sampling plane in the direction indicated by the second hand of a watch at a given instant. To avoid bias in placement of the sampling plane, do not look at the fuel or ground while turning the interval.

C. Denote position of sampling plane by placing a 6.8-ft inventory rod (diameter of 1/300-acre plot) out from the chaining pin parallel to the ground in the direction determined in 2. A 50-foot tape is used along this same line to measure large pieces. The tape and rod fix the position of vertical sampling planes.

D. Next, locate four relative estimate subplots and two 1/4-milacre shrub plots on the ground. Mark the two shrub plots with chaining pins or similar devices. They are located 90º to the sampling plane. Place the relative estimate frames parallel to the slope, and maintain this position when collecting samples. Similarly, count shrub stems from plots delineated parallel to the slope.

Some vegetation could be sampled by more than one technique. To avoid double sampling of any component, definitions of vegetation to be sampled by each technique must be consistently and closely followed.

4. Measurements

After the subplots and line transects have been established on the ground, begin recording general information at the top of the inventory form.

A. General Information:

(1) Date

(2) Identify stands and plots by consecutive number. Stand numbers can be placed on a field map for referencing locations (e.g., stand No. 1, plots numbered 1-10; stand No. 2, plots numbered 11-20).

(3) Determine topographic slope in percent. A Relaskop, Abney, or a clinometer is useful for measuring slope.

(4) Using a compass, record aspect of the area near the sample point in degrees.

(5) Determine elevation by an altimeter or from reading a contour map. If an altimeter is used, calibrate it daily to a known elevation.

(6) Determine stand age by extracting increment cores from three or four dominant or codominant trees in the stand. Take the cores at d.b.h. on the uphill side of the tree. Average the ages and enter the average on the form. Age needs to be recorded on only one plot per stand.

(7) Cover type is used to determine duff loading. For proper duff calculations, record the cover type that most resembles one of the following species categories:

Cover type is most like	Code
Long-needled pine	PP
Intermediate-needled conifer	LP
Other conifers that typically occur in mixed pine-fir types	DF
Predominantly short-needled conifers (except true fir, spruce, and hemlock) code	Any other code

(8) Record habitat type using a 3-digit code. (The habitat type system developed by Pfister and others (1977) is appropriate here)

(9) Estimate or measure the slope of the planar intersect sampling plane by sighting along the transect pole or tape previously positioned on the ground. Record this as a percentage.

(10) Record the transect lengths. (Refer to the discussion on sampling plane lengths.) Note on the inventory form that sampling plane lengths for 0- to 1-inch (0- to 2.5-cm) and 1- to 3-inch (2.5- to 7.6-cm) material require a decimal place.

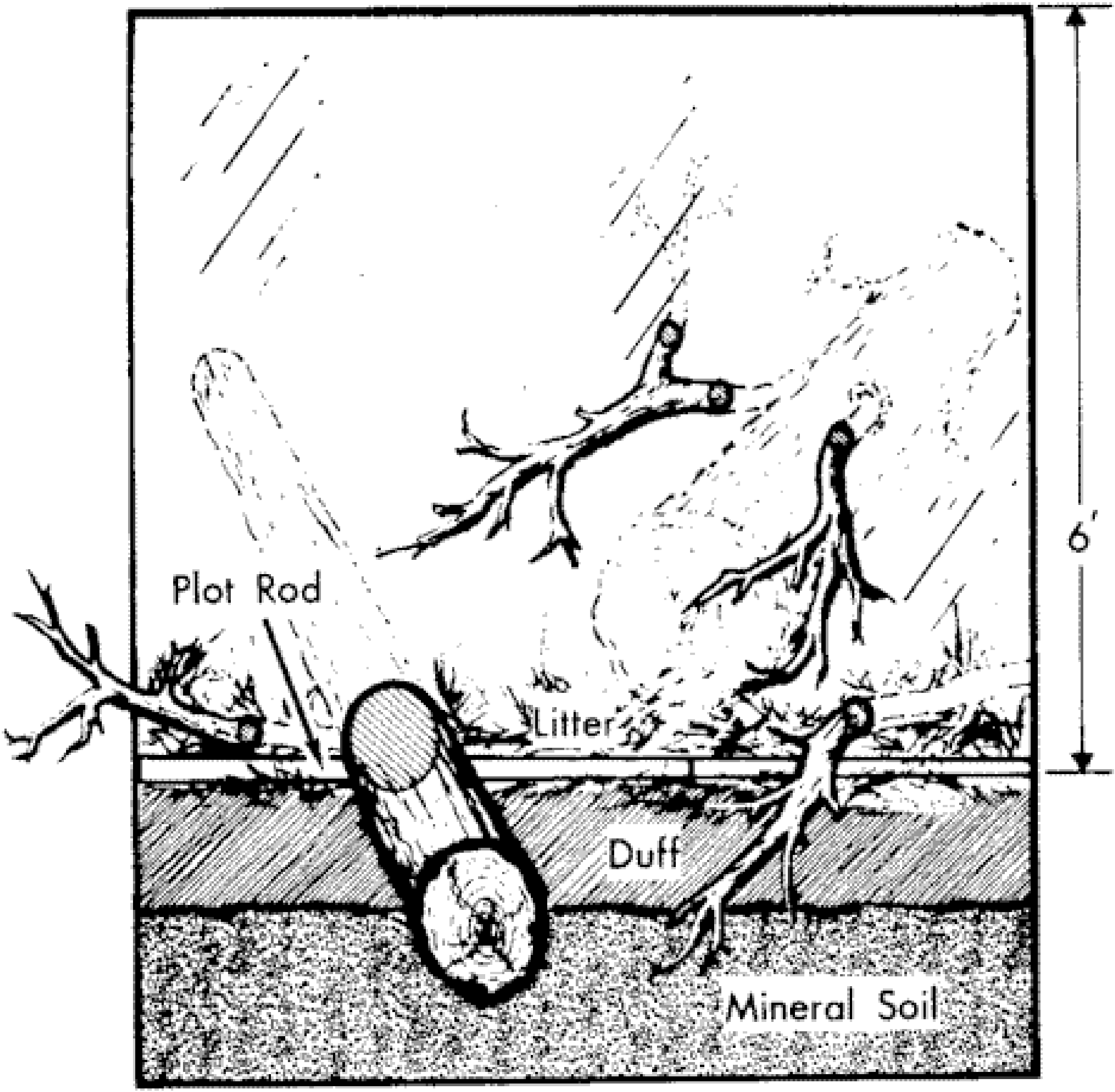
B. Specific Inventory Procedures

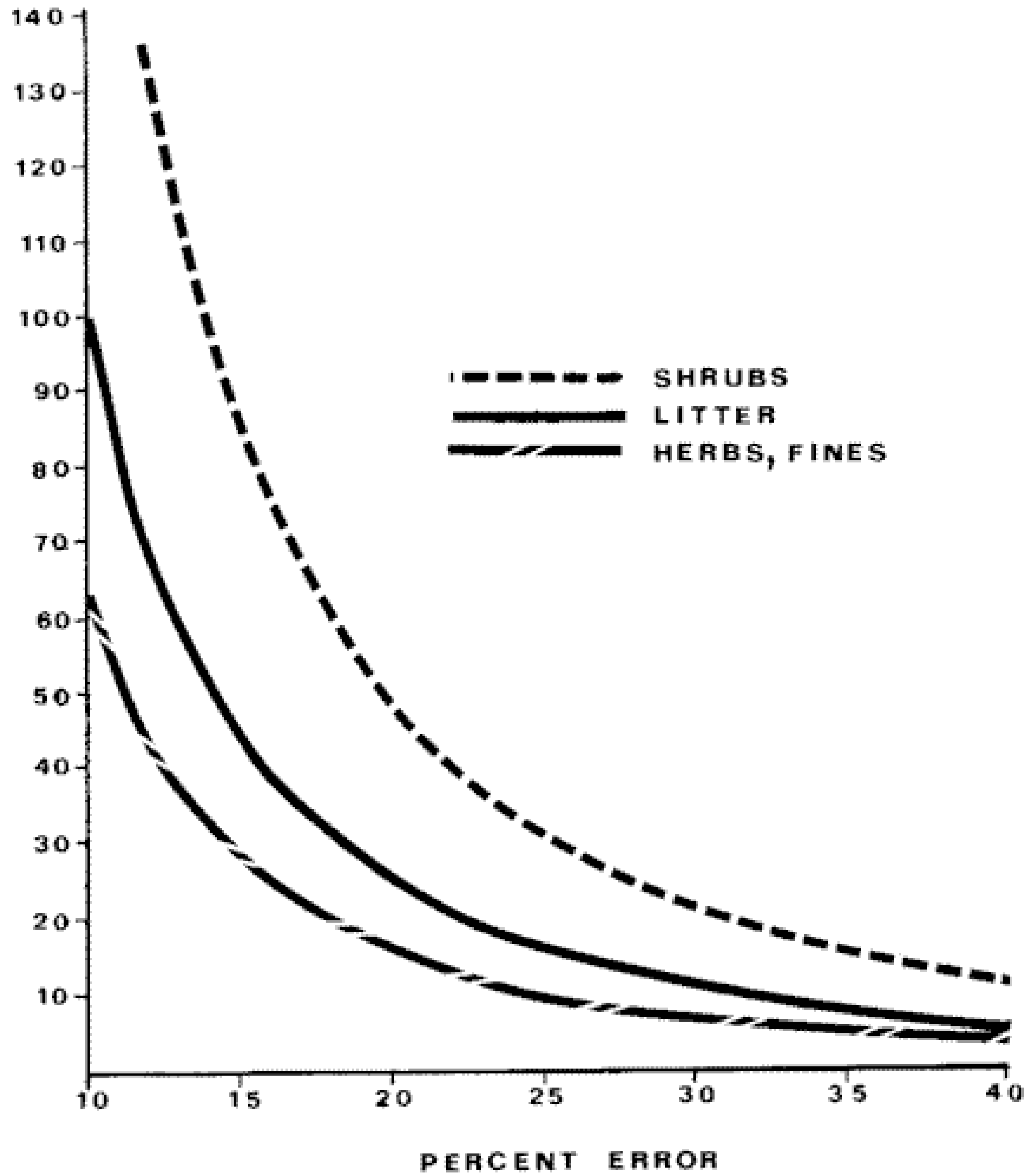
1. Downed Woody Material
2. Duff Depth
3. Herbaceous Vegetation and Litter

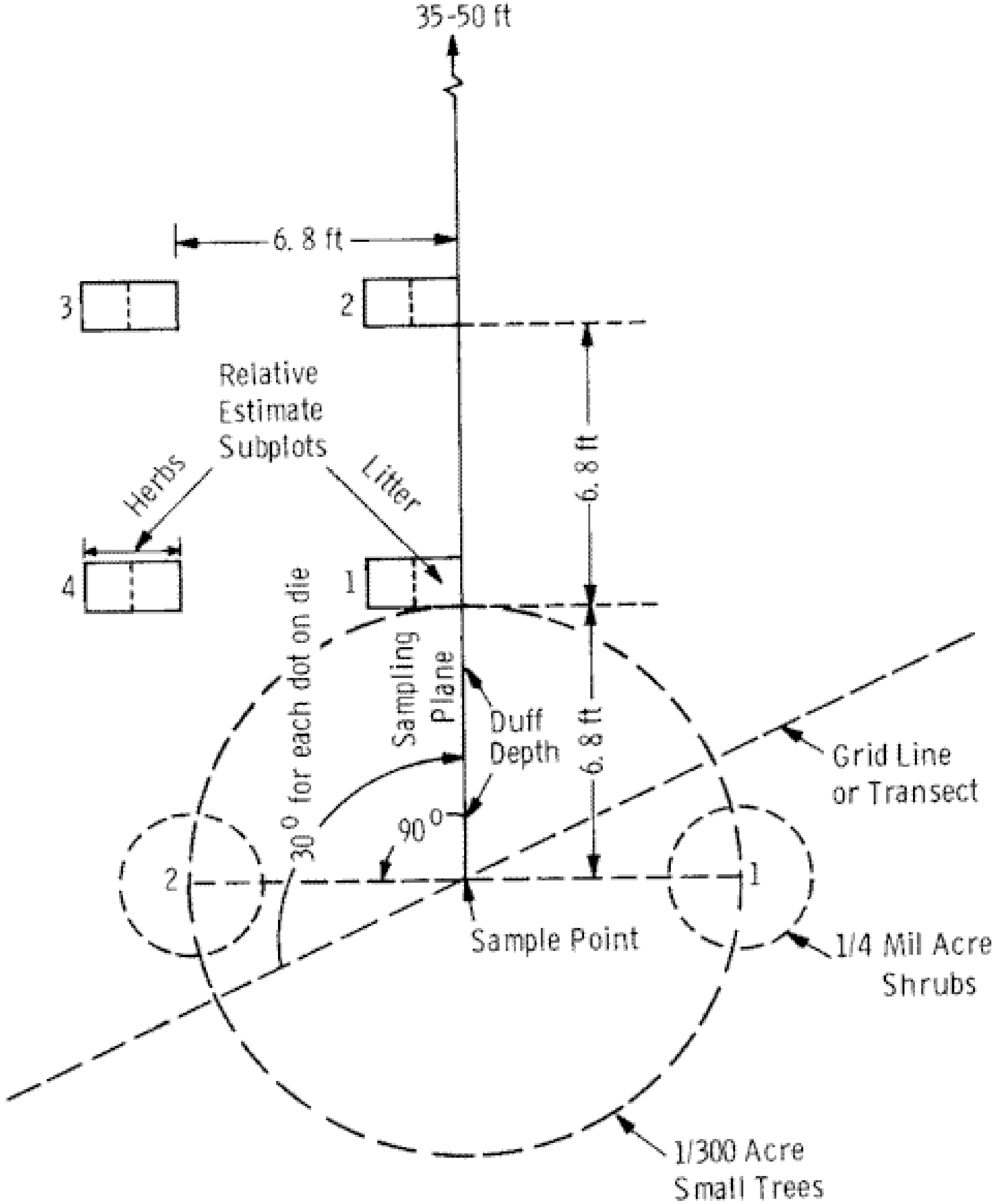
5.   Field Equipment

Item	Use

6.8-ft plot rod marked in 1-ft intervals (fiberglass rod, bamboo, or aluminum tubing works well)	Plot and transect layout, measure small tree and shrub heights
1-ft ruler or steel pocket tape	Measure duff depth and diameter of intersected pieces
Go/no-go gage (can be cut from 1/16-1/8-in sheet aluminum) or small caliper	Determine 1/4-, 1-, and 3-in diameter of downed woody pieces and 0.2, 0.3, 0.6, 0.8, 1.2, and 2 in basal stem diameters of shrubs
1.86-ft plot rode marked in 1-in increments (wood dowel works well)	Shrub plat layout; measure height of small trees and shrubs
Five chaining pins	Mark plot locations
Four 0/96- by 1.97- ft (inside measurement) subplot frames (Four pieces of 1/4-in square aluminum rods, loosely riveted at three corners, allows frame to be placed through and under vegetation. A solid frame is difficult to place without bias.)	Sample herbaceous vegetation and litter
Hand compass	Measure aspect. Locate sample points
Relaskop, Abney, or clinometer	Measure slope
Altimeter	Measure elevation
Increment borer	Determine tree age
50-ft tape (reel up cloth or fiberglass works best)	Delineate sampling plane
Gaming die or watch with second hand	Orient sampling plane
Paper bags (size 10 to 12) and rubber bands	Collect herb and litter samples
Grass clippers	Clip subplots
Clipboard, forms, maps, and pencils	Record data
Pack., map tube	Cary equipment. Map tube keeps small rods and subplot frames together.


6'
Plot Rod
Litter
Duff
Mineral Soil


140
130
120
110
100
90
80
70
60
50
40
30
20
10
SHRUBS
LITTER
HERBS, FINES
10
15
20
25
30
35
40
PERCENT ERROR


35-50 ft
6. 8 ft
3
2
Relative
Estimate
Subplots
Herbs
Litter
6. 8 ft
4
1
30° for each dot on die
Sampling
Plane
Duff
Depth
6. 8 ft
Grid Line
or Transect
90°
2
1
Sample Point
1/4 Mil Acre
Shrubs
1/300 Acre
Small Trees

INVENTORY FORM

CREW :

CARD 1

DATE		STAND NO.		PLOT NO.		TERRAIN SLOPE		ASPECT	
ELEV.		STAND AGE		COVER TYPE		H. T.		PLANER SLOPE	

TRANSECT LENGTHS				NO. INTERSECTIONS < 3 IN						TRAN. LENGTH	
0-1 IN		1-3 IN		0- ½ IN		½ - 1 IN		1-3 IN		> 3 IN	

DIAMETER INTERSECTIONS 3 IN										
SOUND										

CARD 2

ROTTEN										

DUFF DEPTH (IN)	HERBS				LITTER	
	%STAND	% DEAD	% COV.	BASE WT.	% STAND	BASE WT.

SHRUBS		
% COV.	% DEAD	AVE. HT. (IN)

CARD 3

PLOT		SPECIES		NO. STEMS BY DIAMETER CLASS (CM)												
				0- 0.5		0.5-1		1-1.5		1.5-2		2-3		3-5		5+

PERCENT CODES

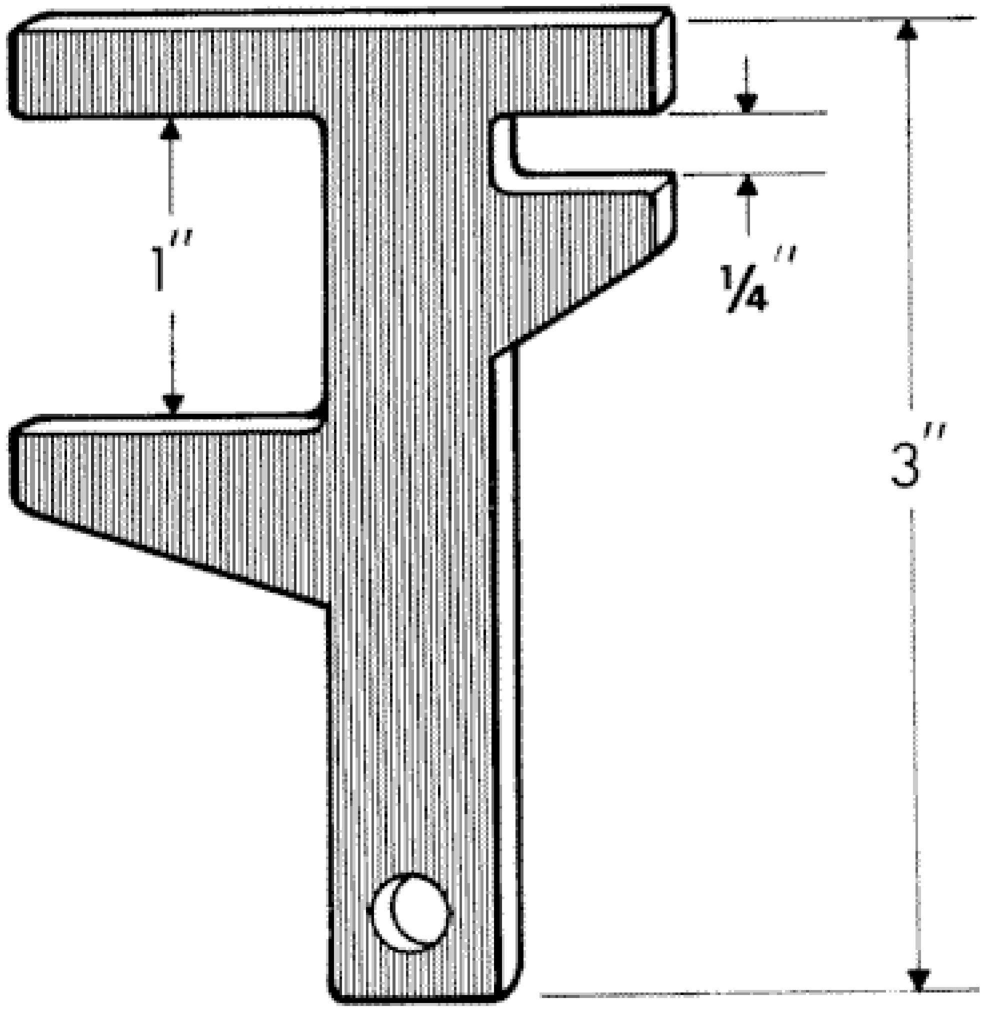
1 = 0- 5%
2 = 6- 20
3 = 21- 40
4 = 41- 60
5 = 61- 80
6 = 81- 95
7 = 96- 100%

CARD 4

CARD 5

CARD 6

SMALL TREE COUNT														
SP.	NO.	HT.	SP.	NO.	HT.	SP.	NO.	HT.	SP.	NO.	HT.	SP.	NO.	HT.


1"
¼"
3"

STANDING TREES
Weight-height Relationship

---

1. Introduction

A method for estimating biomass of conifers less than 10 ft (3 m) in height was included because small trees can contribute significantly to propagation of both surface and crown fires. The method requires measurement of number of trees per acre by species and height. Biomass of foliage and branchwood by size class is calculated from weight and height relationships.

Biomass of trees over 2 inches (5 cm) d.b.h. can be estimated from biomass tables or from tree volume estimates converted to weight using wood densities. To determine volumes from tree volume tables, estimates of the number of trees per acre or basal area per acre by d.b.h. and species required to access the tables can be determined from commonly used plot and plotless sampling methods. Procedures for inventorying trees greater than 10 ft (3 m) in height are not included here because they are commonly understood and used in forestry. If desired, they can be readily applied along with the procedures for surface vegetation.

2. Applicability

Estimates of biomass for trees less than 10 ft (3 m) in height are based on data from western Montana and northern Idaho for Engelmann spruce, western hemlock, western white pine, whitebark pine, ponderosa pine, todgepole pine, grand fir, western redcedar, western larch, Douglas-fir, and subalpine fir. Equating a species not listed to one of the above may provide reasonable estimates of biomass.

3. Procedure

Delineate the plot by swinging the 6.8-ft rod about the sample point pin and parallel to the slope. Within the 1/300-acre plot, count the number of trees less than 10 ft (3 m) in height by species. Record the number of trees within each species and average their height to the nearest 0.5 ft. To avoid the potential of a substantial bias, however, do not average heights differing by more than 5 ft. If trees of the same species differ by more than 5 ft in height, record them separately on the data form. If more than five species are identified, consolidate similar species. Tally only individual trees that have survived one growing season, are free to grow, have good coloration, and have root systems in mineral soil.

Record the species, number, and height on the data form.

4. Calculations

Small tree loading can be computed by summing the weights of individual trees. The simplest approach is to firest construct a table showing the total number of sample trees per stand by species and 1-ft height increments. Loasing for each species can then be calculated by:

$tl = 300\ \hat{E}\ N_h * W_h / N$

where:
tl = tree loading
Ê = sum for all height classes recorded
N_h = total number sampled trees by height class per stand
W_h = weight per tree by height class (lb)
i = index for height classes

The 300 in the equasion expands the 1/300-ac plot estimates to a per-acre basis. If other plot sizes are used, the 300 should be repolaced with appropriate expansion factors.

Weight (lb) Per Tree of Aboveground Foliage, Bark, and Wood by 1-ft Tree Height Increments

	Height (ft)									
Species	1	2	3	4	5	6	7	8	9	10
Ponderosa Pine, Douglas fir, Subalpine fir, Engelmann spruce	0.03	0.20	0.56	1.18	2.09	3.33	4.94	6.95	9.39	12.30
Western white pine, Grand fire, Whitebark or limber pine	0.06	0.25	0.61	1.15	1.87	2.78	3.88	5.19	6.71	8.43
Western redcedar, Lodgepole pine, Western larch	0.02	0.13	0.34	0.69	1.17	1.82	2.64	3.65	4.84	6.24
Western hemlock	0.01	0.05	0.16	0.35	0.64	1.05	1.60	2.31	3.18	4.24

SHRUBS
Stem Diameter Correlation

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1. Introduction

Shrub biomass can be estimated nondestructively by one of two basic methods. High correlation between stem diameters and weights of various shrub parts have been reported (Lyon 1970; Buckman 1966; Whittaker 1965). This approach requires a tally of number of stems by stem diameter on plots of known size. Another method relies on the relationships between biomass, canopy area, and canopy volume as described for semidesert shrubs in New Mexico (Ludwig and others 1975), sagebrush (*Artemisia tridentata*) (Rittenhouse and Sneva 1977), and low shrubs in California (Bently and others 1970). This method requires measurements of crown diameters and shrub height.

The method involving measurement of stem diameters has the advantage of applying easily to tall shrubs compared to the method of measuring crown dimensions. Measurement of stem diameters probably permits the most accurate estimation of biomass because stem diameters should relate more directly to biomass than does space occupied by shrubs. A disadvantage of measuring stem diameters is that fieldwork can involve considerable time, especially for small shrubs comprised of many stems such as grouse whortleberry (*Vaccinium scoparium*). The fieldwork can be minimized by recording diameters by size classes. The method requiring measurement of crown dimensions is rapid and well suited to small- and medium-size shrubs. The method involving measurement of stem diameters was incorporated in these procedures because it applies to shrubs of all sizes, and relationships for estimating biomass of leaves and stemwood by diameter class were available for 25 species (Brown 1976).

2. Applicability

Biomass estimates are based on data from shrubs in western Montana and northern Idaho. The weight relationships for low, medium, and high shrubs may be used to estimate biomass of any species. Accuracy of these relationships outside of the Northern Rocky Mountains is unknown.

3. Procedure

A. Shrubs are tallied on the two 1/4-milacre subplots (fig. 2). Using a 1.86-ft (57-cm) rod (radius of 1/4-milacre plot), swing around the subplot center parallel to the ground and note the species that occur. Within each subplot, ocularly estimate percent cover of all shrubs together, both live and dead, according to the established percentage classes.

B. Ocularly estimate the percentage of shrub biomass that is dead according to the established percentage classes.

C. Measure the height of shrubs within each subplot from the forest floor to what appears as the average top. Record to the nearest whole inch.

D. On each subplot, count the number of stems by species and the following basal diameter classes:

- 0 to 0.2 inch (O to 0.5 cm)
- 0.2 to 0.4 inch (0.5 to 1.0 cm)
- 0.4 to 0.6 inch (1.0 to 1.5 cm)
- 0.6 to 0.8 inch (1.5 to 2.0 cm)
- 0.8 to 1.2 inches (2.0 to 3.0 cm)
- 1.2 to 2.0 inches (3.0 to 5.0 cm)
- Over 2.0 inches (5.0 cm)

Determine basal diameters above the root crown or above the swelling of the root crown, which is usually within 1 or 2 inches above the top of the litter. A go/no-go gage or calipers is helpful for checking diameters. The basal diameter classes are identified on the data form in centimeter units because they can be visualized more easily than inches for estimating shrub diameters.

Record species. If a sampled species is not in the list, record it as a low, medium, or high shrub, depending on the group it most resembles.

4. Calculations

Shrub loading is calculated by summing the weights of individual stems by species

$sl = 8.8185 * Ê\ c_i(s_k w_k)_{ij}/(2N)$

where
sl = shrub loading
Ê = sum of sample plots, shrub subplots, basal diameter classes
c = topographic slope correction
s = number of stems per basal diameter class
w = weight per stem of foliage and wood by basal diameter class (g)
j = index for shrub subplots
k = index for basal diameter classes
N = number of plots

Dead shrub weight is calculated by multiplying the fraction dead on each subplot by estimated weight per subplot.

$sl = 8.8185 * Ê\ c_i * D_{ij}(s_k w_k)_{ij}/(2N)$

where
sl = shrub loading
Ê = sum of sample plots, shrub subplots, basal diameter classes
c = topographic slope correction
s = number of stems per basal diameter class
w = weight per stem of foliage and wood by basal diameter class (g)
j = index for shrub subplots
k = index for basal diameter classes

N = number of plots

Total Aboveground Weight of Shrubs by Basal Diameter Classes (g)

Species	Stem basal diameter (cm)						
	0-0.5	0.5-1.0	1.0-1.5	1.5-2.0	2-3	3-5	5-6
Low Shrubs							
Snowberry	2.8	17.0	54.6	118.0	226	-	-
Blue huckleberry	1.0	12.0	59.8	173.0	531	-	-
Goose whortleberry	2.2	12.1	36.3	74.8	161	-	-
Wild rose	1.9	16.9	70.0	178.0	480	-	-
Gosseberry	1.7	20.0	98.4	281.0	856	-	-
White spirea	2.2	17.4	65.7	158.0	399	-	-
Oregon grape	2.0	10.7	31.3	63.2	133	-	-
Thimbleberry	2.1	15.5	56.6	133.0	328	-	-
Red raspberry	2.0	19.3	83.3	218.0	605	-	-
Combined species	2.0	16.4	64.1	157.0	407	-	-
Medium shrubs							
Ninebark	3.9	19.9	74.1	176.0	442	1150	-
Smooth menziesia	1.2	8.7	43.6	126.0	387	1240	-
Utah honeysuckle	2.9	18.5	83.8	226.0	650	1940	-
Oceanspray	2.7	18.1	85.3	237.0	698	2140	-
Evergreen ceanothus	2.9	17.3	74.1	193.0	533	1530	-
Mock orange	2.6	17.2	78.6	218.0	636	1930	-
Russet buffaloberry	3.6	16.5	56.5	127.0	300	730	-
Big sagebrush	3.0	12.4	38.9	82.7	184	422	871

Common juniper	7.9	31.3	96.8	203.0	445	1010	-
Combined species	2.6	15.8	67.8	177.0	490	1410	-
High shrubs							
Serviceberry	3.4	16.1	70.2	185.0	519	1510	3840
Mountain maple	4.0	17.2	70.0	177.0	417	1310	3180
Mountain ash	2.5	11.5	50.2	132.0	370	1070	2720
Mountain alder	4.5	16.7	58.8	135.0	325	809	1790
Redosier dogwood	4.8	18.9	70.5	168.0	420	1090	2500
Willow	2.8	12.3	50.4	128.0	342	950	2320
Chokecherry	2.7	12.9	57.4	153.0	434	1280	3290
Combined species	3.6	15.4	60.9	151.0	394	1070	2560

HERBACEOUS VEGETATION AND LITTER
Relative Weight Estimate

1. Introduction

An extensive body of literature exists on estimating weight and production of range vegetation. Techniques for estimating weight basically fall into three categories: (1) clipping and weighing, (2) estimation, and (3) a combination of weighing and estimation.

To aid in extensive surveys, a quick, easy-to-use method is needed for estimating weight. Studies in pasture grasses and annual range species gave reasonably high correlation between weight per unit area, and ground cover and height. Similar investigation of grasses, forbs, and small woody plants in forest areas showed that as more plant sizes and shapes are included in plots, poorer accuracy can be expected. Unless relationships of suitable accuracy are known for specific sites, some clipping and weighing is desirable for estimating herbaceous vegetation.

The weight-estimate method has been widely used and tested in the southern and western United States in a variety of vegetation including large and small grasses and understory vegetation. It requires an estimate of actual weights and can be effectively used with double sampling on clipped and weighed plots. Trained observers can estimate within 10 percent of actual weights. When used with double sampling, variance of estimates can be reduced. This method, coupled with double sampling, has proved very useful in estimating forest floor litter and herbaceous fuels for research purposes.

Another similar technique, the relative-weight estimate method has been useful in estimating fuels. This method is based on the assumption that it is easier to compare weights than estimate weights. It involves identifying a base plot having the most weight from a set of four or five plots. The weight on the other plots is estimated as a fraction of the base plot. The base plot is then clipped and weighted and weights on other plots calculated as a fraction of the base plot.

The relative weight-estimate method was incorporated in these procedures because it is easy to use, requires a minimum of training, and is based on some clipping and weighing. The advantages and disadvantages of this method include:

2. Advantages

1. Requires little training or experience to learn the method; remembering weight images is minimal.
2. Checking weight estimates against actual weights is unnecessary.
3. Estimates are not affected by changes in light and moisture content as can happen with the weight-estimate technique.
4. Quantities of vegetation can be rated on a relative basis more easily than they can be actually estimated.

3. Disadvantages

1. The set of plots must all be readily visible to the observer to permit accurate comparisons.
2. Clipping and bagging on one out of every four or five plots is necessary.
3. Accuracy of the method has had little study.
4. Probably not as accurate as weight-estimate method used by trained and experienced observers.

4. Applicability

Average diameters of size classes less than 3 inches (7.6 cm) are based on an average of major western tree species. The estimates of this material are robust and should be reasonably accurate in coniferous forests. No limitations are built into the technique for material greater than 3 inches (7.6 cm) in diameter.

The litter and herbaceous vegetation relative estimate technique has no geographic restrictions.

5. Procedure

A. View all four subplots and judge which one has the greatest weight of herbaceous plants, bot live and dead. The subplot picked with the greatest weight is the standard subplot and is recorded as an 8. Rate the amount herbaceous plants on the remaining three subplots as a percentage of that on the standard subplot using the following codes:

Percent	Code
0-5	1
6-20	2
21-40	3
41-60	4
61-80	5
81-95	6
96-100	7

B. For each individual subplot, ocularly estimate the percentage of herbaceous vegetation that is dead. Use the established percentage code.

C. Ocularly estimate, in percentage, cover of herbaceous vegetation on subplots 1 and 2. (Percentage of cover is the percentage of subplot area covered by a vertical projection of herbaceous material.) Record cover using the established codes.

D. View the right half of all four subplots and judge which one has the greatest quantity of litter. Occasional probing of the litter may help in judging quantities. Be sure to examine only material qualifying as litter. See table 2 for material to be included as litter. Record the standard litter subplot with an 8. Rate the quantity of litter on the remaining three subplots as a percent of that on the standard subplot. Be sure to view only the right half of each subplot. Use the established codes.

E. Clip the herbaceous vegetation from the herb standard subplot and place in a paper bag. Collect litter from the litter standard subplot (right half only) and place in a paper bag. Label bags with date, stand number, plot number, and litter or herb. The samples should be ovendried at 95º C for a period of 24 hours. Record the ovendry weights, labeled as base weights on the inventory form, to the nearest 0.01 gram. Gunnysacks work well for transporting and storing samples. Airtight containers, such as plastic sacks, may promote decay.

6. Calculations

A. **Litter loading**

$$ll = 24.78 * Ê\ c_i*w_i*(1+P_2+P_3+P_4)_i\ /N$$

where:
ll = Litter loading
Ê = sum of sample plots from 1 to N
N = number of sample plots
c = topographic slope correction
w = weight on standard plot (g)
P = fraction of weight on standard plot for individual subplots
i = index of sample plots

B. **Herbaceous vegetation loading**

(1) Herbaceous vegetation loading is calculated as:

$$hl = 12.39 * Ê\ c_i*w_i*(1+P_2+P_3+P_4)_i\ /N$$

(2) To calculate the amount of dead herbaceous vegetation, the fraction of weight on the standard plot is multiplied by the fraction dead:

$$hl = 12.39 * Ê\ c_i*w_i*(D+P_2*D_2+P_3*D_3+P_4*D_4)_i\ /N$$

where:
hl = Herbaceous loading
Ê = sum of sample plots from 1 to N
N = number of sample plots
c = topographic slope correction
w = weight on standard plot (g)
D = fraction of dead on individual subplots
P = fraction of weight on standard plot for individual subplots
i = index of sample plots

Use the midpoints of the established percentage classes for factions in the calculations.

The slope correction may be handled differently depending on the amount of slope and its variability. If slope is less than about 40 percent, the correction is 8 percent and, for practical purposes, could be ignored.

If the slope in a stand is steep and uniform, the slope correction factor can be multiplied times the average stand loading rather than times the loading at each sampling point.

DUFF
Depth

1. Introduction

Sampling the forest floor litter separately from the duff is desirable because the litter is usually much less dense than the duff and frequently burns independently of the duff. The most accurate method of estimating forest floor weights is by collecting and weighing samples. This necessitates a cumbersome field procedure involving transport of soil containers and eventual ovendrying. Attempts to correlate stand characteristics and forest floor weights and depths have not always been successful. For example, forest floor weights in red pine plantations (Dieterich 1963) and ponderosa pine stands (Ffolliott and others 1968) were highly correlated with tree basal area. On the other hand, relationships between forest floor weights and basal area, site index, and stand age were insignificant in natural stands of red pine and jack pine (Brown 1966), and poorly correlated in eastern white pine (Mader and Lull 1968). In an extensive study of southwestern ponderosa pine and mixed conifers, Sackett (1979) found a lack of reliable relationships for predicting forest floor quantities from basal area or duff depth. Factors such as fire history, decay rates, and storms can strongly influence forest floor quantities. Thus, high correlations between forest floor quantities and basal area, site index, and stand age appear to have a limited basis-low correlations should not be surprising. The relationship between depth and weight of duff can be used to estimate weight recognizing that accuracy can be low. Measurement of duff depth was adopted for these procedures because:

1. Collecting and weighting duff would be impractical for large inventories.

2. The literature on duff bulk density seemed substantial enough to use in estimating weight from depth.

3. Depth is easily measured and can be a useful measurement itself for planning and evaluating prescribed fires conducted for fuel reduction and site preparation.

The following bulk densities were obtained from the literature.

Cover type	Bulk density (lb/ft^3)
Ponderosa pine, Douglas-fir, Shrubfields, Grand fir	5
Lodgepole pine	8
Others	10

Because the bulk densities used to calculate duff weights are approximations, the weights are approximations and must be interpreted accordingly. If desired, bulk densities other than those above can be used to calculate duff loadings as described in the section on calculations. For comparing change in litter and duff fuel, the actual depth is more applicable than weights.

Litter depth was not adopted as a basis for estimating litter weight because the literature on bulk density of litter was scant. More important, perhaps, is that considerable judgment is required to identify the top of litter. This problem is serious because the litter layer is often very thin and large errors in depth measurement could result. The relative weight-estimate technique was chosen for litter because it applies readily to litter and was also being used for herbaceous vegetation.

2. Applicability

Estimates of depth apply without geographic limitations. However, the duff bulk densities used to determine loading are based on a small amount of data from western coniferous forests. Although the loading estimates are probably applicable throughout coniferous forests in the United States and perhaps elsewhere, they should be viewed as crude approximations.

3. Procedure

Measure depth of duff to the nearest 0.1 inch, using a ruler held vertically at two points along the sampling plane: (1) 1 ft (0.3 m) from the sample point; and (2) a fixed distance of 3 to 5 ft (1 to 1.5 m) from the first measurement.

Duff is the fermentation and humus layers on the forest floor. It does not include the freshly cast material in the litter layer. The top of the duff is where needles, leaves, and other castoff vegetative material have noticeably begun to decompose. Often the color of duff differs from the litter above. Individual particles usually will be bound by fungal mycelium. When moss is present, the top of the duff is just below the green portion of the moss. The bottom of the duff is mineral soil.

Carefully expose a profile of the forest floor for the measurement. A knife or hatchet helps but is not essential. Avoid compacting or loosening the duff where the depth is measured. Measure duff depth after sampling the downed woody material to avoid disturbing the downed woody material along the sampling plane.

When stumps, logs, and trees occur at the point of measurement, offset 1 ft (0.3 m) perpendicular to the right side of the sampling plane. Measure through rotten logs whose central axis is in the duff layer.

> Yes= center of log is in duff layer or below.
> No= center of log is above duff layer.

4. Calculations

Duff loading is calculated as

dl = 3,630 * B *d

where
dl = duff loading
B = bulk density (lb/ft^3)
d = average duff depth for a stand (in)

DOWNED WOOD MATERIAL
Planar Intersect

Downed woody material is the dead twigs, branches, stems, and boles of trees and shrubs that have fallen and lie on or above the ground. Loadings of downed woody material vary considerably among stands due primarily to site productivity and stand history.

Collecting and weighing downed woody material is impractical in most forest stands. The planar intersect technique adopted here is nondestructive and avoids the time-consuming and costly task of collecting and weighing large quantities of downed woody material. It has the same theoretical basis as the line intersect technique. The planar intersect technique involves counting intersections of woody pieces with vertical sampling planes that resemble guillotines dropped through the downed debris. Volume is estimated; then weight is calculated from volume by applying estimates of specific gravity of woody material.

1. General Description To facilitate fuels monitoring, procedures for inventorying downed woody material are presented. Instructions show how to estimate weights and volumes of downed woody material, fuel depth, and duff depth. Using the planar intersect technique, downed material is inventoried by 0- to 0. 25-inch, 0. 25- to 1-inch, and I- to 3-inch diameter classes; and by 1-inch classes for sound and rotten pieces over 3 inches. The method is rapid and easy to use and can be applied to naturally fallen debris and to slash. The method involves counting downed woody pieces that intersect vertical sampling planes and measuring the diameters of pieces larger than 3 inches in diameter. The piece counts and diameters permit calculation of tons per acre.

2. Area of Use The inventory can be done to provide all or any part of the following information:

A. Weights and volumes per acre of downed woody material for:

(1) Diameter size classes of 0 to 0.25, 0.25 to 1. and 1 to 3 inches; and

(2) Diameters of 3 inches and larger for solid and rotten conditions.

B. Average diameter of debris larger than 3 inches.

C. Depth of fuel and forest floor duff.

3. Advantages and Limitations This method applies most accurately in the western United States because it contains average particle diameters for western conifers; however, the procedures are appropriate for forests everywhere. The inventory procedures are rapid and easy to use.

The inventory of volumes and weights is based on the planar intersect technique, which has the same theoretical basis as the line intersect technique. The planar intersect technique involves counting intersections of woody pieces with vertical sampling planes that resemble guillotines dropped through the downed debris. Volume is estimated; then weight is calculated from volume by applying estimates of specific gravity of woody material. The planar intersect technique is nondestructive and avoids the time-consuming, costly, and often impractical task of collecting and weighing large quantities of forest debris.

Woody pieces less than 3 inches in diameter are tallied by size classes. Pieces 3 inches arid larger are recorded by their diameters. Size classes of 0 to 0.25, 0.25 to 1, and 1 to 3 inches were chosen for tallying intersections because:

A. The class intervals provides the most resolution for fine fuels and are small enough to permit precise estimates of volume.

B. They correspond, in increasing size, to 1-, 10-, 100-hour average moisture-timelag classes for many woody materials and are the standard moisture timelags used in the National Fire-Danger Rating System.

Inventory chosen areas as follows:

4. Equipment

A. Study Location and Documentation Data form
B. Fuel Inventory Form
C. Hammer
D. Permanent yellow or orange spray paint
E. Two stakes: 3/4 - or 1 -inch angle iron not less than 16 inches long.
F. Two tapes: 100- or 200-foot, delineated in tenths and hundredths, or a metric tape of the desired length
G. Compass
H. Steel post and driver

5. Training A minimum of training is needed to make sure the examiners understand how to lay out baselines and transects and how to make the measurements. The examiner must also be able to identify the difference between sound and rotten woody debris. One-half hour training and 1 day of practice to obtain consistency is adequate.

6. Establishing Studies Careful establishment of studies is a critical element in obtaining meaningful data.

A. **Site Selection** The most important factor in obtaining usable data is selecting representative areas (critical or key areas) in which to run the study. Study sites should be located within a single plant community within a single ecological site. Transects and sampling points need to be randomly located within the critical or key areas.

B. **Pilot Studies** Collect data on several pilot studies to determine the number of samples (transects or observation points) and the number and size of quadrats needed to collect a statistically valid sample.

C. **Number and Length of Transects** Establish the minimum number of transects to achieve the desired level of precision for the key species in each study site. Choose sampling plane lengths from the following tabulation:

Downed Material	Diameter of Debris (inches)		
	0-1	1-3	>3
	Sampling plane (feet)		
Nonslash (naturally fallen material)	6	10-12	35-50
Discontinuous light slash	6	10-12	35-50
Continuous heavy slash	3	6	15-25

For any area where estimates are desired, 15 to 20 sample points should be located using the sampling plane lengths shown above. This sampling intensity will often yield estimates having standard errors within 20 percent of the mean estimates. Areas larger than approximately 50 acres that contain a high diversity in amount and distribution of downed material should be sampled with more than 20 points. If material larger than 3 inches in diameter is scanty or unevenly distributed, the longer sampling planes in the tabulation should be used.

The amount and distribution of downed woody material vary greatly among and within stands. Thus, these sampling recommendations should be considered approximate because a greater or fewer number of plots may be required to furnish adequate precision for any given area. Sampling intensities are discussed further in Fuel Monitoring Sampling Design.

D. **Study Layout** Locate plots systematically; two methods are:

(1) Locate plots at a fixed interval along transects that lace regularly across a sample area (uniform sampling grid). For example, on a sample area, mark off parallel transects that are 330 to 660 ft apart. Then along the transects locate plots at 132- to 330-ft intervals.

(2) Locate plots at a fixed interval along a transect that runs diagonally through the sample area. To minimize bias, have the transect cross obvious changes in fuels. Before entering the sample area, determine a transect azimuth and distance between plots.

E. **Reference Post or Point** Permanently mark the location of each study with a reference post and a study location stake.

F. **Study Identification** Number studies for proper identification to ensure that the data collected can be positively associated with specific sites on the ground.

G. **Study Documentation** Document pertinent information concerning the study on the Study Location and Documentation Data form .

7. Taking Photographs Establish photo plots.

8. Sampling Process

A. Mark the sampling point with a pin or similar item. Avoid disturbing material around the point. Accurate estimates require measurements of undisturbed material: If standing tree measurements (d.b.h. and height) are a part of the inventory, measure downed material first.

B. Determine direction of sampling plane by randomly selecting one of six 30' angles between 0 and 150 degrees. The 0 degree heading is the transect direction. Turn a fixed direction, such as clockwise, to position the sampling plane. As an alternative for indicating direction of the sampling plane, use the position of the second hand on a watch at a given instant. To avoid bias in placement of the sampling plane, do not look at the fuel or ground while turning the interval.

C. Denote position of the sampling plain by running a tape or string out from the sampling point parallel to the ground in the direction determined in 8.B. above. Extend the tape to the length of the longest sampling plane. A fiberglass rod or 1/2 in aluminum tube placed along the string beginning at the sampling point facilitates counting pieces less than 1-in in diameter. The rod should be 6 feet long, the length of sampling plane for small particles. The tape and rod fix the position of vertical sampling planes.

D. Measure or estimate slope by sighting along the sampling plane from the sample point using an Abney level or similar device. Ample precision is the nearest 10 percent, which can be coded using one digit (10 percent = 1, 90 percent = 9, etc.).

E. Tally the number of particles that intersect the sampling plane by the following size class:

(1) 0 to 0.24 inch (0 to 0.6 cm)
(2) 0.25 to 0.99 inch (0.6 to 2.5 cm.)
(3) 1.0 to 2.99 inches (2.5 to 7.6 cm)

The intersections can be counted one size class at a time or "dot tallied," which takes slightly longer than counting (see sample data form).

The actual diameter of the particle at the point of intersection determines its size class. A go/no-go gage with openings 0.5 inch, 1 inch, and 3 inches works well for separating borderline particles into size classes and for training the eye to recognize size classes.

The vertical plane is a plot. Consequently, in counting particle intersections, it is very important to visualize the plane passing through one edge of the plot rod and terminating along an imaginary fixed line on the ground. Once visualized on the ground, the position of the line should not be changed while counting particles.

Depth should be measured from only those particles included in the inventory for loading. For example, particles acceptable for measurement by the planar intersect technique are also acceptable for determining depth. If other techniques are used to estimate weight per acre of grass and forbs, this vegetation would also qualify for determining depth.

F. Measure vertical depth of duff to the nearest 0.1 inch using a ruler along the sampling plane at two points:

(1) 1 foot from the plot center; and
(2) a fixed distance of 3 to 5 feet from the first measurement.

Duff is the fermentation and humus layers of the forest floor. It does not include the freshly cast material in the litter layer. The top of the duff is where needles, leaves, and other castoff vegetative material have noticeably begun to decompose. Individual particles usually will be bound by fungal mycelium. When moss is present, the top of the duff is just below the green portion of the moss. The bottom of the duff is mineral soil.

Carefully expose a profile of the forest floor for the measurement. A knife or hatchet helps but is not essential. Avoid compacting or loosening the duff where the depth is measured.

When stumps, logs, and trees occur at the point of measurement, offset 1 foot perpendicular to the right side of the sampling plane. Measure through rotten logs whose central axis is in the duff layer

G. Measure or estimate the diameters of all pieces 3 inches in diameter and larger that intersect the sampling plane. Measure the diameters at the point of intersection to the nearest whole inch.

Record diameters separately for rotten and nonrotten pieces. Consider pieces rotten when the piece at the intersection is obviously punky or can be easily kicked apart.

A ruler laid perpendicularly across a large piece of fuel works satisfactorily for measuring diameter. Be sure to avoid parallax in reading the ruler. Calipers also work well for measuring diameter. A diameter tape, however, is unsatisfactory for pieces in contact with the ground.

Use as many consecutive lines on the data form, as necessary to record diameters.

H. For the entire sample area, record the predominate species of the 0- to 1-inch-diameter branchwood. An average diameter for the 0- to 0.25-inch, and 0.25- to 1-inch size classes will be selected from this information. If several species comprise the downed debris, estimate the proportion of the two or three most common species. Base this estimate on a general impression of what exists on the sample area and record as percentages of total 0- to 1-inch branchwood. Or, for a slight reduction in accuracy, omit this step and in the calculations use an average diameter for a composite of species.

I. **Tally Rules** The following rules apply to downed woody pieces of all diameters:

(1) Particles qualifying for tally include downed, dead woody material (twigs, stems, branches, and bolewood) from trees and shrubs. Dead branches attached to boles of standing trees are omitted because they are not downed vegetation. Consider a particle downed when it has fallen to the ground or is severed from its original source of growth. Cones, bark flakes, needles, leaves, grass, and forbs are not counted. Dead woody stems and branches still attached to standing brush and trees are not counted.

(2) Twigs or branches lying in the litter layer and above are counted. However, they are not counted when the intersection between the central axis of the particle and the sampling plane lies in the duff (forest floor below the litter).

(3) If the sampling plane intersects the end of a piece, tally only if the central axis is crossed. If the plane exactly intersects the central axis, tally every other such piece.

(4) Don't tally any particle having a central axis hat coincides perfectly with the sampling plane. (This should rarely happen.)

(5) If the sampling plane intersects a curved more than once, tally each intersection .

(6) Tally wood slivers and chunks left after logging. Visually mold these pieces into cylinders for determining size class or recording diameters.

(7) Tally uprooted stumps and roots not encased in dirt. For tallying consider uprooted stumps as tree holes or individual roots, depending on where the sampling planes intersect the stumps. Do not tally undisturbed stumps.

(8) For rotten logs that have fallen apart, visually construct a cylinder containing the rotten material and estimate its diameter. The cylinder will probably be smaller in diameter than the original log.

(9) Be sure to look up from the ground when sampling because downed material can be tallied up to any height. A practical upper cutoff is about 6 feet. However, in deep slash it may be necessary to tally above 6 feet.

When standing trees are inventoried along with downed material, it is necessary to fix a limit above the ground for sampling downed material. An upper limit helps define a downed tree so that inventory of standing and downed materials will not overlap.

J. **Utilization Options** For pieces over 3 inches in diameter, the following additional measurement can be useful for describing utilization potential.

(1) Species
(2) Length of pieces
(3) Diameter at large end
(4) Degree of checking, rot, and other defects that apply to the entire piece

9. Calculations

The calculations can be readily processed by computer and are also easy using a desk calculator. For a given sample area, fill in the computation summary sheet as follows.

(1) Slope correction factor

% Slope	0	10	20	30	40	50	60	70	80	90	100	110
Correction Factor (c)	1.00	1.00	1.02	1.04	1.08	1.12	1.17	1.22	1.28	1.35	1.41	1.49

(2) Squared average diameters (d^2), specific gravity (s), and angle factors (a). These values are:

Size Class (inches)	d^2	s	a
0 - 0.25	0.0151	0.48	1.13
0.25 - 1	0.289	0.48	1.13
1 - 3	2.76	0.40	1.13
3+ sound		0.40	1.0
3+ rotten		0.30	1.0

Decay and variability in density make specific gravity difficult to handle with accuracy.

(3) Calculate the total length of sampling line (Nl) for each size class: Nl = number of sample point multiplied by length of sampling plane (ft).

(4) For material 3 in or larger, square the diameter of each intersected piece and sum the squared values ($\hat{E}d^2$) [Ê = summation] for all pieces in the sampled area. Compute $\hat{E}d^2$ separately for sound and rotten categories. To obtain weights or volume for certain diameter ranges (3 to 9 inches, for example), compute $\hat{E}d^2$ for the specified range.

(5) **Calculate tons/acre**. The formulas used to arrive at tons/acre by size class is:

0 - 3" diameter: tons/acre = $(11.64 * n * d^2 * s * c * a) / Nl$

> 3" diameter: tons/acre = $(11.64 * n * \hat{E}d^2 * s * c) / Nl$

where:
n = number of intersections
d^2 = squared diameters
$\hat{E}d^2$ = sum of squared diameters
s = specific gravity
a = angle factor
c = slope correction factor
Nl - length of the sampling plane

(6) If desired, calculate volumes with the following formula

Cubic feet/acre = (32.05 * tons/acre) / specific gravity

(7) Calculate duff and letter fuel loads Duff and litter fuel load can be derived from duff and litter depths,

Tons/acre of duff = 14 * average inches of duff

10. Data Analysis It is important to realize that each transect is a single sampling unit. For trend analysis permanent sampling units are suggested. If permanent transects are monitored, use the appropriate paired analysis technique. Use either a paired t-test or the nonparametric Wilcoxon signed rank test when testing for change between years. When comparing more than two sampling periods, use repeated measures ANOVA. If the transects are not permanently marked, use the appropriate nonpaired test.

11. Cost For average amounts of downed debris, about 5 to 6 minutes per sample point are required for the measurements. More time is usually, spent in traveling and locating sample points than in making the measurements. If only downed wood material is inventoried, a two-man crew can complete 20 to 40 plots a day, depending on how much debris is present.

U.S. Fish & Wildlife Service

Fuel and Fire Effects Monitoring Guide

PLANT MORTALITY

Plant mortality is difficult to document immediately following a fire. Plants may take months or years to die from stem and root injury. Fire intensity is not necessarily a good indicator of possible plant mortality. Low intensity litter or duff consumption fires create significant soil heating and root injury.

- Direct
    - Tagged individuals
    - Chemical tests
- Indirect
    - Plant injury
        - Trees
            - Mortality predicted from fire behavior calculations (BEHAVE)
            - Crown scorch height
                - Measured
                - Predicted from fire behavior calculations (BEHAVE)
            - Percent crown scorch
            - Char height
    - Burn Severity - Burn Severity Classes

HOME

WHAT'S NEW

PLANNING

Project Planning
Design & Analysis
Reporting Results

MONITORING ATTRIBUTES

Fuel

Wildlife Habitat
- Plant Mortality
- Frequency
- Cover
- Density
- Production
- Structure
- Composition

Wildlife Populations
- Direct Mortality
- Populations

Water

Soil

Air Quality

Fire Effects Predictors

TRAINING

Opportunities

CREDITS

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PLANT INJURY

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1. Scorch Height

Record the maximum scorch height on each overstory tree two weeks to two months after the fire has burned across the monitoring plot. If the one year post bon visit exposes scorch patterns more definitively, measure scorch height again at that time.

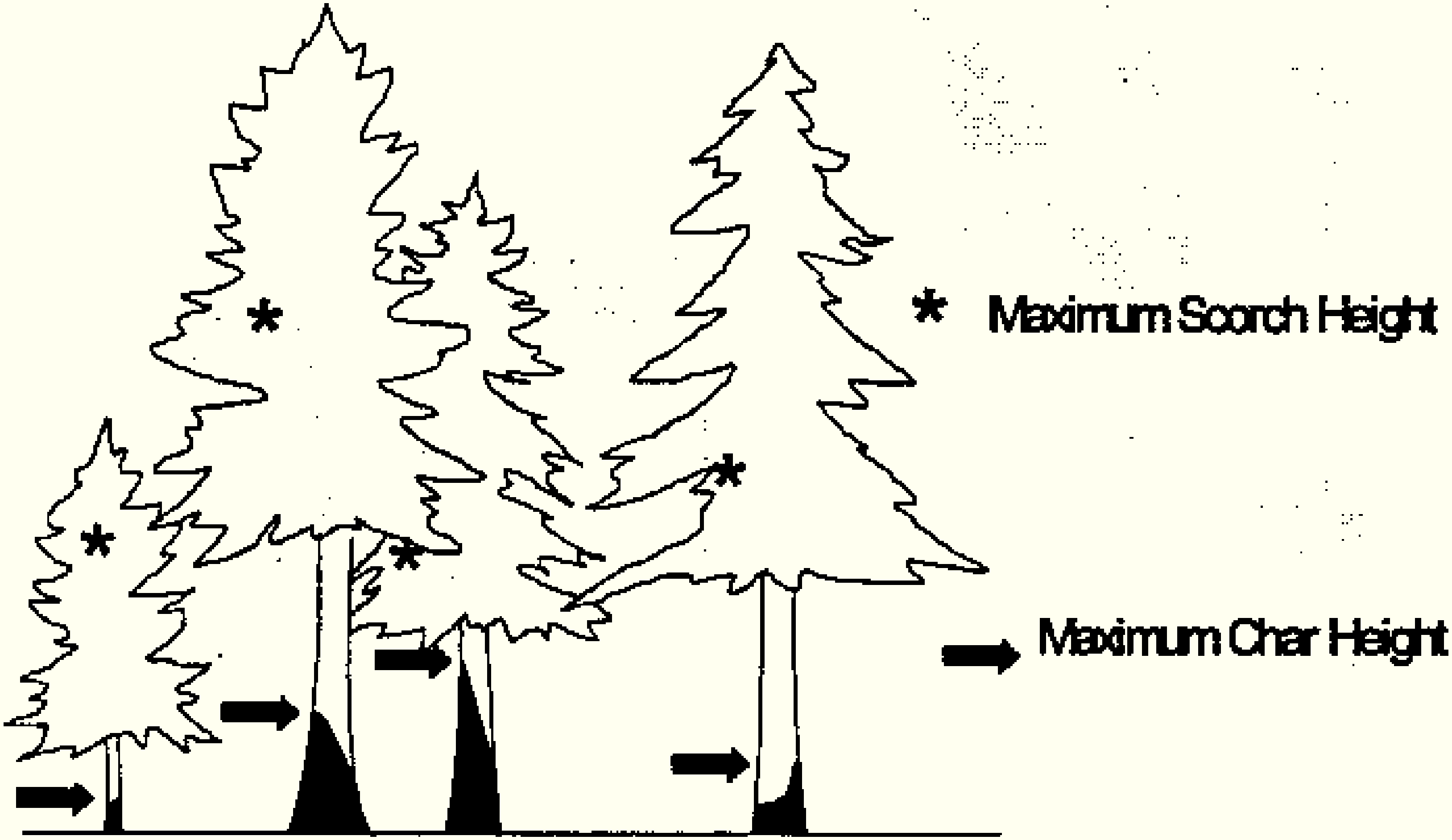
Maximum scorch height is measured from ground level to the highest point in the crown where foliar death is evident. Some trees will show no signs of scorch, but the surrounding fuels and vegetation will have obviously burned. In this case, you can estimate scorch height by examining adjacent vegetation. It may be useful to produce a graph of scorch heights to show the variation around the average. Managers may want to correlate scorch height with the preburn locations of large dead and down fuels; these correlations;usually require photographs or maps of fuel pockets.

2. Percent Crown Scorched

For each overstory tree, estimate the percent of the entire crown that is scorched. Average percent crown scorched may be calculated, but percent crown scorched is a better.indicator of individual tree mortality.

3. Char Height

Char height is often measured simultaneously with scorch height. To obtain an average maximum char height, measure the height of the maximum point of char for each overstory tree. For these calculate the mean of maximum char heights.


Maximum Scorch Height
Maximum Char Height

BURN SEVERITY

Burn severity is a term that qualitatively describes classes of surface fuel and duff consumption. Large diameter down, dead woody fuels and organic soil horizons are consumed during long-term, smoldering and glowing combustion. The amount of duff or organic layer reduction is also called depth of burn, or ground char. Because the amount and duration of subsurface heating can be inferred from burn severity, this variable can be related to fire effects on plants and soils.

Burn severity is a subjective classification. It can be monitored independently or in conjunction with other attributes under an appropriate study design.

Class	Substrate - litter/duff	Vegetation - understory/brush/herbs
Unburned	not burned	not burned
Scorched	litter partially blackened; duff nearly unchanged; wood/leaf structures unchanged	foliage scorched and attached to supporting twigs
Lightly Burned	litter charred to partially consumed; upper duff layer burned; wood/leaf structures charred. but recognizable	foliage and smaller twigs partially to completely consumed
Moderately Burned	litter mostly to entirely consumed, leaving course, light colored ash; duff deeply burned; wood/leaf structures unrecognizable	foliage, twigs and small stems consumed
Heavily Burned	litter and duff consumed, leaving fine white ash; mineral soil visibly altered, often reddish	all plant parts consumed leaving some or no major stems/trunks
Not Applicable	inorganic	not present

- Bunchgrass Damage Classes
- Relationship of Sprouting to Burn Severity

U.S. Fish & Wildlife Service

Fuel and Fire Effects Monitoring Guide

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Plant Mortality
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Density
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Composition

Wildlife Populations
Direct Mortality
Populations

FREQUENCY

1. **Description** Frequency is one of the easiest and fastest methods available for monitoring. It describes the abundance and distribution of species and is useful to detect changes over time. Frequency is most use in monitoring vegetation.

Frequency has been used to determine land condition but only limited work has been done in most communities. This makes the interpretation difficult. The literature has discussed the relationship between density and frequency but this relationship is only consistent with randomly distributed plants (Greig-Smith 1983).

Frequency is the number of times a species is present in a given number of sampling units. It is usually expressed as a percentage.

2 **Advantages and Limitations**

a. Frequency is highly influenced by the size and shape of the quadrats used. Quadrats or nested quadrats are the most common measurement used; however, point sampling and step point methods have also been used to estimate frequency. The size and shape of a quadrat needed to adequately determine frequency depends on the distribution, number, and size of the plant species.

b. To determine change, the frequency of a species must generally be at least 20% and no greater than 80%. Frequency comparisons must be made with quadrats of the same size and shape. While change can be detected with frequency, the extent to which the vegetation community has changed cannot be determined.

c. High repeatability is obtainable.

d. Frequency is highly sensitive to changes resulting from seedling establishment. Seedlings present one year may not be persistent the following year. This situation is problematic if data is collected only

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every few years. It is less of a problem if seedlings are recorded separately.

e. Frequency is also very sensitive to changes in pattern of distribution in the sampled area.

f. Rooted frequency data is less sensitive to fluctuations in climatic and biotic influences.

g. Interpretation of changes in frequency is difficult because of the inability to determine the vegetation attribute that changed. Frequency cannot tell which of three parameters has changed: canopy cover, density, or pattern of distribution.

3. **Appropriate Use of Frequency for Monitoring** If the primary reason for collecting frequency data is to demonstrate that a change in vegetation has occurred, then on most sites the frequency method is capable of accomplishing the task with statistical evidence more rapidly and at less cost than any other method that is currently available (Hironaka 1985).

Frequency should not be the only data collected if time and money are available. Additional information on ground cover, plant cover, and other vegetation and site data would contribute to a better understanding of the changes that have occurred (Hironaka 1985).

West (1985) noted the following limitations: "Because of the greater risk of misjudging a downward than upward trend, frequency may provide the easiest early warning of undesirable changes in key or indicator species. However, because frequency data are so dependent on quadrat size and sensitive to non-random dispersion patterns, managers are fooling themselves if they calculate percentage composition from frequency data and try to compare different sites at the same time or the same site over time in terms of total species composition. This is because the numbers derived for frequency sampling are unique to the choice of sample size, shape, number, and placement. For variables of cover and weight, accuracy is mostly what is affected by these choices and the variable can be conceived independently of the sampling protocol."

4. **Techniques**

- Primary attributed that the technique collects.
  - **Frequency**

- Secondary attributed that can be collected or calculated
  - **Dry Weight Rank**
  - **Daubenmier**

This page was last modified 05/30/01

FREQUENCY METHODS
Pace Frequency, Quadrat Frequency, and Nested Frequency Methods

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1. General Description All three methods consist of observing quadrats along transects, with quadrats systematically located at specified intervals along each transect. The only differences in these technique are the size and configuration of the quadrat frames and the layout of the transect. The following vegetation attributes are monitored with this method:

A. Frequency
B. Basal cover and general cover categories (including litter)
C. Reproduction of key species (if seedling data are collected)

It is important to establish a photo plot and take both close-up and general view photographs. This allows the portrayal of resource values and conditions and furnishes visual evidence of vegetation and soil changes over time.

2. Areas of Use This method is applicable to a wide variety of vegetation types and is suited for use with grasses, forbs, and shrubs.

3. Advantages and Limitations

A. Frequency sampling is highly objective, repeatable, rapid, and simple to perform, and it involves a minimum number of decisions. Decisions are limited to identifying species and determining whether or not species are rooted within the quadrats (presence or absence).

B. Frequency data can be collected in different-sized quadrats with the use of the nested frame. When a plant of a particular species occurs within a plot, it also occurs in all of the successively larger plots. Frequency of occurrence for various size plots can be analyzed even though frequency is recorded for only one size plot. This eliminates problems with comparing frequency data from different plot sizes. Use of the nested plot configuration improves the chance of selecting a proper size plot for frequency sampling.

C. Cover data can also be collected at the same time frequency data is gathered. However, cover data collected in this manner will greatly overestimate cover; unless the tines are honed to a fine point, observer bias will come into play. Another limitation is that the use of one size quadrat will likely result in values falling outside the optimum frequency range (greater than 20 percent to less than 80 percent) for some of the species of interest.

4. Equipment The following equipment is needed.

A. Study Location and Documentation Data form
B. Frequency form
C. Nested Frequency form
D. Permanent yellow or orange spray paint
E. Frequency frames

F. One transect location stake: 3/4 - or 1 -inch angle iron not less than 16 inches long
G. Hammer
H. Tally counter (optional)
I. Compass
J. Steel post and driver
K. Tape: 50-, 100-, or 200-foot delineated in tenths and hundreds or a metric tape of the desired length.

5. Training A minimum amount of training is needed for this method. Examiners must be able to identify the plant species and be able to tell whether or not a species occurs, according to study specifications, within a quadrat. Examiners must be familiar with the cover categories and how to collect cover data using the tines on the quadrat frame.

6. Establishing Studies Careful establishment of studies is a critical element in obtaining meaningful data.

A. **Site Selection** The most important factor in obtaining usable data is selecting representative areas (critical or key areas) in which to run the study. Study sites should be located within a single plant community within a single ecological site. Transects and sampling points need to be randomly located within the critical or key areas.

B. **Pilot Studies** Collect data on several pilot studies to determine the number of samples (transects or observation points) and the number and size of quadrats needed to collect a statistically valid sample.

C. **Selecting Quadrat Size** The selection of quadrat size is important and depends on the characteristics of the vegetation to be sampled.

1. As a rule of thumb, it is expected that all frequency percentages for important species should fall between 10 and 90 percent or, if possible, between 20 and 80 percent. This will provide the greatest possible chance for detecting an important trend for a species when the study is read again. Use a frame size that will produce frequencies falling in this range for the greatest number of species possible.

2. To build a sample frame which shows an example of a frequency frame.

3. Use the same size quadrat throughout a study and for rereading the study. If frequencies for a specific species approach the extremes of either 0 or 100 percent, it may be necessary to use a different sized quadrat for that species. The nested plot concept would be suitable in this instance.

D. **Nested Plot Technique** The use of one size plot is usually not adequate to collect frequency data on all the important species within a community. For each species occurring on a site, there is a limited range of plot sizes capable of producing frequency percentages between 20 and 80 percent. A plot size appropriate for one species may not be appropriate for another. The nested plot concept is a simple approach to collecting data on two or more different sized plots at one time. Several different sized plots are placed inside each other in a smallest to largest sequence.

E. **Number of Studies** Establish at least one frequency study on each study site; establish more if needed.

F. **Study Layout** Frequency data can be collected using either the baseline, macroplot, or linear study designs. The baseline technique is the one most often used.

Align a tape (100-, or 200-foot, or metric equivalent) in a straight line by stretching it between the baseline beginning stake and the baseline end point stake. A pin may also be driven into the ground at the midpoint of the transect. Do not allow vegetation to deflect the alignment of the tape. A spring and pulley may be useful to help maintain a straight line.

With the baseline technique, any number of transects can be run perpendicularly to the baseline, depending on the intensity of the sample needed. Each transect originates at a randomly selected mark along the baseline. The randomization is restricted so that half of the transects are randomized on each side of the halfway mark.

The starting point for each transect off the base line and the distance between each quadrat should not be any closer than the width of the quadrat being used to avoid the possibility that any two quadrats might overlap.

G. **Reference Post or Point** Permanently mark the location of each study with a reference post and study location stake.

H. **Study Identification** Number studies for proper identification to ensure that the data collected can be positively associated with specific studies on the ground.

I. **Study Documentation** Document pertinent information concerning the study on the Study Location and Documentation Data form.

7. Taking Photographs Establish photo plots.

8. Sampling Process In addition to collecting the specific study data, general observations should be made of the study sites.

A. **Running the Transect** Study data are collected along several transects. The location of each transect (distance along the baseline) and the direction (to left or right from the baseline) are randomly determined for each study site. A quadrat is read at the specified interval until all quadrats have been read. The interval between quadrats can be either paced or measured. To widen the area transected, add additional paces or distance (20 paces, 50 feet) between quadrats.

Additional transects can be added to obtain an adequate sample.

1. Start each transect by placing the rear corner of the quadrat frame at the starting point along

the baseline tape.

2. Place the quadrat frame at the designated interval along a transect perpendicular to the baseline until the specified number of quadrats have been read. The interval between quadrats can be measured or estimated by pacing.

3. When a transect is completed, move to the next starting point on the baseline tape and run the next transect.

B. **Collecting Cover Data** Record, by dot count tally, the cover category at each of the four corners and at the tip of any tines on the frame. Enter this data in the Cover Summary section of the Frequency and Nested Frequency forms. The cover categories are bare ground (gravel less than 1/1 2 inch in diameter is tallied as bare ground), litter, and gravel (1/1 2 inch and larger). Additional cover categories can be added as needed. Vegetation is recorded as basal hits or canopy layers in the bottom portion of the form. Up to three canopy layers can be recorded.

Read the same points on the frame and the same number of points at each placement of the frame throughout a study and when rereading that study.

C. **Collecting Frequency Data** Collect frequency data for all plant species. Record the data by species within each quadrat using the Frequency form. Only one record is made for each species per quadrat, regardless of the number of individual plants of a species that occurs within the quadrat.

1. Herbaceous plants (grasses and forbs) must be rooted in the quadrat to be counted.

2. On many occasions, rooted frequency on trees and shrubs (including half shrubs) does not provide an adequate sample (occurring within 20% of the plots). To increase the sample size on trees and shrubs, the canopy overhanging the quadrat can be counted.

3. Annual plants are counted whether green or dried.

4. Specimens of the plants that are unknown should be collected and marked for later identification.

5. Frequency occurrence of seedlings by plant species should be tallied separately from mature plants.

D. **Nested Plot Method** Collect frequency data for all plant species. For uniformity in recording data, the four nested plots in a quadrat are numbered from 1 through 4, with the largest plot size corresponding with the higher number. Each time the quadrat frame is placed on the ground, determine the smallest size plot each species occurs in and record the plot number for that quadrat on the Nested Frequency form.

9. Calculations Make the calculations and record the results in the appropriate columns on the Frequency form.

A. **Cover** Calculate the percent cover for each cover category by dividing the number of hits for each category by the total number of hits for all categories, including hits on vegetation, and multiplying the value by 100. The total of the percent cover for all cover categories equals 100 percent.

B. **Frequency: Single Plot** On the Frequency form total the frequency hits by species. Calculate the percent frequency for each plant species by dividing the total number of hits for that species by the total number of quadrats sampled along the transect and multiplying the value by 100. Record the percent frequency on the form.

C **Frequency: Nested Plot** Percent frequency by species can be calculated for each transect and/or for the total of all transects.

(1) **Compiling data** Determine the number of occurrences for each species for each plot size.

a. Count the number of occurrences of a species in plot 1 and record the value in the Hits portion of column 1 in the Frequency Summary portion of the Nested Frequency form.

b. Count the number of occurrences of the same species in plot 2 and add this number to the number recorded for plot 1. Record this total in the Hits portion of column 2.

c. Count the number of occurrences of the same species in plot 3 and add this number to the number recorded for plot 2. Record this total in the Hits portion of column 3.

d. Count the number of occurrences of the same species in plot 4 and add this number to the number recorded for plot 3. Record this total in the Hits portion of column 4.

(2) **Frequency for each transect** Calculate the percent frequency of a plant species by plot size for a transect by dividing the number of occurrences by the number of quadrats sampled and multiplying the value by 100. Record in the "% Freq" section of the Frequency Summary portion.

(3) **Total frequency for all transects** Calculate the percent frequency of a plant species by plot size for the total of all transects by adding the occurrences of a species by plot size on all transects, dividing the total by the total number of quadrats sampled for the study, and multiplying the value by 100. Record the percent frequency in the appropriate plot size on a separate form.

10. Data Analysis To determine if the change between sampling periods is significant, a Chi Square contingency table analysis should be used. Frequency must be analyzed separately for each species. Chi Square analysis of variance can also be used to detect changes in cover classes between sampling periods.

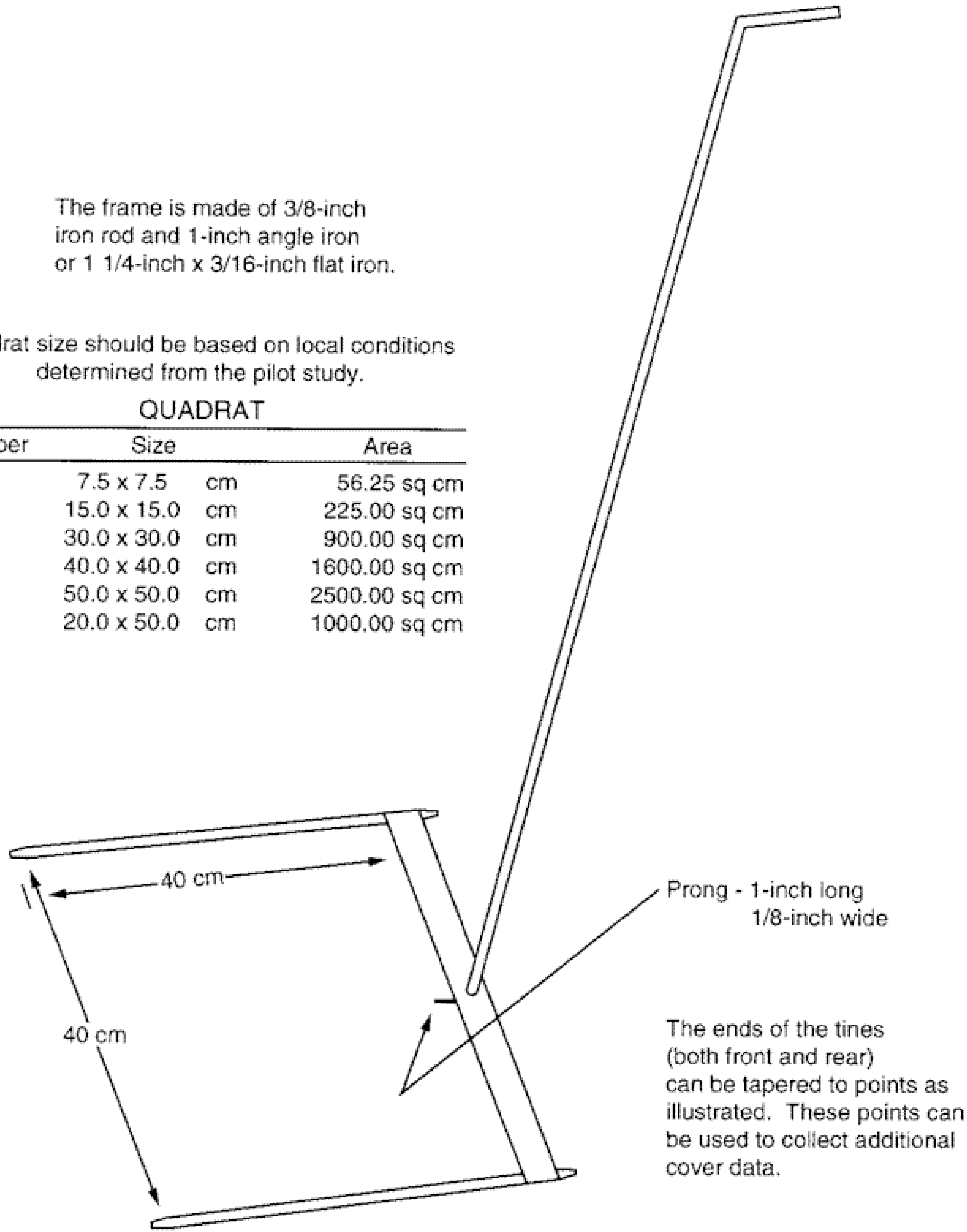
Frequency Frame

The frame is made of 3/8-inch iron rod and 1-inch angle iron or 1 1/4-inch x 3/16-inch flat iron.

Quadrat size should be based on local conditions determined from the pilot study.

QUADRAT

Number	Size		Area
1	7.5 x 7.5	cm	56.25 sq cm
2	15.0 x 15.0	cm	225.00 sq cm
3	30.0 x 30.0	cm	900.00 sq cm
4	40.0 x 40.0	cm	1600.00 sq cm
5	50.0 x 50.0	cm	2500.00 sq cm
6	20.0 x 50.0	cm	1000.00 sq cm



Nested Plot Frame

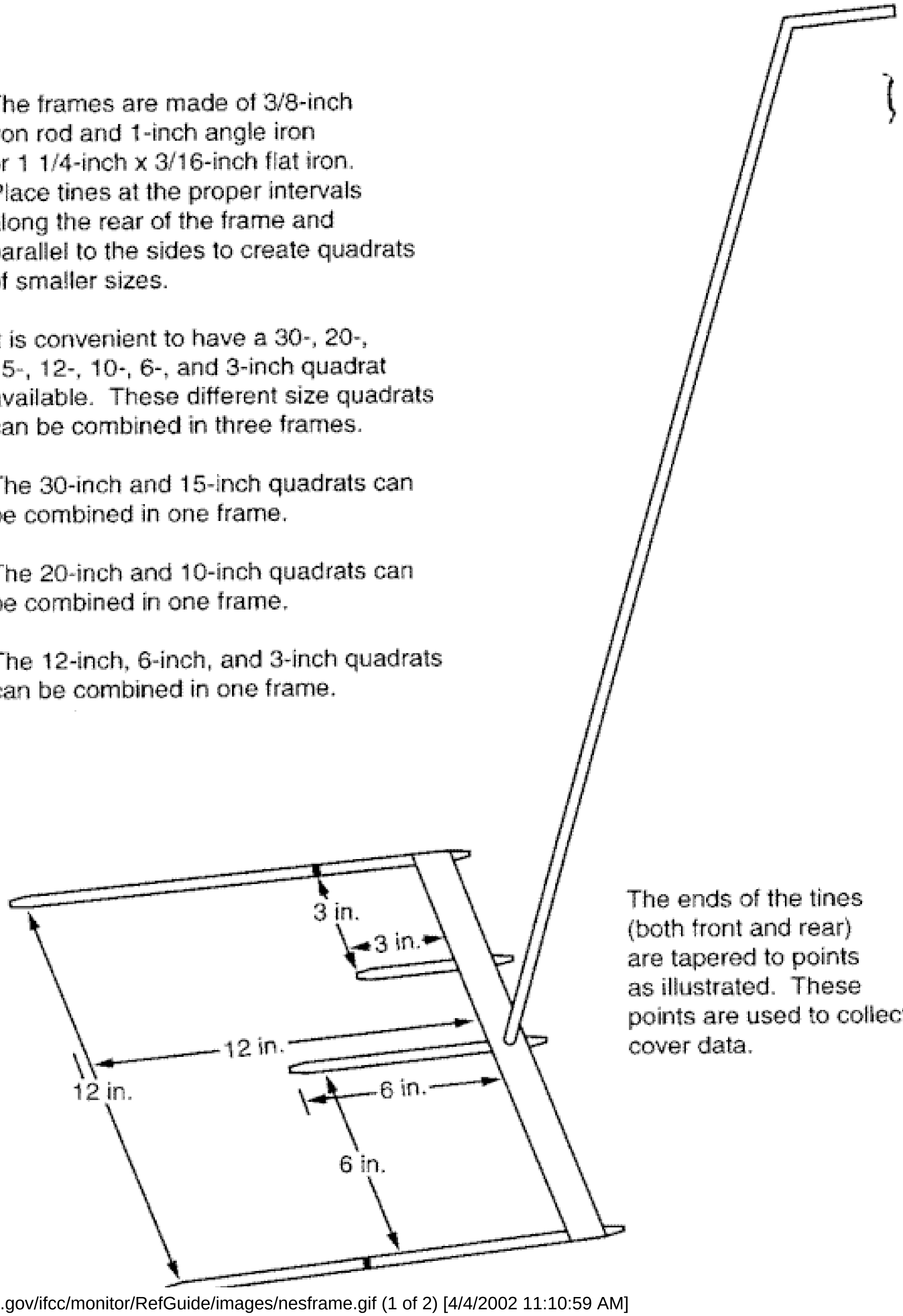
The frames are made of 3/8-inch iron rod and 1-inch angle iron or 1 1/4-inch x 3/16-inch flat iron. Place tines at the proper intervals along the rear of the frame and parallel to the sides to create quadrats of smaller sizes.

It is convenient to have a 30-, 20-, 15-, 12-, 10-, 6-, and 3-inch quadrat available. These different size quadrats can be combined in three frames.

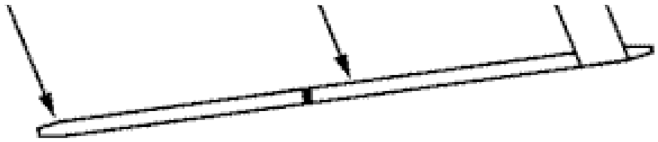
The 30-inch and 15-inch quadrats can be combined in one frame.

The 20-inch and 10-inch quadrats can be combined in one frame.

The 12-inch, 6-inch, and 3-inch quadrats can be combined in one frame.



The ends of the tines (both front and rear) are tapered to points as illustrated. These points are used to collect cover data.



Frequency

Page ____ of ____

Study Number	Date	Examiner	Allotment Name & Number	Pasture

Transect Location	Number of Quadrats	Quadrat Size

Plant Species	Quadrat Number										
	0	10	20	30	40	50	60	70	80	90	100	Total

Cover Summary

Vegetation (Basal)	Vegetation (Canopy)	Litter	Bare Ground	Gravel/Stone	
Hits %Cover	Hits %Cover	Hits %Cover	Hits %Cover	Hits %Cover	Hits %Cover

Notes (use other side or another page)

Nested Frequency

Page ____ of ____

Study Number	Date	Examiner	Allotment Name & Number	Pasture
Transect Location		Number of Quadrats		Quadrat Size

Plant Species	Quadrats																				Frequency Summary by Plot Size							
																					1		2		3		4	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Hits	% Freq	Hits	% Freq	Hits	% Freq	Hits	% Freq

Cover Summary	
Vegetation (Basal)	
Hits	%Cover
Vegetation (Canopy)	
Hits	%Cover
Litter	
Hits	%Cover
Bare Ground	
Hits	%Cover
Gravel/Stone	
Hits	%Cover
Crytogamie crust	
Hits	%Cover

Observations/Comments

Notes (Use other side or another page)

Canopy* Dont record ground cover under canopy hits of shrubs under 10ft in height

Notes (Use other side or another page)

Canopy* Dont record ground cover under canopy hits of shrubs under 10ft in height

Hits	%Cover

DRY WEIGHT RANK METHOD

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1. General Description The Dry Weight Rank method is used to determine species composition. It consists of observing various quadrats and ranking the three species which contribute the most weight in the quadrat.

It is important to establish a photo plot and take both close-up and general view photographs. This allows the portrayal of resource values and conditions and furnishes visual evidence of vegetation and soil changes over time.

2. Areas of Use This method has been tested in a wide variety of vegetation types and is generally considered suitable for grassland/small shrubs types or understory communities of large shrub or tree communities. It does not work well on large shrubs and trees.

3. Advantages and Limitations

A. One advantage of the Dry Weight Rank Method is that a large number of samples can be obtained very quickly. Another advantage is that it deals with estimates of production, which allows for better interpretation of the data to make management decisions. It can be done in conjunction with frequency, canopy cover, or comparative yield methods. Because it is easier to rank the top three species in a quadrat, there is less observer bias.

B. The limitation with this technique is that, by itself, it will not give a reliable estimate of plant standing crop, and it assumes there are few empty quadrats. In many large shrub or sparse desert communities, a high percentage of quadrats are empty or have only one species present. The quadrat size required to address these concerns is often impractical.

4. Equipment The following equipment is needed:

A. Study Location and Documentation Data form
B. Dry Weight Rank form
C. Quadrat frame
D. Hammer
E. Permanent yellow or orange spray paint
F. One stake: 3/4- or 1-inch angle iron not less than 16 inches long
G. Compass
H. Steel post and driver

5. Training Examiners must be able to identify the plants. Experience in weight estimate is desirable, but those with experience must break the habit of assigning percentages and just rank the species, as well as not debating over the close calls. The large number of sampling units tends to reduce the problems with close calls.

6. Establishing Studies

A. **Site Selection** The most important factor in obtaining usable data is selecting representative areas (critical or key areas) in which to run the study. Study sites should be located within a single plant community within a single ecological site. Transects and sampling points need to be randomly located within the critical or key areas.

B. **Pilot Studies** Collect data on several pilot studies to determine the number of samples (transects or observation points) and the number and size of quadrats needed to collect a statistically valid sample.

C. **Selecting Quadrat Size** Adapt the size and shape of quadrats to the vegetation community to be sampled.

(1) Select a plot size on the premise that most plots should contain three species.

(2) Determine the proper size quadrat to use by doing preliminary sampling with different size frames.

(3) Use the same size quadrat throughout a study and for rereading the study. If frequencies approach the extremes of either 0 or 100 percent, it may be necessary to change the quadrat size.

D. **Number of Studies** At least one Dry Weight Rank study should be established on each study site, depending on the objectives; establish more if needed. Evaluate the plant communities where studies will be located and determine the number of transects and quadrats needed. The purpose is to collect the best possible sample for the greatest number of species in any plant community.

E. **Study Layout** The Dry Weight Rank data can be collected using the baseline, macroplot, or linear study designs. The linear technique is the one most often used.

F. **Reference Post or Point** Permanently mark the location of each study with a reference post and a study location stake.

G. **Study Identification** Number studies for proper identification to ensure that the data collected can be positively associated with specific sites on the ground.

H. **Study Documentation** Document pertinent information concerning the study on the Study Location and Documentation Data form.

7. Taking Photographs Establish photo plots.

8. Sampling Process In addition to collecting the specific study data, general observations should be made of the study sites.

Determine the transect bearing and select a prominent distant landmark such as a peak, rocky point, etc., that can be used as the transect bearing point.

After the quadrat location has been determined, the observer decides which three species in the quadrat have the greatest yield of current year's growth on a dry matter basis. The species with the highest yield is given a rank of 1, the next 2, and the third highest a 3. Data are record by quadrat on the Dry Weight Rank form. All other species present are ignored. If there are not three species present in the quadrat, a multiple rank is assigned.

The Dry Weight Rank method assumes that a rank of I corresponds to 70% composition, rank 2 to 20%, and rank 3 to 10%. If only one species is found in a quadrat, it would be ranked 1, 2 and 3 (100%). If two species are found, one may be given ranks of 1 and 2 (90%), ranks 1 and 3 (80%), or ranks 2 and 3 (30%), depending on the relative weight for the two species. For each species, record the number of 1, 2, or 3 ranks received in the sample.

Data can also be collected and recorded for each quadrat for use in conjunction with the Comparative Yield Method.

9. Calculations

A. For each species multiply the number of ranks of 1, 2, and 3 by 7, 2, and 1,respectively, and record under the appropriate weight column. Add the amounts in the weight columns of each species and record in the weighted column.

B. Total the weighted column for all species. The total of this column will always be ten times the number of quadrats.

C. Divide the value recorded for each species in the weighted column by the total of the weighted column to get percent composition for each species. Percent composition, by definition, should total 100 percent.

10. Data Analysis Chi Square analysis can be used to determine if the frequency of each species in each rank tally group (1,2, or 3) has changed from one sampling period to another. Each species must be analyzed separately.

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Wildlife Populations
Direct Mortality
Populations

COVER

1. **Description** Cover is an important vegetation and hydrologic characteristic. It can be used in various ways to determine the contribution of each species to a plant community. Cover is also important in determining the proper hydrologic function of a site. This characteristic is very sensitive to biotic and edaphic forces. For watershed stability, some have tried to use a standard soil cover, but research has shown each edaphic site has its own potential cover.

Cover is generally referred to as the percentage of ground surface covered by vegetation. However, numerous definitions exist. It can be expressed in absolute terms (square meters/hectares) but is most often expressed as a percentage. The objective being measured will determine the definition and type of cover measured.

a. Vegetation cover is the total cover of vegetation on a site.

b. Foliar cover is the area of ground covered by the vertical projection of the aerial portions of the plants. Small openings in the canopy and intraspecific overlap are excluded.

c. Canopy cover is the area of ground covered by the vertical projection of the outermost perimeter of the natural spread of foliage of plants. Small openings within the canopy are included. It may exceed I 00%.

d. Basal cover (area) is the area of ground surface occupied by the basal portion of the plants. Ecologists and range managers typically use a height close to the ground (e.g., about 1 in; 2.5 cm); foresters typically use "breast height" (4.5 ft; 1.4 m).

e. Ground cover is the cover of plants, litter, rocks, and gravel on a site.

2. **Advantages and Limitations**

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a. Ground cover is most often used to determine the watershed stability of the site, but comparisons between sites are difficult to interpret because of the different potentials associated with each ecological site.

b. Vegetation cover is a component of ground cover and is often sensitive to climatic fluctuations that can cause errors in interpretation. Canopy cover and foliar cover are components of vegetation cover and are the most sensitive to climatic and biotic factors. This is particularly true with herbaceous vegetation.

c. Overlapping canopy cover often creates problems, particularly in mixed communities. If species composition is to be determined, the canopy of each species is counted regardless of any overlap with other species. If watershed characteristics are the objective, only the uppermost canopy is generally counted.

d. For trend comparisons in herbaceous plant communities, basal cover is generally considered to be the most stable. It does not vary as much due to climatic fluctuations or current-year defoliation.

3. **Techniques**

- Primary attributed that the technique collects.
  - **Daubenmier**
  - **Line Intercept**
  - **Step Point**
  - **Point Intercept**
    - **Spherical Densiometer**
  - **Cover Board**
  - **Biltmore Stick**
  - **Bitterlich Method**
- Secondary attributed that can be collected or calculated
  - **Frequency**
  - **Calculated Cover**

This page was last modified 06/19/01

DAUBENMIRE METHOD

1. General Description The Daubenmire method consists of systematically placing a 20- x 50-cm quadrat frame along a tape on permanently located transects. The following vegetation attributes are monitored using the Daubenmire method·

A. Canopy cover
B. Frequency
C. Composition by canopy cover

It is important to establish a photo plot and take both close-up and general view photographs. This allows the portrayal of resource values and conditions and furnishes visual evidence of vegetation and soil changes over time.

2. Areas of Use This method is applicable to a wide variety of vegetation types as long as the plants do not exceed waist height. It tends to be inexpensive. Estimates can be made very quickly. It is necessary for the plants' canopies to be distinct.

3 . Advantages and Limitations This method is relatively simple and rapid to use. A limitation is that there can be large changes in canopy cover of herbaceous species between years because of climatic conditions, with no relationship to the effects of management. In general, quadrats are not recommended for estimating cover. This method cannot be used to calculate rooted frequency.

This method can be moderately accurate. Where greater accuracy is required, Line Intercept or Point Intercept techniques can be used.

4. Equipment The following equipment is needed.

A. Study Location and Documentation Data form
B. Daubenmire forms (Daubenmire form and Daubenmire Summary form).
C. Hammer
D. Permanent yellow or orange spray paint
E. Two stakes: 3/4 - or 1 -inch angle iron not less than 16 inches long
F. Tape: 100- or 200-foot, delineated in tenths and hundreds, or a metric tape of the desired length.
G. Steel pins (reinforcement bar) for marking zero, mid, and end points of the transect
H. Frame to delineate the 20- x 50-cm quadrats
I. Compass
J. Steel post and driver

5. Training The accuracy of data depends on the training and ability of the examiners. Error arises simple from inadequate training, but can be minimized by making quantitative measurements of cover using other techniques (e.g., line intercept). Examiners must be able to identify the plant species. They must receive adequate and consistent training in laying out transects and making canopy coverage estimates using the frame.

6. Establishing Studies Careful establishment of studies is a critical element in obtaining meaningful data.

A. **Site Selection** The most important factor in obtaining usable data is selecting representative areas (critical or key areas) in which to run the study. Study sites should be located within a single plant community within a single ecological site. Transects and sampling points need to be randomly located within the critical or key areas (see Section III).

B. **Pilot Studies** Collect data on several pilot studies to determine the number of samples (transects or observation points) and the number and size of quadrats needed to collect a statistically valid sample.

C. **Number of Studies** Establish a minimum of one study on each study site; establish more if needed (see Section II.D and III.B).

D. **Study Layout** Data can be collected using the baseline, macroplot, or linear study designs. The linear technique is the one most often used.

(1) Align a tape (100-, or 200-foot, or metric equivalent) in a straight line by stretching it between the transect location and the transect bearing stakes. Do not allow vegetation to deflect the alignment of the tape. A spring and pulley may be useful to maintain a straight line. The tape should be aligned as close to the ground as possible.

(2) Drive steel pins almost to the ground surface at the zero point on the tape and at the end of the transect. A pin may also be driven into the ground at the midpoint of the transect.

E. **Reference Post or Point** Permanently mark the location of each study with a reference post and a study location stake.

F. **Study Identification** Number studies for proper identification to ensure that the data collected can be positively associated with specific sites on the ground.

G. **Study Documentation** Document pertinent information concerning the study on the Study Location and Documentation Data form.

7. Taking Photographs Establish photo plots.

8. Sampling Process In addition to collecting the specific studies data, general observations should be made of the study sites.

A. **Cover Classes** This method uses six separate cover classes. The cover classes are:

Cover Class	Range of Coverage	Midpoint of Range
1	- 5%	2.5%
2	5- 25%	15.0%
3	25 - 50%	37.5%
4	50 - 75%	62.5%
5	75 - 95%	85.0%
6	95 - 100%	97.5%

B. **Ten Cover Classes** Where narrower and more numerous classes are preferred, a ten-cover class system can be used.

C. **Collecting Cover Data** As the quadrat frame is placed along the tape at the specified intervals, estimate the canopy coverage of each plant species. Record the data by quadrat, by species, and by cover class on the Daubenmire form. Canopy coverage estimates can be made for both perennial and annual plant species.

(1) Observe the quadrat frame from directly above and estimate the cover class for all individuals of a plant species in the quadrat as a unit. All other kinds of plants are ignored as each plant species is considered separately.

(2) Imagine a line drawn about the leaf tips of the undisturbed canopies (ignoring inflorescence) and project these polygonal images onto the ground. This projection is considered "canopy coverage." Decide which of the classes the canopy coverage of the species falls into and record on the form.

(3) Canopies extending over the quadrat are estimated even if the plants are not rooted in the quadrat.

(4) Collect the data at a time of maximum growth of the key species.

(5) For tiny annuals, it is helpful to estimate the number of individuals that would be required to fill 5% of the frame (the 71 - x 71 -mm area). A quick estimate of the numbers of individuals in each frame will then provide an estimate as to whether the aggregate coverage falls in Class I or 2, etc.

(6) Overlapping canopy cover is included in the cover estimates by species; therefore, total cover may exceed 100 percent. Total cover may not reflect actual ground cover.

9. **Calculations** Make the calculations and record the results in the appropriate columns on the Daubenmire and Daubenmire Summary forms.

A. **Canopy Cover** Calculate the percent canopy cover by species as follows:

(1) On the Daubenmire form count the number of quadrats in each of the six cover class (by species) and record in the Number column on the Daubenmire Summary form.

(2) Multiply this value times the midpoint of the appropriate cover class.

(3) Total the products for all cover classes by species.

(4) Divide the sum by the total number of quadrats sampled on the transect.

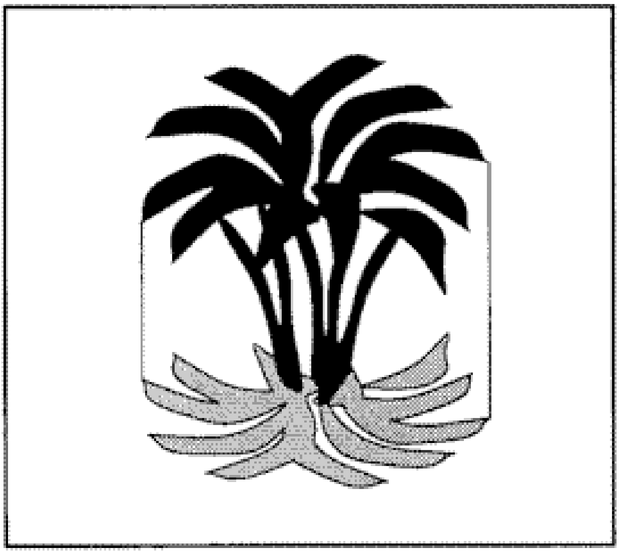
(5) Record the percent cover by species on the form.

B. **Frequency** Calculate the percent frequency for each plant species by dividing the number of occurrences of a plant species (the number of quadrats in which a plant species was observed) by the total number of quadrats sampled along the transect. Multiply the resulting value by 100. Record the percent frequency on the form.

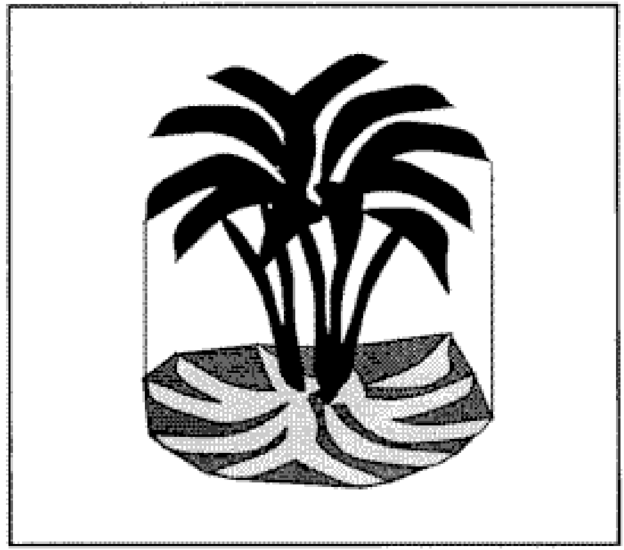
C. **Species Composition** With this method, species composition is based on canopy cover of the various species. It is determined by dividing the percent canopy cover of each plant species by the total canopy cover of all plant species. Record the percent composition on the form.

10. Data Analysis Tests should be directed at detecting changes in cover of the species and/or in major ground cover classes. Tests for changes in minor species will have low power to detect change. If quadrats are spaced far enough apart on each transect so as to be considered independent, the quadrat can be analyzed as the sampling unit. Otherwise, the transects should be considered the sampling units. If the transects are treated as the sampling unit, and given that the transects are permanent, either the paired t-test or the nonparametric Wilcoxon signed rank test should be used to test for change between two years. Repeated measures ANOVA can be used to test for differences between 3 or more years. If the quadrats are treated as the sampling units, care must be taken to ensure they are positioned the same along each transect in each year of measurement. A paired t-test, Wilcoxon signed rank test, or ANOVA is then used as described above for transects.

11. Cost About 5-25 min/10 quadrats.



Foliar cover.



Canopy cover.

Page ____ of ____

Study Location & Documentation Data

Study Method					Study Number
Allotment Name & Number				Pasture	
District			Resource Area		
Ecological Site			Plant Community		
Date Established	Established by (Name)			Map Reference	
Elevation	Slope	Exposure		Aerial Photo Reference	

	Township	Range	Section	1/4	1/4	1/4	
Location							Scale: ____ inches equals one mile

Key Species

1 2 3

Distance and bearing between reference post or reference point and the transect location stake, beginning of transect, or plot

Distance and bearing between location stake and bearing stake

Transect Bearing	Vertical Distance Between Ground & Aligned Tape
Length of Transect	Plot/Frame Size
Sampling Interval	Total Number of Samples

Notes (Description of study location, diagram of transect/plot layout, description of photo points, etc. If more space is needed, use reverse side or another page.)

Note: Depending on the study method, fill in the blocks that apply when a study is established. This documentation enables the examiners to conduct follow-up studies in a consistant manner to provide comparable data for analysis, interpretation, and evaluation.

Daubenmire

Page ____ of ____

Study Number	Date	Examiner	Allotment Name & Number	Pasture
Transect Number and Location			Number of Quadrats	

Plant Species	Quadrat																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

Plant Species	Quadrat																								
	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50

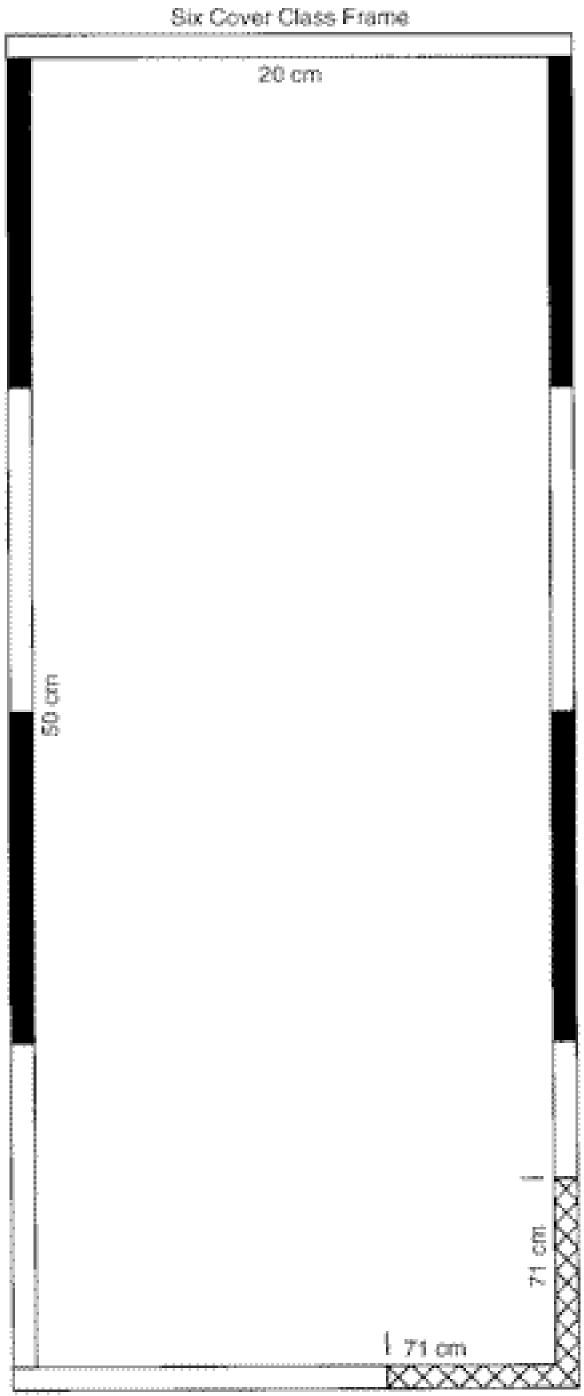
Daubenmire Summary

Page ____ of ____

Study Number	Date	Examiner	Allotment Name & Number	Pasture
Study Location				Number of Quadrats

Cover Class	Mid-Point	Species		Species		Species		Species		Species		Species		Species		Species		Species		Species		Species	
		Number	Product	Number	Product	Number	Product	Number	Product	Number	Product	Number	Product	Number	Product	Number	Product	Number	Product	Number	Product	Number	Product
1 1-5%	2.5																						
2 5-25%	15																						
3 26-50%	37.5																						
4 51-75%	62.5																						
5 76-95%	85																						
6 96-100%	97.5																						
Total canopy																							
Number of Samples																							
% canopy cover																							
Species composition																							
Frequency																							

Daubenmire Frame



The frame is made of 3/8-inch iron rod. The inside dimensions of the frame are 20 x 50 centimeters. The frame should have sharpened legs 3 centimenters long welded to each corner to help hold the frame in place.

The six cover class frame is divided into fourths by painting alternate sections of the frame different colors as illustrated. Use orange and white or red and white paint.

In one corner of the frame, delineate two sides of an area 71 millimeters square as illustrated. This area represents 5% of the quadrat area.

The painted design provides visual reference areas equal to 5, 25, 50, 75, 95, and 100% of the plot area.

LINE INTERCEPT METHOD

1. General Description The Line Intercept method consists of horizontal, linear measurements of plant intercepts along the course of a line (tape). It is designed for measuring grass or grass-like plants, forbs, shrubs, and trees. The following vegetation attributes are monitored with this method:

A. Foliar and basal cover
B. Composition (by cover)

It is important to establish a photo plot and take both close-up and general view photographs. This allows the portrayal of resource values and conditions and furnishes visual evidence of vegetation and soil changes over time.

2. Areas of Use This method is best suited for conditions in which it is easy lay out straight lines. This implies a relatively open vegetation at a height of less than 2 m.

The Line Intercept method is applicable to vegetation ranging from low herbaceous growth to the tallest forests. It is necessary to modify the length of the transect line and the precision with which the intercept points are recorded under these various conditions. For low or herbaceous vegetation, it is often desirable to use lengths of about 10m. Data should be recorded to the nearest cm. In shrubby vegetation and in forests, it if often desirable to use transects of > 100 m length. Data should be recorded to the nearest 10 cm. For vegetation with multiple strata, it is often desirable to run separate transects to deal with the different layers. The layers measured can be defined arbitrarily.

3. Advantages and Limitations The Line Intercept method is best suited where the boundaries of plant growth are relatively easy to determine. It can be adapted to sampling varying densities and types of vegetation. It is not well adapted, however, for estimating cover on single-stemmed species, dense grassland situations, litter, or gravel less than 1/2 inch in diameter. It is best suited to estimating cover on shrubs.

This technique gives quite accurate results. Accuracy is highest if the plants measured have the same growth form and similar crown diameters. Accuracy is lower when it is difficult to set up a straight line using a stretched tape. It is also necessary to be able to clearly see the projection of the canopy (or basal area) of the plant on the line. As for other techniques for examining canopy cover, if canopies intermingle or are highly irregular, it becomes difficult to say precisely where the margin of the plant's canopy is and, consequently, accuracy is affected. It is desirable to use multiple line transects, rather than a single line, to insure adequate coverage of the site and a random sample.

4. Equipment The following equipment is needed.

A. Study Location and Documentation Data form

B. Line Intercept form
C. Hammer
D. Permanent yellow or orange spray paint
E. Two stakes: 3/4 - or 1 -inch angle iron not less than 16 inches long.
F. Two tapes: 100- or 200-foot, delineated in tenths and hundredths, or a metric tape of the desired length
G. Compass
H. Steel post and driver

5. Training A minimum of training is needed to make sure the examiners understand how to lay out baselines and transects and how to make the measurements. The examiner must also be able to identify the plant species. One-half hour training and 1 day of practice to obtain consistency is adequate.

6. Establishing Studies Careful establishment of studies is a critical element in obtaining meaningful data.

A. **Site Selection** The most important factor in obtaining usable data is selecting representative areas (critical or key areas) in which to run the study. Study sites should be located within a single plant community within a single ecological site. Transects and sampling points need to be randomly located within the critical or key areas.

B. **Pilot Studies** Collect data on several pilot studies to determine the number of samples (transects or observation points) and the number and size of quadrats needed to collect a statistically valid sample.

C. **Number of Transects** Establish the minimum number of transects to achieve the desired level of precision for the key species in each study site.

D. **Length of Transect** The length of a transect is based on the density and homogeneity of the vegetation. If the vegetation is sparse, a longer transect is needed. Transects may be any length (eg. 100 feet, 200 feet, or even longer). For low or herbaceous vegetation, it is often desirable to use lengths of about 10m. Data should be recorded to the nearest cm. In shrubby vegetation and in forests, it if often desirable to use transects of > 100 m length. Data should be recorded to the nearest 10 cm. For vegetation with multiple strata, it is often desirable to run separate transects to deal with the different layers. The layers measured can be defined arbitrarily.

E. **Study Layout** Line Intercept data can be collected using either the baseline or linear study design. The baseline technique is the recommended study design.

(1) The study location stake is placed at the beginning of the baseline. After determining the bearing of the study, a stake is placed at the end of the baseline. Transects are run perpendicular to and at random distances along the baseline. Transect location stakes are placed at the beginning and end of each transect. The distance between the stakes dependents on the length of the transect. The height of the stakes depends on the height of the vegetation.

Transect location stakes may be left in place as permanent markers or removed at the conclusion of the study. Permanently marking transects will result in greater power to detect change.

(2) Stretch the transect tapes between stakes as close to the ground as possible, with the zero point of the tape aligned on the baseline (the beginning point of the transect). Do not allow vegetation to deflect the alignment of the tape.

F. **Reference Post or Point** Permanently mark the location of each study with a reference post and a study location stake.

G. **Study Identification** Number studies for proper identification to ensure that the data collected can be positively associated with specific sites on the ground.

H. **Study Documentation** Document pertinent information concerning the study on the Study Location and Documentation Data form .

7. Taking Photographs Establish photo plots.

8. Sampling Process In addition to collecting the specific studies data, general observations should be made of the study sites.

Proceed down the tape stretched along the transect line and measure the horizontal linear length of each plant that intercepts the line. Measure grasses and grass-like plants, along with rosette-forming plants, at ground level. For forbs, shrubs, and trees, measure the vertical projection of the foliar cover intercepting one side of the tape. Be sure not to inadvertently move the tape to include or exclude certain plants. If the measurements are made in 10ths and 100ths of feet, the totals are easily converted to percentages. The measurements are recorded by species on the Line Intercept form.

9. Calculations Make the calculations and record the results on the Line Intercept form.

A. **Cover**

(1) Calculate the percent cover of each plant species by totaling the intercept measurements for all individuals of that species along the transect line and convert this total to a percent.

(2) Where the measurements are made in 10ths and 100ths of feet along a 100-foot transect, the totals for each species are the cover percentages.

(3) Calculate the total cover measured on the transect by adding the cover percentages for all the species. This total could exceed 100% if the intercepts of overlapping canopies are recorded.

B. **Composition** With this method, species composition is based on the percent cover of each species. Calculate percent composition by dividing the percent cover for each plant species by the total cover for all plant species.

10. Data Analysis It is important to realize that each transect is a single sampling unit. For trend analysis permanent sampling units are suggested. If permanent transects are monitored, use the appropriate paired analysis technique. Use either a paired t-test or the nonparametric Wilcoxon signed rank test when testing for change between years. When comparing more than two sampling periods, use repeated measures ANOVA. If the transects are not permanently marked, use the appropriate nonpaired test.

11. Cost Approximately 1 hour per 25 intercepts. This can be a 10 m transect in herbaceous vegetation to a 250 m transect in a forest.

Line Intercept

Page ____ of ____

Study Number	Date	Examiner	Allotment Name & Number	Pasture
Line Length	Transect Location			

NOTES (Use other side or another page, if necessary)	Grass Species							Forb Species						Shrub Species					NOTES
																			Totals
Totals																			
% Cover																			
% Comp																			

00%

1

POINT-INTERCEPT METHOD

Sighting Devices, Pin Frames, and Point Frames

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1. General Description The Point-Intercept method consists of employing a sighting device or pin/point frame along a set of transects to arrive at an estimate of cover. It measures cover for individual species, total cover, and species composition by cover. Point-Intercept is the method used in the NPS Fire Monitoring Handbook to estimate cover.

It is important to establish a photo plot and take both close-up and general view photographs. This allows the portrayal of resource values and conditions and furnishes visual evidence of vegetation and soil changes over time.

2. Areas of Use This method is suited to all vegetation types less than about 1.5 meters in height. This is because sighting devices and pin/point frames require the observer to look down on the vegetation from above in a vertical line with the ground. If the sighting device allows upward viewing, the method can also be used to estimate the canopy cover of large shrubs and trees.

3 . Advantages and Limitations Point interception measurements are highly repeatable and lead to more precise measurements than cover estimates using quadrats. The method is more efficient than line intercept techniques, at least for herbaceous vegetation, and it is the best method of determining ground cover and the cover of the more dominant species. Given the choice between sighting devices and pin/point frames, the optical sighting device is preferable.

A limitation of point-intercept sampling is the difficulty in picking up the minor species in the community without using a very large number of points. In addition, wind will increase the time required to complete a study because of the need to view a stationary plant.

One limitation that is specific to the use of point frames is that a given number of points grouped in frames gives less precise estimates of cover than the same number of points distributed individually. In fact, single-pin measurements require only one-third as many points as when point frames are used . Another problem with frames is that they overestimate the cover of large or dumped plants because the same plant is intercepted by different points on the same frame. This problem is overcome with the method described here by treating the frames as the sampling units (rather than using the individual points as sampling units). However, this approach doesn't change the fact that more points must be read than when the points are independent.

Use of a pin frame device (as opposed to a grid frame made of crossing strings) will result in overestimation of cover because the pins have finite diameter. The use of a sharpened pin will greatly reduce overestimation when only the point of the pin is used to record a hit or a miss.

4. Equipment The following equipment is needed.

A. Study Location and Documentation Data form

B. Cover Data form

C. Sighting device (A sighting device is available commercially from ESCO, P.O. Box 18775, Boulder, Colorado 80308)
D. Tripod for mounting sighting device
E. Panhead for tripod (makes possible rapid positioning of sighting device)
F. Pin or point frame. This can be a pin frame usually with 10 pins or a point frame , consisting of two superimposed string grids mounted one above the other on three adjustable legs.
G. Hammer
H. Permanent yellow or orange spray paint
I. Tally counter (optional)
J. Two stakes: 3/4 - or I -inch angle iron not less than 16 inches long
K. Compass
L. Steel post and driver
M. Tape: 50-, 100-, or 200-foot delineated in tenths and hundreds or a metric tape of the desired length.

5. Training A minimum of training is needed to make sure the examiners understand how to lay out baselines and transects and position and read the specific sighting device or pin/point frame being employed. The examiners must learn what constitutes a "hit". The technique should take about 1/2 hr training instruction and 1 day of practice to develop consistency. The examiners must also be able to identify the plant species.

6. Establishing Studies Careful establishment of studies is a critical element in obtaining meaningful data.

A. **Site Selection** The most important factor in obtaining usable data is selecting representative areas (critical or key areas) in which to run the study. Study sites should be located within a single plant community within a single ecological site. Transects and sampling points need to be randomly located within the critical or key areas (see Section III).

B. **Pilot Studies** Collect data on several pilot studies to determine the number of samples (transects or observation points) and the number and size of quadrats needed to collect a statistically valid sample.

C. **Number of Studies** Establish a minimum of one study on each study site; establish more if needed (see Section II.D and III.B).

D. **Study Layout** Data can be collected using the baseline, macroplot, or linear study designs. The baseline technique is the recommended procedure.

E. **Reference Post or Point** Permanently mark the location of each study with a reference post and a study location stake.

F. **Study Identification** Number studies for proper identification to ensure that the data collected can be positively associated with specific sites on the ground.

G. **Study Documentation** Document pertinent information concerning the study on the Study

Location and Documentation Data form.

7. Taking Photographs Establish photo plots.

8. Sampling Process In addition to collecting the specific studies data, general observations should be made of the study sites.

A. **Transects** Run a series of transects perpendicular to the baseline in both directions. The beginning points for each transect are randomly selected points along the baseline and the direction of each transect is also randomly determined.

To ensure that both transects and points/point frames are independent, spacing between transects and between points/point frames on each transect should be greater than the average diameter of the largest plants likely to be sampled. (If only basal cover is to be sampled, this diameter is the basal diameter; otherwise, it is canopy diameter.)

B. **Sampling along Transects** The first point/point frame read on each transect should be randomly determined. After the first point/point frame is read, all others are spaced the predetermined interval from the first point. If a tape is used for the transects, always read on the same side of the tape. (One of the devices manufactured by ESCO employs a mounting arm that is exactly 0.5 m long from tripod pivot to the axis of point projection. With this device, two points along each transect can be read with each placement of the tripod (assuming that I m is the selected interval between points). If this device is used, the tripod is placed at 2 m intervals along the tape (or at a number of paces approximating 2 m if no tape is used), the arm is rotated toward the baseline, the intercepted object is recorded, the arm rotated 180 degrees, the next intercepted object is recorded, and so on.)

(1) **Sighting Device** Determine hits by sighting through the device and recording the cover category in the cross hairs.

(2) **Pin/point frames** Determine hits by recording the cover category intercepted by each of the points. For pin frames, this is the cover category hit by each pin; for grid frames, this is the cover category determined by sighting through the "cross hairs" formed by each of the intersections of strings.

Hits are recorded on the Cover Data form in the following categories: vegetation (by plant species), litter, gravel, stone, and bare ground. Prior to recording data, the examiner needs to determine if canopy/foliar cover or basal cover (or both) will be recorded and if hits will be recorded in more than one canopy layer. For sighting devices and some pin/point frames, recording hits in more than one canopy layer requires that upper layers be temporarily moved out of the way to provide a direct line of sight to the lower canopy layers.

C. **Paired Samples** If the data are to be analyzed as paired samples, each transect should be permanently marked the first year at both ends. In each subsequent year of measurement, a tape should be run from one end to the other and the points/point frames read at the selected intervals along the transect. This process should then be repeated for each transect.

D. **Independent Samples** If the data are to be analyzed as independent samples, the transects do not have to be permanently marked. In this case, it is sufficient to pace each transect, taking measurements at each specified pace interval. The observer must ensure, however, that no bias is introduced by subconsciously "choosing" the point to be read. Such bias can be avoided by looking at the horizon when placing the tripod down.

9. Calculations Make the calculations and record the results on the Cover Data form.

A. **Cover of Individual Plants, Litter, Gravel, Stone, and Bare Ground**

(1) **Paired samples** Calculate the percent cover of each species along each transect by totaling all of the "hits" for that species along the transect, dividing the hits by the total number of points along the transect, and multiplying by 100. Calculate the total percent cover for the species in the sampled area by adding together all the transect cover values for the species and dividing by the number of transects. Do the same for litter, gravel, stone, and bare ground.

When point frames are used, the point frames themselves can be analyzed as sampling units. In this case, percent cover of each species is calculated for each point frame. Percent cover is calculated by totaling all of the "hits" for that species in one frame, dividing the hits by the total number of points in that frame, and multiplying by I 00. In this situation, cover data for each frame must be recorded separately on one form or on separate forms.

(2) **Independent samples: Sighting device and Pin frames** Calculate the percent cover of each species in the study area as a whole by totaling all the "hits" for that species along all of the transects, dividing by the total number of points in the study, and multiplying by 100. Do the same for litter, gravel, stone, and bare ground.

(3) **Independent samples: Point frames** For independent samples, the frames themselves can be considered the sampling units. Calculate the percent cover of each species in each point frame by totaling all the "hits" for that species in the frame, dividing the hits by the total number of points in the frame, and multiplying by 100. Calculate the total percent cover for the species in the sampled area by adding together all of the point frame cover values for the species and dividing by the number of point frames. Do the same for litter, gravel, stone, and bare ground.

(4) **Total vegetation cover** Calculate total vegetation cover by adding the study area cover percentages for all plant species. This total could exceed 100 percent if multiple hits (overlapping canopies) were recorded at each point along the transect.

B. **Species Composition** Species composition is based on the percent cover of the various species. Calculate percent composition by dividing the percent cover for each plant species by the total cover for all plant species.

10. Data Analysis The method of data analysis depends upon whether or not the transects are permanent.

A. **Permanent Transects** If the transects are permanent, the transects or point frames are the sampling units. Either a paired t test or the nonparametric Wilcoxon signed rank test is used to test for significant change in average cover between two sampling periods. Repeated measures analysis of variance is used to test for significant change in average cover between three or more sampling periods.

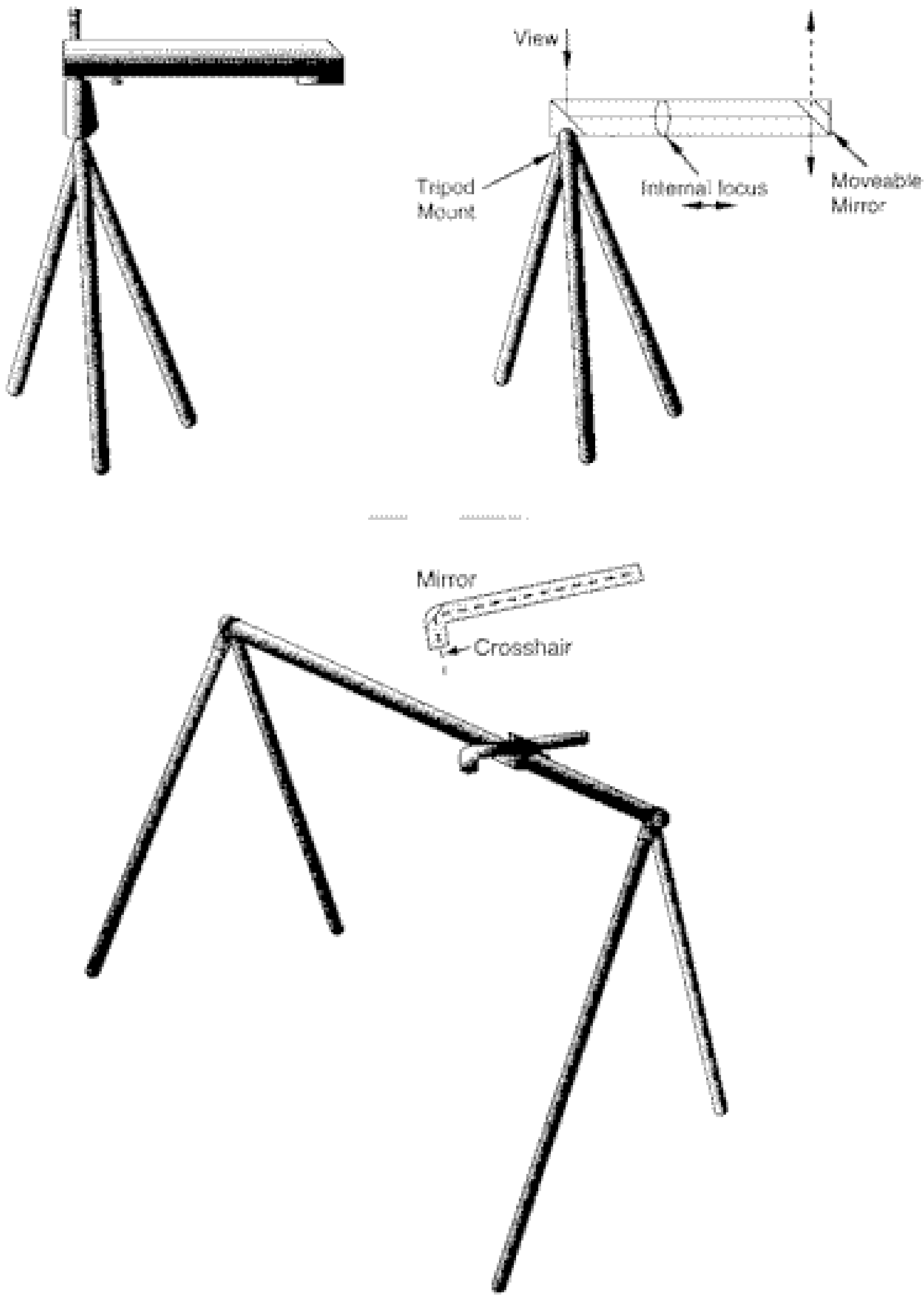
B. **Transects Not Permanent** If the transects are not permanent, that is, if they are randomly located in each sampling period, then the samples are independent and the points can be treated as the sampling units.

Sighting Devices: Analysis consists of a Chi Square contingency table analysis to test for significant change between years in numbers of "hits" on the key species, other plant species, or cover classes.

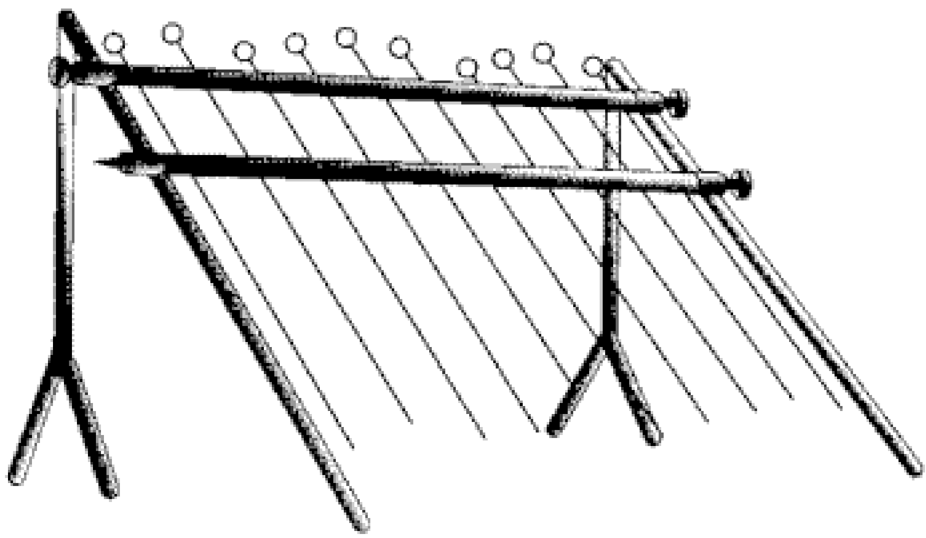
Point Frames: Analysis consists of testing for significant changes in average cover between sampling periods using the independent sample t test or the nonparametric Mann Whiitney U test. Independent sample analysis of variance or the nonparametric Kruskal-Wallis test is used to test for significant changes in average cover between three or more years.

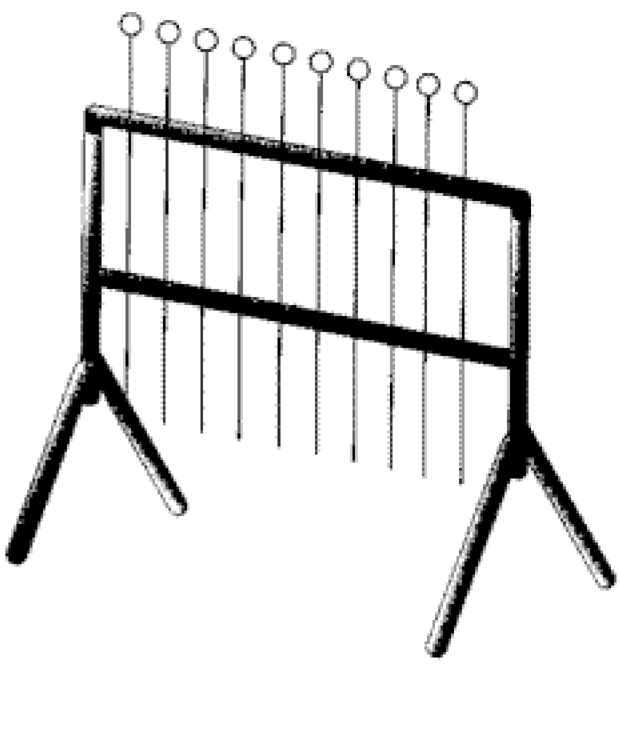
11. Cost Ten minutes per 10 pins (for a 10 pin frame).

Examples of Sighting Devices

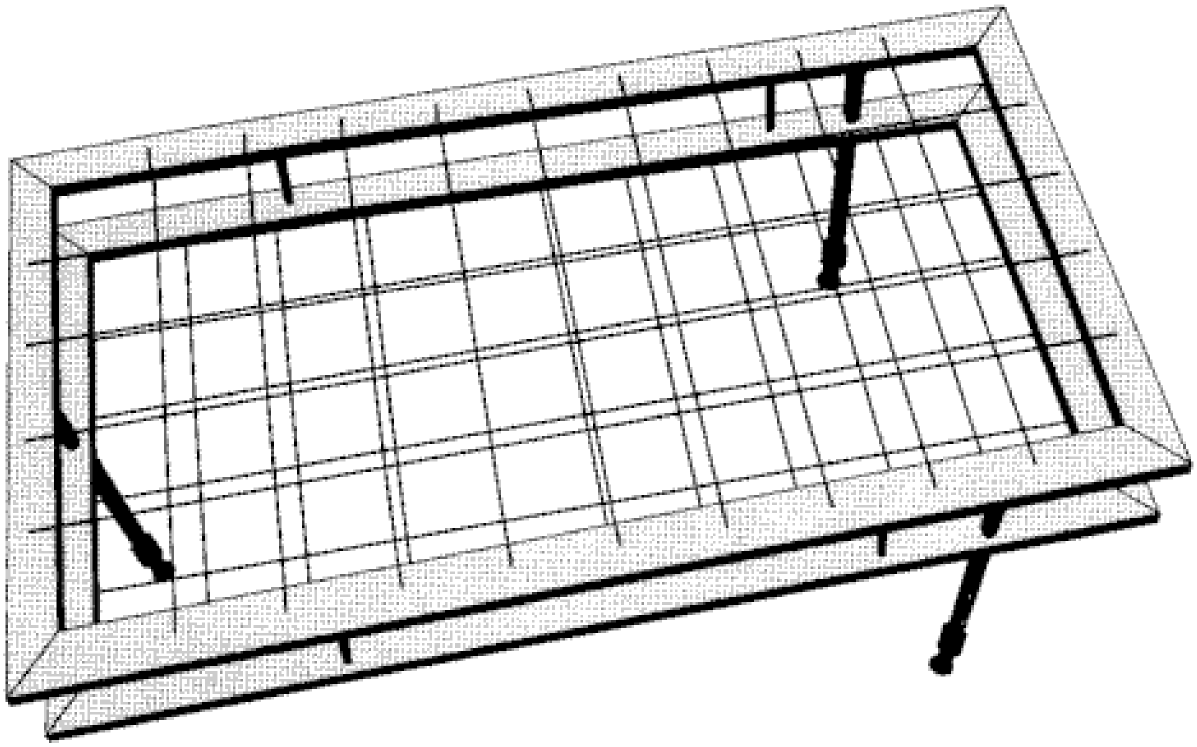


Examples of Pin Frames





Example of a Point Frame



STEP POINT METHOD

1. General Description The Step-Point Method involves making observations along a transect at specified intervals, using a pin to record cover "hits." It measures cover for individual species, total cover, and species composition by cover.

It is important to establish a photo plot and take both close-up and general view photographs. This allows the portrayal of resource values and conditions and furnishes visual evidence of vegetation and soil changes over time.

2 . Areas of Use This method is best suited for use with bare ground, litter, grasses, forbs, as well as low shrubs, but can be used large shrubs and trees. The greater the structure to the community, the more difficult it becomes to determine "hits" due to parallax, observer bias, wind, etc. This method is good for an initial overview of an area not yet subjected to intensive monitoring.

3 . Advantages and Limitations. This method is relatively simple and easy to use as long as careful consideration is given to the vegetation type to which it is applied. It is suitable for measuring major characteristics of the ground and vegetation cover of an area. Large areas can easily be sampled, particularly if the cover is reasonably uniform. It is possible to collect a fairly large number of samples within a relatively short time.

A limitation of this method is that there can be extreme variation in the data collected among examiners when sample sizes are small. Tall or armored vegetation reduces the ability to pace in a straight line, and the offset for obstructions described in the procedures adds bias to the data collection by avoiding certain components of the community. Another limitation is that less predominant plant species may not be hit on the transects and therefore do not show up in the study records. The literature contains numerous studies utilizing point intercept procedures that required point densities ranging from 300 to 39,000 in order to adequately sample for minor species. One major consideration in the use of this method is to assure that a sharpened pin is used and that only the point is used to record "hits." Pins have finite diameters and therefore overestimate cover (Goodall 1952). Another limitation of this method is that statistical analysis of the data is suspect unless two and preferably more transects are run per site.

This method is rather crude. Errors in pacing the transect invariably occur, usually resulting in underestimation of shrubs and other obstacles. In addition, its is often hard to eliminate errors caused by moving vegetation out of its original position. A sharpened pin may diminish some of this bias. Estimation of taller vegetation (e.g., trees) by line of sight is even less accurate than the results for low grasses and forbs, but using the vertical rod to project upward will give results whose accuracy is comparable to those for herbs. Error can also result for the uniform spacing of points. This can be minimized by using several short transects, rather than one or two long ones.

4. Equipment The following equipment is needed.

A. Study Location and Documentation Data form

B. Cover Data form
C. Permanent yellow or orange spray paint
D. Tally counter (optional)
E. One stake: 3/4- or I -inch angle iron not less than 16 inches long
F. 3-foot long, 3/16th-inch diameter sharpened pin
G. Compass
H. Steel post and driver

5. Training A minimum amount of training is needed for this method. The technique can be learned in less than 1 hr. A 1/2 hr practice session in the field is usually adequate. Complex communities may require 4 hr of practice. Examiners must be able to identify the plant species, be familiar with the ground-level cover categories, know how to collect canopy or foliar cover data, and know how to collect cover data using a pin and notch in the boot.

6. Establishing Studies Careful establishment of studies is a critical element in obtaining meaningful data.

A. **Site Selection** The most important factor in obtaining usable data is selecting representative areas (critical or key areas) in which to run the study. Study sites should be located within a single plant community within a single ecological site. Transects and sampling points need to be randomly located within the critical or key areas.

B. **Pilot Studies** Collect data on several pilot studies to determine the number of samples (transects or observation points) and the number and size of quadrats needed to collect a statistically valid sample.

C. **Number of Transects** Establish the minimum number of transects to achieve the desired level of precision.

D. **Study Layout** Data can be collected using either the baseline or linear study designs. The linear technique is the one most often used.

E. **Reference Post or Point** Permanently mark the location of each study with a reference post and a study location stake.

F. **Study Identification** Number studies for proper identification to ensure that the data collected can be positively associated with specific sites on the ground.

G. **Study Documentation** Document pertinent information concerning the study on the Study Location and Documentation Data form.

7. Taking Photographs Establish photo plots.

8. Sampling Process In addition to collecting the specific studies data, general observations should be made of the study sites

A. **Running a Transect** Determine the transect bearing and select a prominent distant landmark such as a peak, rocky point, etc., that can be used as the transect bearing point.

(1) Start a transect by randomly selecting a point along the transect bearing and reading the first hit (observation point).

(2) Read hits at specified intervals by placing the heel of the boot on the ground with the sole of the boot at a 30-degree angle to the ground. Place the pin into the 3/16th inch wide by 1/8th inch deep notch in the toe of the boot and vertically lower the pin until it either intersects an herbaceous plant or the ground for the specified number of hits. It is recommended that the interval be a minimum of 5 paces. To lengthen the transect, increase the distance between hits (10 paces, 20 paces, etc.) -

(3) When obstructions such as trees, cactus, ledge rock, etc., are encountered, sidestep at 90' from the transect line and continue pacing parallel to the transect to avoid the obstructions. Return to the original transect line as soon as possible by sidestepping at 90' in the opposite direction. Continue pacing along the transect bearing. If the obstruction is determined to be a highly important component of the community, this information can be recorded qualitatively on the back of the form.

(4) In most cases, do not count hits along portions of a transect that have been unnaturally disturbed, such as roads or trails. When such areas are encountered, proceed three paces past the disturbance before resuming the reading of hits along the transect line.

B. **Collecting Cover Data** At each observation point, identify the ground level or basal hit with the point of the pin and record the data by dot count tally by category and/or plant species code in the appropriate section of the Cover Data form . If there is a vegetation canopy layer, lower the pin through the vegetation until a basal or ground level hit is determined. Record the basal or ground level hit and any subsequent vegetation layers that intersect the pin. For vegetation structure above 3-feet (length of pin), a visual observation of plant intercepts above the notch in the boot can be made and recorded as additional canopy or foliar level hits on the data form.

(1) Ground-level or basal hits

(a) Ground-level hits (excluding basal vegetation hits) will fall into four cover categories. They can be redefined and/or additional categories added, depending on the data needed. The four categories are:

L - Litter
B - Bare ground
G - Gravel (particle sizes between 1/12 inch and 10 inches)
S - Stone (greater than 10 inches)

(b) Record the ground-level hits by dot count tally by ground-level cover category in the Ground-Level Cover section of the form, except where there are ground-level and, basal or canopy cover hit combinations. In this situation, use the Basal and Canopy/Foliar Cover section of the form.

(c) Basal hits on live vegetation are identified by species (includes mosses and lichens more than 1/16 inch thick). To count as a basal hit on live vegetation, the plant crown at or below a 1-inch height above the ground MUST be intercepted by the pin.

(d) Enter the appropriate plant species code in the Basal or Ground-Level Column in the Basal and Canopy/Foliar Cover section of the form.

(e) Enter a dot count tally for each basal hit on a species in the Dot Count Column in the Basal and Canopy/Foliar Cover section of the form when the plant species code is first entered on the form. Enter an additional dot count tally each time there is a basal hit on that species on the transect, except where there are basal and canopy/foliar cover hit combinations.

(2) Ground-level or basal and canopy/foliar cover hit combinations

(a) Identify the ground-level or basal hit, as well as any canopy cover hit(s) below 3 feet in height, intercepted at each point by the pin. For canopy cover above 3 feet, use line-of-sight observations directly perpendicular to the notch in the boot.

(b) Enter the appropriate ground-level cover category code and/or plant species code for each level of hit (up to four levels) in the appropriate columns in the Basal and Canopy/Foliar Cover section of the form .

(c) Enter a dot count tally for each ground-level or basal and canopy/foliar cover hit combination when it is first entered on the form and each time this same combination is encountered on the transect.

(d) Enclose plant species codes for vegetation cover hits more than 20 feet above ground level in brackets [ ].

9. Calculations Calculate the percent cover for each cover category by dividing the number of hits for each category by the total number of hits for all categories, including hits on vegetation.

A. **Ground Cove**r Ground cover is determined by dividing the total number of hits for all categories except bare ground by the total number of hits (including bare ground).

B. **Canopy/Foliar Cover** Canopy/Foliar cover is determined by dividing the total number of hits on vegetation (includes all basal and canopy/foliar hits) by the total number of hits.

C. **Basal Cover** Basal cover is determined by dividing the number of basal hits by the total number of hits.

10. Data Analysis

A. When transects are the sampling units: For trend analysis, permanent sampling units are suggested. If permanent transects are monitored, use the appropriate paired analysis technique to compare change in average cover by species and cover class. When comparing more than two sampling periods, use repeated measures ANOVA. If the transects are not permanently marked, use the appropriate nonpaired test.

B. When points are the sampling units: To determine if the change between sampling periods is significant, use Chi Square analysis of variance for cover data.

11. Costs One-half to 1 hr per 200 m transect.

Page ____ of ____

Cover Data

Study Number	Date	Examiner	Pasture
Allotment Name & Number	Study Location		Number of Points

Ground-Level Cover

Category	**B** Bare Ground	**L** Litter	**G** Gravel (2mm-10")	**S** Stone (>10")	Vegetation	Total
Dot Count						
Total Hits						
% Cover						

Basal and Canopy/Foliar Cover

Bsl or Grnd-Lev	Level 1	Level 2	Level 3	Dot Count	Total Hits
				Total	

Notes (use other side or another page)

COVER BOARD METHOD

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1. General Description The Cover Board method uses a profile board or density board to estimate the vertical area of a board covered by vegetation from a specified distance away. This technique is designed to evaluate changes in the vegetation structure over time. The following vegetation attributes are monitored using this method:

A. Vertical cover
B. Structure

It is important to establish a photo plot and take both close-up and general view photographs. This allows the portrayal of resource values and conditions and furnishes visual evidence of vegetation and soil changes over time.

2. Areas of Use This method is applicable to a wide variety of vegetation types. It should be used with those that show potential for changes, such as woody riparian vegetation.

3 . Advantages and Limitations The Cover Board technique is a fast and easily duplicated procedure. The size of the board can be modified to meet the purpose of the study.

It is moderately accurate for measuring vertical cover. However, the vertical cover is usually used to measure something else such as "perceived sight distance" for a given wildlife species, or for estimation of the quantity of vegetation at a give height in a stand. Its accuracy under these conditions becomes largely a function of the extent to which there is a direct relationship between the measured vertical cover and the variable of which it is used as an indicator. Precision is largely a function of one's ability to ocularly estimate the amount of the board which is obscured. (For characterizing a site, precision also becomes a function of the sample size.)

The major sources of error include selecting points which are not truly random (e.g., avoiding standing in briar patches when the randomly selected location would put the examiner there), not moving along the same direction in a straight line, and errors in the ocular estimation of the amount of the board which is covered. The error in ocular estimation can be minimized by using a "comparator". It is probably minimal in the variable distance approach.

4. Equipment The following equipment is needed.

A. Study Location and Documentation Data form
B. Density or Profile Board Method forms
C. Cover board
D. One stake: 3/4- or 1 -inch angle iron not less than 16 inches long
E. Hammer
F. Permanent yellow or orange spray paint
G. Compass
H. Steel post and driver

5. Training The accuracy of the data depends on the training and ability of the examiners. They must receive adequate and consistent training in laying out transects. A minimum of training is needed to make sure the examiners understand how to position the cover board and estimate percent cover. Examiners must also be able to identify plant species if estimates are to be made be species.

6. Establishing Studies Careful establishment of studies is a critical element in obtaining meaningful data.

A. **Site Selection** The most important factor in obtaining usable data is selecting representative areas (critical or key areas) in which to run the study. Study sites should be located within a single plant community within a single ecological site. Transects and sampling points need to be randomly located within the critical or key areas (see Section III).

B. **Pilot Studies** Collect data on several pilot studies to determine the number of samples (transects or observation points) and the number and size of quadrats needed to collect a statistically valid sample.

C. **Number of Studies** Establish a minimum of one study on each study site; establish more if needed (see Section II.D and III.B).

D. **Study Layout** Data can be collected using either the baseline or linear study designs described in Section III.A.2 beginning on page 8. The linear technique is the most often used procedure.

(1) **Linear transect**

(a) Determine the transect bearing and select a prominent distant landmark such as a peak, rocky point, etc., that can be used as the transect bearing point.

(b) Randomly select an observation point along the transect. The cover board will be placed 15 feet from this observation point in a random direction. One way to select a random direction is by using the second hand on a standard watch. Look at the watch and note the direction the second hand is pointing. Another way is to randomly select a three digit number between 0 and 360 from a random number table to represent the degrees on a compass. After taking the initial reading, remain at the observation point on the transect and take three additional readings at 90-degree angles from the original bearing and at the same distance (15 feet). Additional observation points can be established at specified intervals from the initial observation point along the transect bearing. A piece of angle iron or rebar should be placed at each observation point for easy relocation.

(c) Be sure to record the bearing from the observation point to each cover board location on the Cover Board form.

(2) Center location

(a) An alternative method of establishing a transect is to randomly select a center point within an area to be sampled. Set angle iron or rebar at four randomly selected points 15 feet from the center point. Place the cover board at each rebar, facing the center post. Take readings and photographs of the cover board from the center point. Additional center points can be established as needed.

(b) Be sure to record the bearing and distance to each center point location from the reference post on the Cover Board form (see Illustrations 18 and 19).

E. **Reference Post or Point** Permanently mark the location of each study with a reference post and a study location stake.

F. **Study Identification** Number studies for proper identification to ensure that the data collected can be positively associated with specific sites on the ground.

G. **Study Documentation** Document pertinent information concerning the study on the Study Location and Documentation Data form.

7. Taking Photographs Establish photo plots.

8. Sampling Process In addition to collecting the specific studies data, general observations should be made of the study sites.

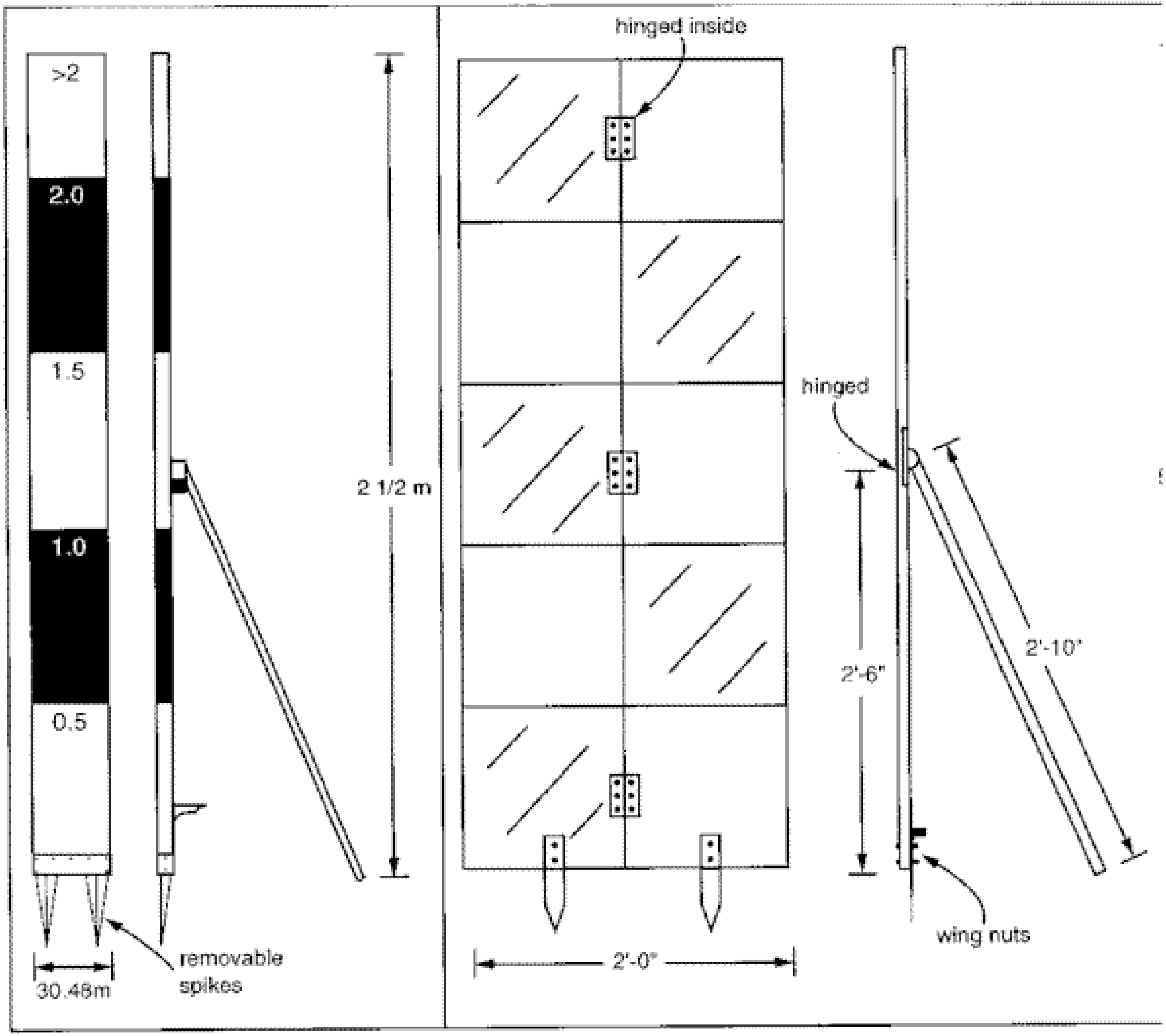
Position the cover board in the appropriate locations 15 feet from the observation point. Record the cover class from the modified Daubenmire cover classes (see Table 2) for each segment of the cover board (see Illustration 20). Depending on the objectives, vegetative cover can be recorded by species or simply for the total of all species. Cover can also be recorded as a straight percentage.

Cover Class	Range of Coverage	Midpoint of Range
0	0%	0%
T	< 1%	0.5%
1	1 to 5%	3.0%
2	5 to 25%	15.0%
3	25 to 50%	37.5%
4	50 to 75%	62.5%
5	75 to 95%	85.0%
6	95 to 100%	97.50%

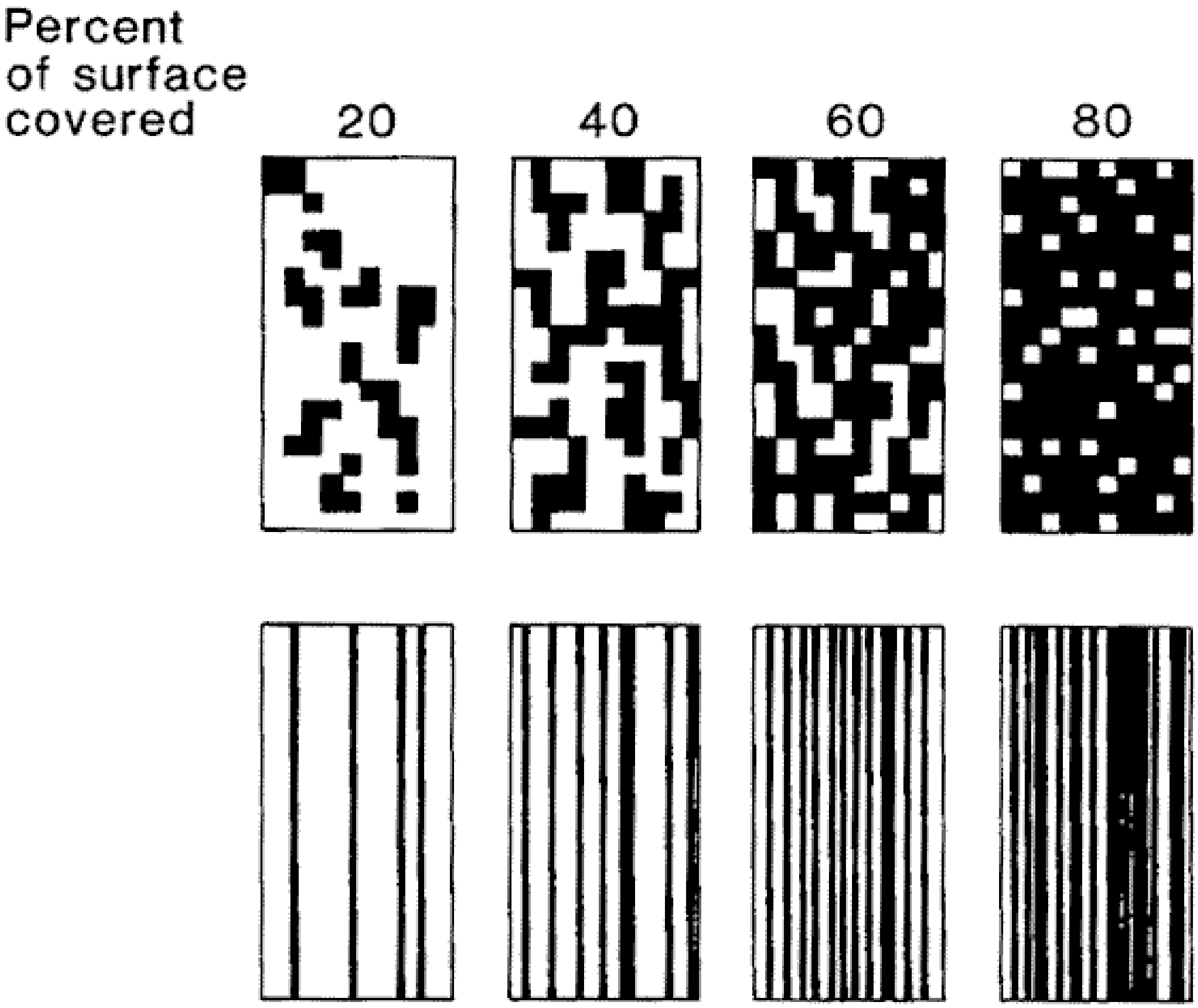
9. Calculations for Vertical Canopy Cover Calculate the average "cover score" by layer. The midpoint of each cover class is used to calculate the average cover for each layer or for the entire transect when using cover classes. If actual percentage estimates are made, calculate an average cover value by averaging cover for each layer. For a total cover average, the calculation involves summing the cover values for all layers and dividing by the number of layers.

1**0. Data Analysis** For trend analysis, permanent sampling units are suggested. If permanent transects are monitored, use the appropriate paired analysis technique. If the transects are not permanently marked, use the appropriate nonpaired test. When comparing more than two sampling periods, use repeated measures ANOVA.

Examples of Cover Boards



Profile Board **Density Board**


Percent
of surface
covered
20
40
60
80

Page ____ of ____

Cover Board Method
Density Board

Study Number	Date	Examiner

Allotment Name & Number	Pasture

Density Board Location -

Percent Cover

	Plot 1		Plot 2		Plot 3		Plot 4		Avg. Cover
5									
4									
3									
2									
1									

Page ____ of ____

Cover Board Method
Profile Board

Study Number	Date	Examiner	Allotment Name & Number	Pasture

Bearing & Distance	Study Location

Observation Points	Cover Board Heights	Cover Readings—Daubenmire Classes[1] or Percentages																				
		Species																				Average
		Bearing				Total	Bearing				Total	Bearing				Total	Bearing				Total	
	0.0 - 0.5m 0.5 - 1.0m 1.0 - 1.5m 1.5 - 2.0m																					
	0.0 - 0.5m 0.5 - 1.0m 1.0 - 1.5m 1.5 - 2.0m																					
	0.0 - 0.5m 0.5 - 1.0m 1.0 - 1.5m 1.5 - 2.0m																					
	0.0 - 0.5m 0.5 - 1.0m 1.0 - 1.5m 1.5 - 2.0m																					

Comments:

[1] Daubenmire Classes: 0=0; 1=1-5; 2=5-25; 3=25-50; 4=50-75; 5=75-95; 6=95-100

BILTMORE STICK

---

1. Variable Estimated

Stem diameter of an individual tree.

2. Description

In summary, the diameter of an individual tree stem is estimated using a stick graduated with a special scale. The stick is held against the tree, and the estimated diameter is read directly off the stick.

If the desired variable is the average for the trees on a site, the tree to be measured should be chosen randomly.

On approaching the tree, one should estimate its diameter and grasp the Biltmore stick near the middle. Place the stick horizontally against the tree trunk at the height to be measured (usually "breast height", 1.4 m or 4.5 ft, Fig. 7). The stick should be perpendicular to the eye. With one eye closed, one aligns the stick so that the center of the stick is the appropriate distance from the eye (usually 64 cm or 25 in.) with the zero end of the scale aligned with the edge of the tree trunk. Without moving one's head, read the number off the scale which aligns with the other side of the tree trunk.

3. Accuracy

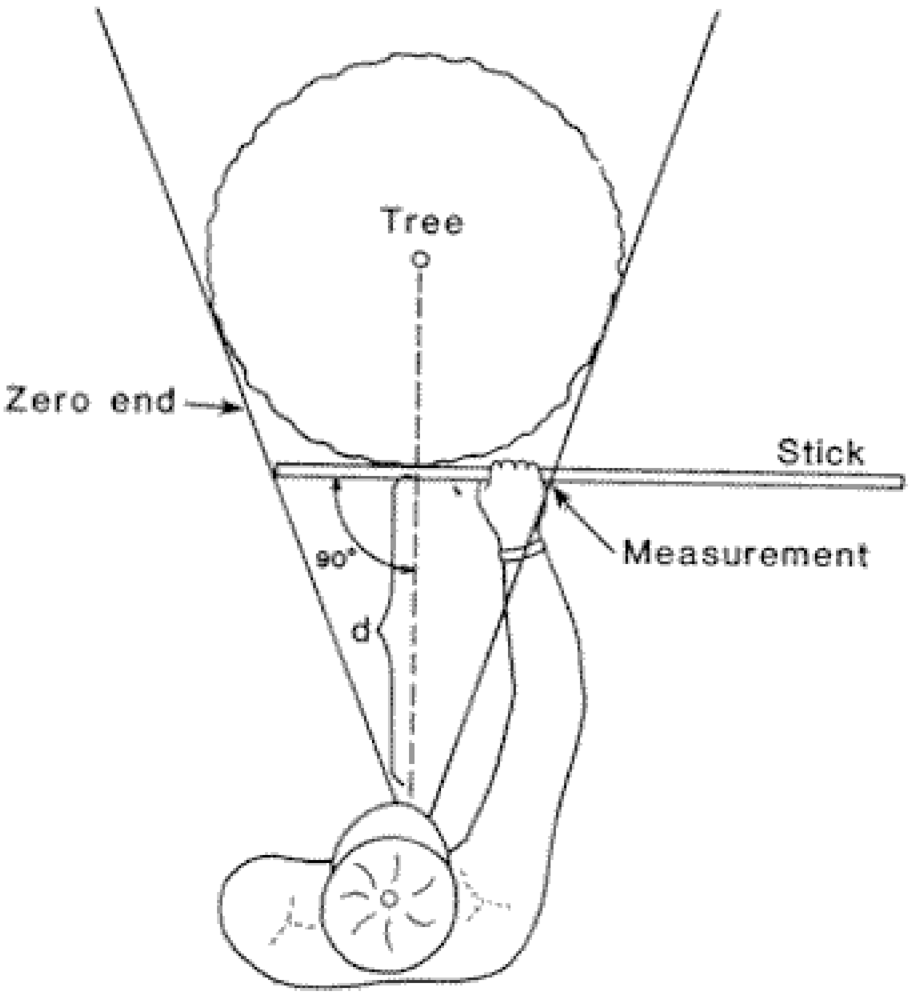
This technique is crude. Sources of error include deviations of the tree from circular in cross section and, most importantly, errors in holding the stick horizontally, perpendicular to the eye, and precisely the specified distance from the eye. Accuracy increases as tree size decreases. Diameter readings for small trees can be measured to about the nearest 2 cm.

4. Application Notes

This technique is inexpensive. It is usually the best technique if 10 accuracy is acceptable. One person can apply the technique without difficulty. It is appropriate except where tree growth form deviates radically from circular.

5. Training One-half hour.

6. Equipment Biltmore stick ($20-$25; Forestry Suppliers, Inc. 1980).



d = Specified distance between eye and tree trunk for the Biltmore stick being used

Figure 7. Use of the Biltmore Stick to estimate the diameter of a tree.

BITTERLICH METHOD

VARIABLE PLOT SAMPLING, PRISM CRUISING, OR THE SHRUB ANGLE GAUGE

---

1. Variables Estimated

Basal cover of trees and tall shrubs, canopy cover of shrubs.

2. Description

In summary, random points are selected in the plot. From each point, a count is made of all plants larger than a certain critical size (which is a function of the diameter of the plant and its distance from the sample point).

Within the site, a random point is selected. The observer stands close to the point, and turns 360' while keeping the gauge directly over the sample point. Each plant seen as the observer turns is inspected using an angle gauge (see equipment section, below). The plant is usually viewed at breast height (1.4 m or 4.5 ft) for trees, or at the widest point for canopy cover of shrubs. If the tree or shrub viewed is sufficiently large or sufficiently close to be wider than the critical angle, it is counted. (See instructions with the gauge used). It is necessary to be careful not to count the first plant twice. The procedure is repeated at several sample points.

For accurate results, it is important that these measurements be made horizontally or corrected for slope (see below). If the observer is measuring low shrubs, it may be necessary to stoop or lie down to get a horizontal measurement. If one is making measurements on a slope, calculated cover will be less than actual cover. For best results, a slope-correcting angle gauge (such as the Relaskop) should be used. If one is not available and small errors are acceptable, ignoring gentle slopes is justified. If the slope is less than 171, the error due to ignoring slope will be less than 5%. For accurate results, the count at each sample point should be divided by the cosine of the slope angle at that point (i.e., multiplied by the secant). The gauge must be perpendicular to the line of sight and vertical (not tilted to the left or right). When small errors are acceptable, individual plants that fall precisely on the critical angle should be counted as one half (Fig. 11). When accurate results are needed, borderline plants should be examined by measurement. When measuring, a plant should be counted if:

Percent	Metric	English
$D^2 <= (0.174 W^2) / BAF$	$D^2 <= (0.25 W^2) / BAF$	$D^2 <= (75.625 W^2) / BAF$

where
D = distance from sample point to center of plant (m for percent and metric, ft for English)
W = width (diameter) of plant (cm for percent and metric, in for English)
BAF = basal area factor (percent cover/plant, MI/ha plant, or ft2 /ac plant)

It is more accurate to count as "in" all plants that clearly are, and to measure D and W for each plant that is "borderline.11

No plant should be counted more than once from a single sample point, even though it may be more than twice as wide as the critical angle. From different sample points, however, it should be counted every time it is larger than the critical angle.

Basal cover is calculated with the following formula. The angle gauge's "basal area factor" (BAF) must be known. (If unknown, this may be determined as described in the Equipment section below).

B = (Ên)/p (BAF)

where
B = basal area (M2 /ha or ft2 /ac)
Ên = total number plants counted at all sample points
p = number of sample points
BAF = basal area factor (M2 /ha plant, or ft2 /ac plant)

Basal area in M^2 /ha or ft^2/ac can be converted to basal cover in percent by multiplying by a conversion factor. The conversion factor for basal area expressed in ml/ha = 100/10,000 = 0.01. The conversion factor for ft^2 /ac = 100/43,560 = 0.0023.

3. Accuracy

This technique can be moderately accurate. The principal sources of error are in systematic errors in using the angle gauge (e.g., systematically including more plants than should be included, or an inaccurate gauge) and deviations of the plants from circular cross section. Error can be introduced if sample points are not selected randomly. In dense stands, errors can arise by one plant being behind another. Sampling on slopes introduces error if no correction is made. If the observer stands on the sample point, rather than holding the gauge over the point, an error of about +4% results.

4. Application Notes

This technique is inexpensive. One person can apply the technique. It is particularly applicable in vegetation that is relatively open at eye level. Basal area of the trees in dense forest can be handled if there is relatively little understory growth to obscure the line of sight.

Shrub cover can be measured provided the density of the shrubs is not so great that some individuals are partially obscured by closer individuals, and provided the shrub canopies are nearly circular.

For measuring basal cover of trees 9 the Bitterlich Method is usually preferred because of its accuracy and low cost. For measuring shrub canopy cover, the Bitterlich Method is a rapid but crude technique. For low shrubs, the Daubenmire Method may be nearly as accurate but faster, especially if quadrats are needed anyway to estimate density or cover by herbs. For accurate results, the Line Intercept is preferred. Of course, RS: Crown Density Scale or RS: Ocular

Estimation of Cover is often much less expensive.

5. Training Instruction and field practice require about 4 hr.

6. Equipment

There are several types of angle gauges on the market for measuring basal areas of trees. These include: glass prism ("cruising prism"); Relaskop; the Cruz-all; and others (Forestry Suppliers, Inc. 1980). The instrument should be accompanied by its specified BAF. If not, the BAF may be calculated as follows: Set up a target of 0.5-1 m in width (e. g. , a horizontal board of appropriate length). Move directly away from the target until the angle gauge precisely measures or displaces the width of the target. Now measure the distance from the target to the eye. BAF is calculated as follows:

BAF (percent/plant)=0.174(W^2/D)

BAF (M2 /ha plant) = 0.25 (W^2/D)

BAF (ft'/ac plant) = 75.625 (W^2/D)

where
BAF = base area factor (M^2 /ha plant or ft^2 /ac plant)
W = width of target (cm for percent and metric, in for English)
D = distance to target (m for percent and metric, ft for English)

Foresters usually use a gauge with a BAF of 4 M^2 /ha plant (or 10 ft^2 /ac plant). In stands of large, old growth trees, a BAF of 8 M^2 /ha is preferable, while in open stands of small (pole-sized) trees, a BAF of 2 M^2 /ha plant should be used. This minimizes the number of borderline trees and the number of trees that should be counted which are hidden behind others.

The shrub angle gauge needs to be calibrated for each user. Cooper (1957) recommends a BAF of 0.5% plant. Convenient dimensions for the gauge are a 10 cm bar width and an eye-bar distance of about 70.7 cm. To adjust the gauge so it has a BAF of 0.5, set up a horizontal target 2 m wide and move directly away until the distance from the eye to the target is 14.14 m. The length of the chain should be adjusted until the target appears exactly "borderline." The observer should then check the calibration by moving toward the target, then slowly backing away until the target is "borderline," and then checking the distance. It is essential that each user recalibrate and readjust the shrub angle gauge to compensate for individual variation in the way the instrument is held.

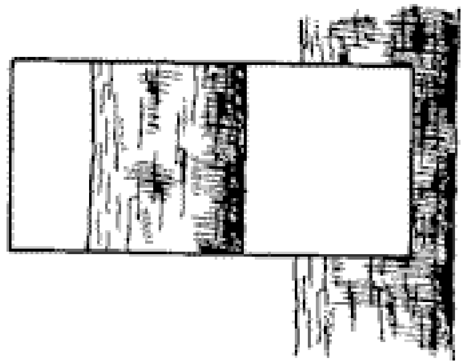
Commercially available angle gauges cost from about $3 for the Cruz-all, $15-20 for prisms, and $600 for the Relaskop (Forestry Suppliers, Inc. 1980). The shrub angle gauge can be constructed for $2-3.

A low cost (i.e. , $2-3), but less convenient angle gauge for use in forests, can be constructed similar to the shrub angle gauge, but using a stick instead of a chain for determining the distance between the eye and the crossarm. Convenient dimensions are a 1 in crossarm and a 33 in stick. This gives a basal area factor of 10 ft/ac plant.

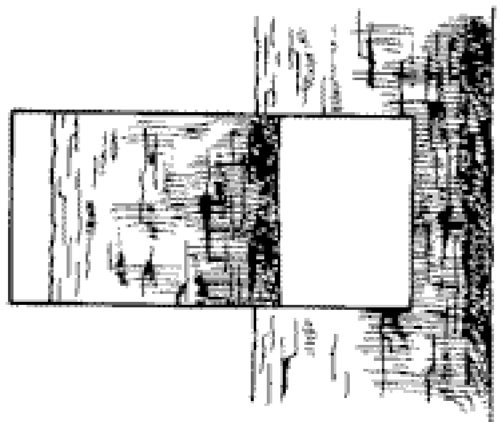
7. Cost

5 min per sample point.

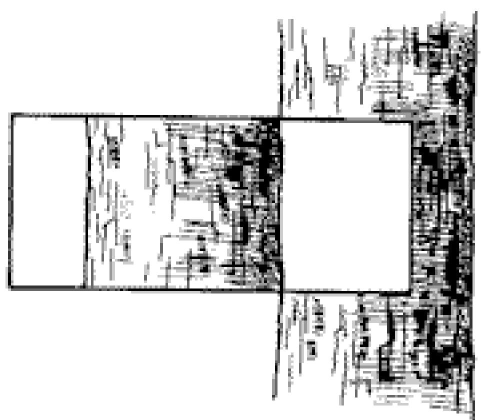
Do not count this tree.



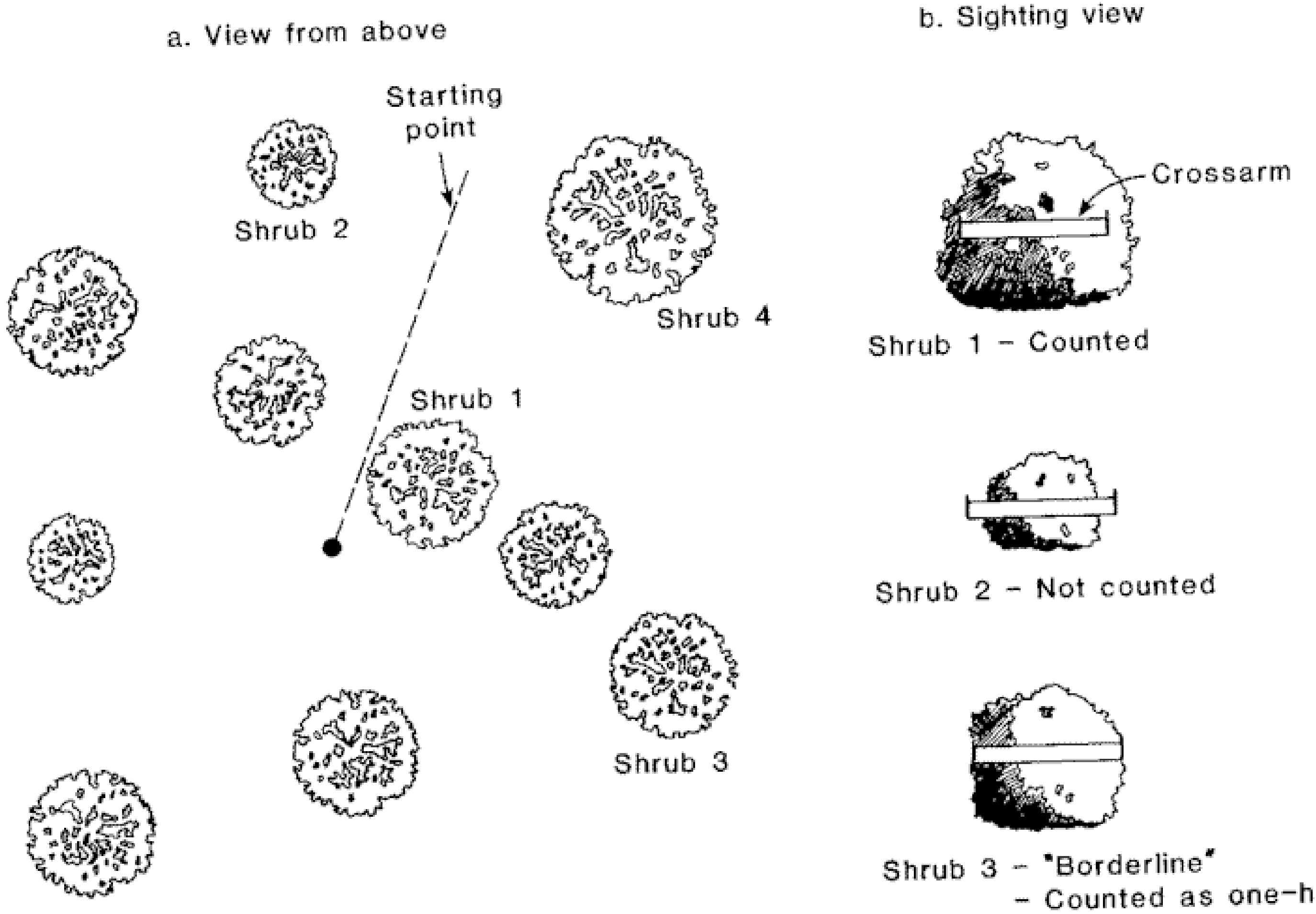
Count this tree.

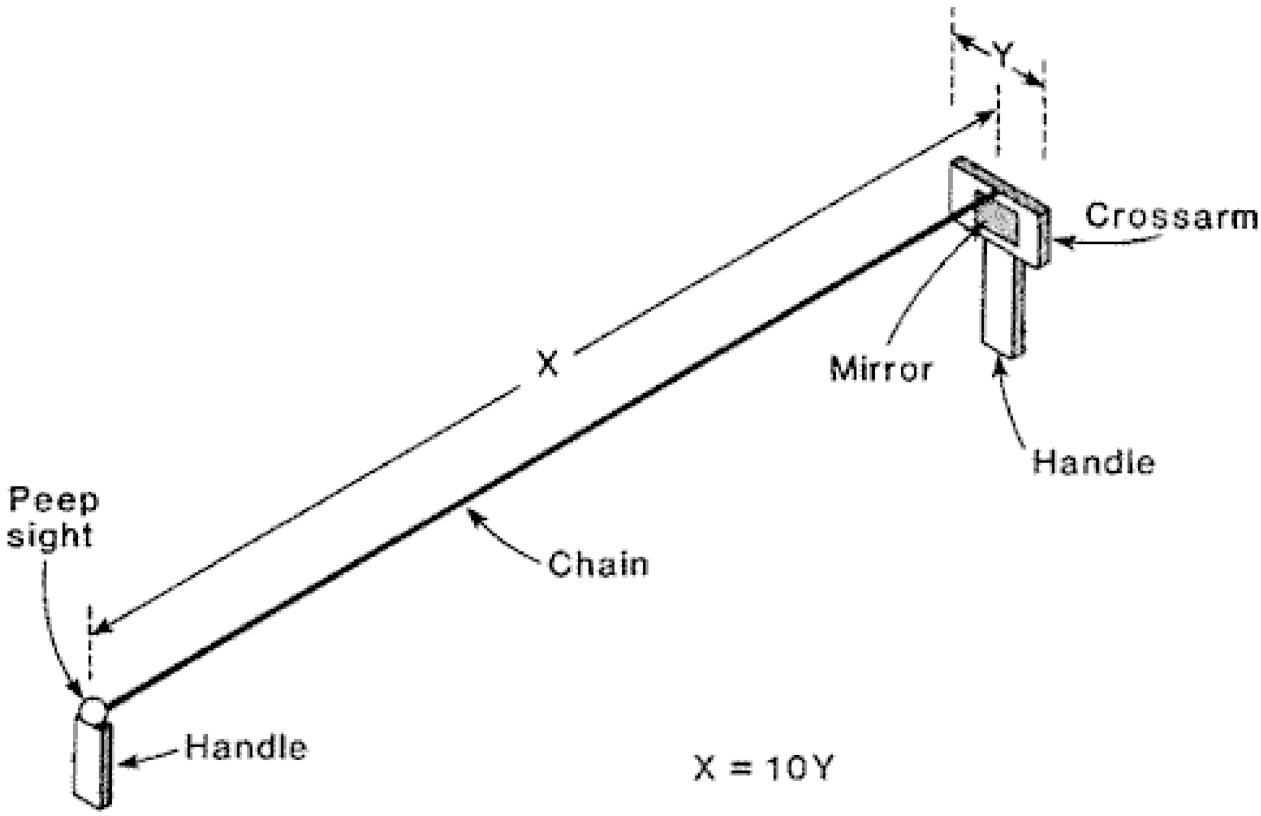


Borderline tree. Count as one-half, or measure the diameter and distance.



Use of a prism to apply the Bitterlich Method.


a. View from above
Starting point
Shrub 2
Shrub 4
Shrub 1
Shrub 3
b. Sighting view
Crossarm
Shrub 1 - Counted
Shrub 2 - Not counted
Shrub 3 - "Borderline"
- Counted as one-h



The shrub angle gauge. When the gauge is held so the crossarm is horizontal and perpendicular, the reflection of the chain in the mirror will align with the chain.

CALCULATED COVER

---

1. Variable Estimated

Canopy or Basal Cover of trees or shrubs.

2. Description

In summary, the results of a measurement of density and of mean canopy area or basal area for the same site are used to calculate cover.

If data are available on density (Techniques 3.20 or 3.21) and mean canopy or basal area for plants (Techniques 3.1 and 3.23) on the same site, these estimates can be combined to estimate cover. The following formula applies:

$$C = 100\ A*D$$

where
C = cover (%)
A = mean area per plant (area)
D = density of plants (number per unit area, where the area units are the same as area for A, above)

3. Accuracy

The accuracy of the calculated cover is a function of the accuracies of the constituent measurements of density and mean area . For basal area of trees, it is usually medium to low in accuracy. For canopy cover, it tends to have low accuracy, due to deviations of canopy shape from circular.

4. Application Notes

This technique is most appropriate where the separate measures of density and canopy or basal area are required for other purposes. A convenient sampling approach is to combine T-square Nearest Neighbor Sampling (p. 62) for density with Crown Diameter (p. 15) or Diameter Tape (p. 18) and Averaging (p. 69). Each plant measured for the T-square sampling can also be used for area measurement. If the average area per plant is not required, it is usually preferable to measure cover with the Line Intercept (p. 40), Bitterlich Method (p. 43), Point Intercept-Spherical Densiometer (p. 55), or RS: Crown Density Scale at the same time density is being measured. One convenient way to do this is by combining a Line Intercept (p. 40) for measuring cover with a belt Quadrat (p. 65) for measuring density. The line transect forms one side of the belt quadrat.

POINT INTERCEPT-SPHERICAL DENSIOMETER

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1. Variables Estimated

Canopy and foliar cover of the very tall shrubs and trees (pp. 5, 7).

2 Description

In summary, a spherical densiometer is set up at randomly located sampling locations in the site. The densiometer optically identifies a series of points in the canopy above the sampling location. The observer records what each point hits.

Random sampling locations should be selected. At each location, the densiometer is set up following the manufacturer's instructions. The crew then sequentially looks at each of the points on the densiometer and records sky or the kind of plant which is intercepted. For foliar cover, if a point falls on a plant, the species should be recorded. If the point hits plant parts from more than one species, all should be recorded as hits. For estimates of canopy cover, the crew must judge where the outer perimeter of the canopies of individual plants lie, and then record for each sample point whether or not it falls within a plant's perimeter. The only data that need to be recorded are the total number of points intercepting each category of interest; e.g., trees by species, and sky. Data are most easily collected by sequentially observing in four directions (north, east, south, west) at a sample location.

To calculate cover for a particular category of data (e. g. , plant species X), the following equation is used:

Cx = Nx/Ên (100)

where
Cx = cover of X (%)
Nx = number of dots intercepting X
Ên = total number of dots sampled

This formula may be applied for either foliar cover or canopy cover, depending upon how the data were collected. Commercially available densiometers use a 96 dot grid. Approximate measures of cover may be made by assuming one dot equals 1%, on the average. This will give an error of less than 5% due to the difference between 96 and 100.

3. Accuracy

Spherical densiometer consistently produces accurate measurements regardless of the operator. Densiometer measurements were found to be highly correlated with those taken with a canopy camera.

4. Application notes

This technique can be applied by one person. It is particularly appropriate to use where vegetation is dense and the user wants to estimate cover by species (e.g., mixed deciduous forest). It is also relatively easy to use in highly uneven terrain where the Line Intercept technique is difficult to apply. Where canopies do not overlap, and canopy cover is the desired variable, Line Intercept, Bitterlich Method, or Daubenmier are often preferred techniques.

5. Training

Instructions included with the instrument are adequate. However, field experience is necessary to improve operator consistency. Fifteen minutes instruction and 0.5 hr practice is adequate.

6. Equipment

Spherical densiometer (about $47, Forest Densiometers 1980). Two types are available: convex and concave. Measurements from the two types should be calculated separately, because slightly different results can occur.

7. Cost

Three minutes per sample location (four directions) for sparse communities; 12 minutes per sample location for dense communities.

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DENSITY

1. **Description** Density has been used to describe characteristics of plant communities. However, comparisons can only be based on similar life-form and size. This is why density is rarely used as a measurement by itself when describing plant communities. For example, the importance of a particular species to a community is very different if there are 1,000 annual plants per acre versus 1,000 shrubs per acre. It should be pointed out that density was synonymous with cover in the earlier literature.

Density is basically the number of individuals per unit area. The term refers to the closeness of individual plants to one another.

2. **Advantages and Limitations**

a. Density is useful in monitoring threatened and endangered species or other special status plants because it samples the number of individuals per unit area.

b. Density is useful when comparing similar life-forms (annuals to annuals, shrubs to shrubs) that are approximately the same size. For trend measurements, this parameter is used to determine if the number of individuals of a specific species is increasing or decreasing.

c. The problem with using density is being able to identify individuals and comparing individuals of different sizes. It is often hard to identify individuals of plants that are capable of vegetative reproduction (e.g., rhizomatous plants like western wheatgrass or Gambles oak). Comparisons of bunchgrass plants to rhizomatous plants are often meaningless because of these problems. Similar problems occur when looking at the density of shrubs of different growth forms or comparing seedlings to mature plants. Density on rhizomatous or stoloniferous plants is determined by counting the number of stems instead of the number of individuals. Seedling density is directly related to environmental conditions and can often be interpreted erroneously as

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a positive or negative trend measurement. Because of these limitations, density has generally been used with shrubs and not herbaceous vegetation. Seedlings and mature plants should be recorded separately.

If the individuals can be identified, density measurements are repeatable over time because there is small observer error. The type of vegetation and distribution will dictate the technique used to obtain the density measurements. In homogenous plant communities, which are rare, square quadrats have been recommended, while heterogeneous communities should be sampled with rectangular or line strip quadrats. Plotless methods have also been developed for widely dispersed plants.

3. **Technique**

- Primary attributed that the technique collects.
    - **Density**

This page was last modified 05/30/01

DENSITY METHOD

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1. General Description Density is the number of individuals of a species in a given unit of area. For rhizomatous and other species for which the delineation of separate individual plants is difficult, density can also mean the number of stems, inflorescences, culm groups, or other plant parts per unit area.

2. Areas of Use This method has wide applicability and is suited for use with grasses, forbs, shrubs, and trees.

3. Advantages and Limitations

A. Generally, the density of mature perennial plants is not affected as much by annual variations in precipitation as are other vegetation attributes such as canopy cover or herbage production.

B. Density is a quantifiable and absolute attribute.

C. Density is sensitive to changes in the adult population caused by long-term climatic conditions or resource uses.

D. Density provides useful information on seedling emergence, survival, and mortality.

E. Sampling is often quick and easy with certain life forms (e.g., trees, shrubs, bunchgrasses).

F. Plant communities on the same ecological sites can be compared using density estimates on specific species or lifeforms.

G. Density can be useful in estimating plant responses to management actions.

H. It can often be difficult to delineate an individual, especially when sampling sod forming plants (stoloniferous, or rhizomatous plants) and multi-stemmed grasses or closely spaced shrubs. Although in these cases a surrogate plant part (e.g., upright stems, inflorescences, culm groups) can be counted, the usefulness of such estimates is limited to the biological significance of changes in these surrogates.

I. Sampling may be slow and tedious in dense populations; this also raises the risk of non-sampling errors.

J. There is no single quadrat size and shape that will efficiently and adequately sample all species and life forms. For this reason, density estimations are usually limited to one or a few key species.

4. Equipment The following equipment is needed

A. Study Location and Documentation Data form

B. Density form

C. Tapes: 50-, 100-, 150-, or 200-meter delineated in centimeters. (Tapes in English measurements can be substituted but metric tapes are preferred.) At least three tapes are required (one, to be used for constructing quadrats, need only be as long as the long side of the quadrat; a rope of the desired length can be substituted for this tape); four are better.

D. Meter sticks (or yard sticks if using English measurements). Two are required.

E. Four stakes: 3/4- or I -inch angle iron not less than 16 inches long

F. Hammer

G. Permanent yellow or orange spray paint

H. Tally counter (optional)

I. Compass

J. Steel post and driver

5. Training As with any monitoring method, adequate training is essential to minimize nonsampling errors.

A. Examiners must be able to identify the target plant species.

B. For sod-forming grasses and other species for which individual plants might be hard to distinguish, written guidelines should be provided on what constitutes an individual unit to be counted. (Determination of what constitutes a unit to be counted is somewhat arbitrary. For rhizomatous grasses such as western wheatgrass (Pascopyrum smithii), each culm group can be visualized as an actual or potential plant unit, as can rooted stoloniferous units of such species as vine mesquite (Panicum obtusum). Mat or sodforming plants such as blue grama (Bouteloua gracilis) or alkali sacaton (Sporobolus airoides) usually start growth as small, distinct clumps, but may spread to plants a meter or more in diameter. As this occurs they tend to fragment into more-or-less separate units, and it is these separate units that should be counted as actual or potential individuals. For rhizomatous or mat-forming forbs, flowering stems may be the units counted. The examiner should ensure, however, that a change in the unit chosen is of biological significance, i.e., reflects a real change in the vegetation community. If it has no such significance, then another unit or a different species should be chosen. (Alternatively, an attribute other than density can be selected for monitoring.)) This will help to ensure consistency among examiners. To assess consistency prior to the study, several examiners should be asked to independently count these units in the same set of quadrats and the results compared. If relatively consistent results cannot be achieved a different species should be chosen for estimation or a different method selected.

6. Establishing Studies Careful establishment of studies is a critical element in obtaining meaningful data.

A. **Site Selection** The most important factor in obtaining usable data is selecting representative areas (critical or key areas) in which to run the study. Study sites should be located within a single plant community within a single ecological site. Transects and sampling points need to be randomly located within the critical or key areas.

B. Pilot Studies Collect data on several pilot studies to determine the number of samples (transects or observation points) and the number and size of quadrats needed to collect a statistically valid sample.

(1) Quadrat size and shape It is vital to choose the quadrat size and shape that will give the highest statistical precision for the area and key species being sampled. As a general rule of thumb long, thin quadrats are better (often very much better) than circles, squares, or shorter and wider quadrats. How narrow the quadrats can be depends upon consideration of measurement errors due to edge effect, but these problems can be largely overcome by incorporating rules for determining whether a plant falls inside or outside a quadrat (discussed in more detail under Sampling Process below).

(a) Subjectively place quadrats' of a certain size and shape in areas with large numbers of the target plant species. See how many plants fall into the quadrat and ask if this is too many to count. See what kind of problems there might be with edge effect: when individuals fall on or near one of the long edges of the quadrat, will it be difficult for examiners to make consistent calls as to whether these individuals are in or out of the quadrat? See if there is a tendency to get more plants in rectangular quadrats when they are run one way as opposed to another.

(b) Determine the standard deviations of those quadrat sizes and shapes deemed to be practical from the subjective examination described above.

(c) Choose the quadrat size and shape with the smallest standard deviation.

(2) **Direction of Quadrats** Determine if there is an environmental gradient affecting the density of the target species in the key area. Examples of such gradients are elevation and moisture. If there is a gradient, the study should be set up so that the long side of each quadrat is placed perpendicular to this gradient. This ensures that there is more variability within each quadrat than there is between quadrats.

Subjectively placing quadrats in different directions can assist in making this determination. For example, if quadrats laid out with the long side going north-south tend to have no or fewer plants of the key species than quadrats with the long side going east-west, the east-west position should be selected. (Note that it is not necessary to construct an actual frame for the quadrats used. It is sufficient to delineate quadrats using a combination of tape measures and meter (or yard) sticks. For example, a 5 m x 0.25 m quadrat can be constructed by selecting a 5 m interval along a meter tape, placing two I -meter sticks perpendicular to the tape at both ends of the interval (with their zero points at the tape), and laying another tape or rope across these two sticks at their 0.25 m points. This then circumscribes a quadrat of the desired size and shape. Alternately place a meter stick perpendicular to the tape at one end of the interval. The meter stick is then moved slowly up the interval and all plants of the species occurring within the first 0.25 m of the meter stick recorded until the end of the interval is reached.)

C. **Study Layout** Data can be collected using the baseline, macroplot or linear study designs. The macroplot technique is the recommended procedure.

D. **Reference Post or Point** Permanently mark the location of each study with a reference post and a study location stake.

E. **Study Identification** Number macroplots for proper identification to ensure that the data collected can be positively associated with specific sites on the ground.

F. Study Documentation Document pertinent information concerning the study on the Study Location and Documentation Data form.

7. Taking Photographs Establish photo plots.

8. Sampling Process In addition to collecting the specific studies data, general observations should be made of the study sites.

A. **Selecting Random Pairs of Coordinates** Using the quadrate locations (example) technique, select coordinates to mark the points at which quadrats will be positioned.

B. **Sampling** Assuming that the x-axis is on the "bottom" and the y-axis is at the "left," each pair of coordinates represents the lower left corner of each quadrat. Thus, if one random set of coordinates is 0,0, the quadrat is positioned with its lower left corner at the origin.

(1) Place the quadrats at each of the random pairs of coordinates and continue reading them until the number of quadrats previously determined to be required has been read.

Make a quadrat of the desired size and shape by running a tape in the direction of the long side of each quadrat from the appropriate axis and using two 1 -meter sticks and another tape or rope. In the example, it has been decided that the quadrats should be placed with their long sides parallel to the x-axis and that the quadrats should be 1 m x 16 m. Based on the random coordinates chosen the first quadrat is to be placed at the 28 m point on the y-axis and the 16 m point on the x-axis. A tape is run parallel to the x-axis beginning at the 28 m point on the y-axis. At the 16 m mark on this tape, a meter stick is positioned perpendicular to the tape with its 0 point at the tape. Another meter stick is similarly placed at the 32 m mark. Another tape or a rope of 16 m in length is placed across the two 1-meter sticks at their 1 m points. The number of plants is counted in this quadrat and sampling continues. If the short side of each quadrat exceeds 1.0 m, more than one 1-meter stick or additional tapes or ropes may need to be used.

(2) Count the number of individuals (or other counting unit) of the key species in each quadrat and record this on the Density form.

Count only those plants that are rooted in the quadrat. Often it is desirable to make separate counts for different size or age classes of the key species. This is particularly true for seedlings, many of which may not survive to the next sampling period.

(a) To eliminate measurement error due to edge effects, it is helpful to have rules for determining whether an individual plant that falls exactly on the edge of a quadrat is considered inside or outside the quadrat.

(b) A good rule to follow is to count those individuals falling on the left and top edges of the quadrat as being inside the quadrat and those individuals falling on the right and bottom edges of the quadrat as being outside the quadrat. Make sure that all observers follow the same set of rules.

9. Calculations Make the calculations and record the results on the Density form.

A. **Average Density per Quadrat** Calculate the estimated average density per quadrat for each size/age class by dividing the total number of plants counted in the sample for each size/age class by the number of quadrats in the sample. If more than one key species is counted, this process is done separately for each species. For example, a sample of 40 quadrats yields a total of 177 individual mature plants of key species Y The estimated average density of mature plants per quadrat is therefore 177/40 = 4.4 plants/quadrat.

B. **Total Density of Macroplot** Calculate the estimated total density of the macroplot by multiplying the average density per quadrat by the total number of possible quadrats in the macroplot. If more than one key species is counted, this process is done separately for each key species. Say the macroplot in the example given in 9.a above is 40 m x 80 m and the quadrat size is 1.0 m x 16 m. There are 200 possible nonoverlapping quadrat placements in a macroplot of this size (40/1 = 40 along one axis and 80/16 = 5 along the other; 40 x 5 = 200 possible quadrats). The estimate of the total density of the macroplot is therefore 4.4 mature plants/quadrat x 200 quadrats = 880 mature plants.

10. Data Analysis and Interpretation Data analysis is straightforward. Confidence intervals should be constructed around each of the estimates of average density per quadrat (hereafter referred to simply as "average") and total macroplot density for each year. The averages of two years should be compared by using a t test (for independent samples). Averages of three or more years can be compared by an analysis of variance.

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Density

Study Number	Date	Examiner	Allotment Name & Number	Pasture	Plot Size

Study Location

Plot	1		2		3		4		5		6		7		8		9		10		Total	
Coordinates																						
Plant Species	Mature	Seedling	Mature	Seedling	Mature	Seedling	Mature	Seedling	Mature	Seedling	Mature	Seedling	Mature	Seedling	Mature	Seedling	Mature	Seedling	Mature	Seedling	Mature	Seedling

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PRODUCTION

1. **Description** Many believe that the relative production of different species in a plant community is the best measure of these species' roles in the ecosystem.

The terminology associated with vegetation biomass is normally related to production.

a. Gross primary production is the total amount of organic material produced, both above ground and below ground.

b. Biomass is the total weight of living organisms in the ecosystem, including plants and animals.

c. Standing crop is the amount of plant biomass present above ground at any given point.

d. Peak standing crop is the greatest amount of plant biomass above ground present during a given year.

e. Total forage is the total herbaceous and woody palatable plant biomass available to herbivores.

f. Allocated forage is the difference of desired amount of residual material subtracted from the total forage.

g. Browse is the portion of woody plant biomass accessible to herbivores.

2. **Advantages and Limitations**

a. Biomass and gross primary production are rarely used in trend studies because it is impractical to obtain the measurements below ground. In addition, the animal portion of biomass is rarely obtainable.

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b. Standing crop and peak standing crop are the measurements most often used in trend studies. Peak standing crop is generally measured at the end of the growing season. However, different species reach their peak standing crop at different times. This can be a significant problem in mixed plant communities.

c. Often, the greater the diversity of plant species or growth patterns, the larger the error if only one measurement is made.

d. Other problems associated with the use of plant biomass are that fluctuations in climate and biotic influences can alter the estimates. When dealing with large ungulates, enclosures are generally required to measure this parameter. Several authors have suggested that approximately 25% of the peak standing crop is consumed by insects or trampled; this is rarely discussed in most trend studies.

e. Collecting production data also tends to be time and labor intensive. Cover and frequency have been used to estimate plant biomass in some species.

3. **Techniques**

- Primary attributed that the technique collects.
  - **Double Weight Sampling**
  - **Harvest**
  - **Comparative Yield**
- Secondary attributed that can be collected or calculated
  - **Dry Weight Rank**
  - **Visual Obstruction - Robel Pole**

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DOUBLE-WEIGHT SAMPLING

1. General Description This technique has been referred to by some as the Calibrated Weight Estimate method. The objective of this method is to determine the amount of current-year above-ground vegetation production on a defined area. The following vegetation attributes are monitored:

A. Peak standing crop, which is the above-ground annual production of each plant species.
B. Species composition by weight.

It is important to establish a photo plot and take both close-up and general view photographs. This allows the portrayal of resource values and conditions and furnishes visual evidence of vegetation and soil changes over time.

2. Areas of Use This method can be used in a wide variety of vegetation types. It is best suited to grasslands and desert shrubs. It can also be used in large shrub and tree communities, but the difficulties increase.

3. Advantages and Limitations

A. Double-weight sampling measures the attribute historically used to determine capabilities of an ecosystem.

B. It provides the basic data currently used for determining ecological status.

C. Seasonal and annual fluctuations in climate can influence plant biomass.

D. Measurements can be time-consuming.

E. Current year's growth can be hard to separate from previous years' growth.

F. Accurate measurements require collecting production data at peak production periods, which are usually short, or using utilization and phenology adjustment factors.

G. Green weights require conversion to air-dry weights.

H. In most areas, the variability in production between quadrats and the accuracy of estimating production within individual quadrats requires the sampling of large numbers of quadrats in order to detect reasonable levels of change.

4. Equipment The following equipment is needed.

A. Study Location and Documentation Data form
B. Production form
C. Sampling frames or hoops

D. One stake: 3/4- or 1-inch angle iron not less than 16 inches long
E. Herbage Yield Tables for Trees by Height, DBH, or Canopy
F. Clippers
G. Paper bags
H. Kilogram and gram spring-loaded scales with clip
I. Tree diameter measuring tape
J. Steel post & driver
K. Oven for drying vegetation
L. Air-dry weight conversion tables
M. Rubber bands
N. Pin flags
O. Compass

5. Training The accuracy of the data depends on the training and ability of the examiners. Examiners must be able to identify plant species and determine current year's growth.

6. Establishing Studies Careful establishment of studies is a critical element in obtaining meaningful data.

A. **Site Selection** The most important factor in obtaining usable data is selecting representative areas (critical or key areas) in which to run the study. Study sites should be located within a single plant community within a single ecological site. Transects and sampling points need to be randomly located within the critical or key areas.

(1) The number of quadrats selected depends on the purpose for which the estimates are to be used, uniformity of the vegetation, and other factors.

(2) The size and shape of quadrats must be adapted to the vegetation community to be sampled.

B. **Pilot Studies** Collect data on several pilot studies to determine the number of samples (transects or observation points) and the number and size of quadrats needed to collect a statistically valid sample (see Section III.B.8).

C. **Study Layout** Production data can be collected using either the baseline, macroplot or linear study designs. The linear technique is the one most often used.

D. **Number of Transects** Establish the minimum number of transects to achieve the desired level of precision for the key species in each study site.

E. **Reference Post or Point** Permanently mark the location of each study with a reference post and a study location stake.

F. **Study Identification** Number studies for proper identification to ensure that the data collected can be positively associated with specific sites on the ground.

G. Study and Documentation Document pertinent information concerning the study on the Study Location and Documentation Data form.

7. Taking Photographs Establish photo plots.

8. Weight Units Double sampling requires the establishment of a weight unit for each species occurring in the area to be sampled. All weight units are based on current year's growth.

A. **Procedures For Establishing Weight Units:**

(1) Decide on a weight unit that is appropriate for each species. A weight unit could be an entire plant, a group of plants, or an easily identifiable portion of a plant, and can be measured in either pounds or grams.

(2) Visually select a representative weight unit.

(3) Harvest and weigh the plant material to determine the actual weight of the weight unit.

(4) Maintain proficiency in estimating by periodically harvesting and weighing to check estimates of production.

B. **Estimating Production of a Single Quadrat:**

(1) Estimate production by counting the weight units of each species in the quadrat.

(2) Convert weight units for each species to grams or pounds.

(3) Harvest and weigh each species to check estimate of production.

(4) Repeat the process until proficiency is attained.

(5) Periodically repeat the process to maintain proficiency in estimating.

(6) Keep the harvested material, when necessary, for air-drying and weighing to convert from green weights to air-dry weights.

C. **Alternate Method of Establishing Weight Units:**

(1) Decide on a weight unit that is appropriate for each species. A weight unit could be an entire plant, a group of plants, or an easily identifiable portion of a plant, and can be measured in either pounds or grams.

(2) Visually select a representative weight unit.

(3) Instead of weighing the material, save it by securing it with rubber bands so portions are not lost.

(4) Use this as a visual model for comparison at each quadrat in the transect. Record on the proper forms only the number of weight units. Do not record the estimated weights.

(5) Weigh each weight unit at the conclusion of the transect. Weighing the weight unit before the conclusion of the transect might influence the weight estimates.

(6) Convert the weight units on the form to actual weight by multiplying the number of units by the weight of the unit.

(7) Harvested weight unit material is not saved for determining air-dry weight conversion. Air-dry conversions are determined from clipped quadrats.

9. Sampling Process In addition to collecting the specific studies data, general observations should be made of the study sites.

A. **Transect Bearing** Determine the transect bearing and select a prominent distant landmark such as a peak, rocky point, etc., that can be used as the transect bearing point.

B. **Double Sampling**

(1) Randomly select the starting point along the transect bearing. Take the specified number of paces and read the first quadrat.

(2) Temporarily mark the quadrat by placing a pin flag next to the quadrat so that it can be relocated later if this quadrat is selected for clipping. Be sure to flag every quadrat.

(3) Estimate and record the weight of each species in the quadrat by means of the weight-unit method. When estimating or harvesting plants, include all parts of all plants within the quadrat. Exclude all parts of herbaceous plants and shrubs outside the vertical projection of the quadrat, even though the base is within the quadrat.

(4) Continue the transect by establishing additional quadrats at specified pace intervals. To change the length of the transect, adjust the number of paces between quadrats.

(5) After weights have been estimated on all quadrats, select the quadrats to be harvested.

(a) The quadrats selected should include all or most of the species in the estimated quadrats. If an important species occurs on some of the estimated quadrats but not on the harvested quadrats, it can be clipped individually on one or more other quadrats.

(b) The number of quadrats harvested depends on the number estimated. At least one quadrat should be harvested for each seven estimated to adequately correct the estimates (see table 3).

Number of Quadrats Estimated	Minimum Number of Quadrats to be Weighed
I - 7	1
8 - 14	2
14 - 21	3

22 - 28	4
29 - 35	5
36 - 42	6

(6) Harvest, weigh, and record the weight of each species in the quadrats selected for harvesting. Harvest all herbaceous plants originating in the quadrat at ground level. Harvest all of the current leaf, twig, and fruit production of woody plants located in the quadrats. On native pasture and grazable woodland, harvest the current leaf, twig, and fruit production of woody plants within the plot up to a height of 4 1/2 feet above the ground.

(7) Correct estimated weights by dividing the harvested weight of each species by the estimated weight for the corresponding species on the harvested quadrats. This factor is used to correct the estimates for that species in each quadrat. A factor of more than 1.0 indicates that the estimate is too low. A factor lower than 1.0 indicates that the estimate is too high.

After quadrats are estimated and harvested and correction factors for estimates are computed, air-dry percentages are determined by air-drying the harvested materials or by selecting the appropriate factor from an airdry percentage table. Values for each species are then converted to air-dry pound per acre or kilograms per hectare for all quadrats. Average weight and percentage composition can then be computed for the sample area.

10. Calculations The weights collected for each species per quadrat placement are recorded on the Production form.

A. Record estimated weights for each species occurring in each-quadrat in the appropriate column (Estimated or Clipped Weight sections of the form.)

B. Quadrats that were harvested are circled. The estimate weights for these quadrats are totaled and shown in column 4. The total harvested weights are shown in column 5. Harvested weights for each quadrat for each species are not shown on the form, only the total for each species.

C. Column 6 is the actual dry weight for each species from the quadrats that were clipped.

D. The Quadrat Correction Factor (QCF) column 7 is calculated by dividing column 5 by column 4.

E. Column 8 is determined by dividing the dry weight by the green weight.

F. The total estimated weights for each species for the entire transect are shown in column 9.

G. The average yield (column 10) is determined by multiplying the Total Estimated Weight of each species (column 9) times the Quadrat Correction Factor (column 7) to adjust for the error in estimating weights and then multiplying that times the percent dry weight (column 8) to determine the adjusted dry weight or the Average Yield (column 10).

H. The Average Yield for each species (column 10) is totaled at the bottom of the form for the composition totals.

J. Percent Composition (column 11) is calculated by dividing the average yield for each species (column 10) by the composition totals.

K. If peak standing crop is collected in grams, it can be easily converted to pounds per acres if the total area sampled is a multiple of 9.6 ft'.

11. Data Analysis This technique involves destructive sampling (clipped plots), so permanent transects or quadrats are not recommended. Since the transects are not permanently marked, use the appropriate nonpaired test. When comparing more than two sampling periods, use ANOVA.

Dry Weight Rank

Page ____ of ____

Study Number	Date	Examiner	Allotment Name & Number	Pasture

Transect Location	Number of Quadrats	Quadrat Size

Species	Quadrat																				Rank Tally			Weighted	% Comp.
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	1	2	3		

Observations/Comments

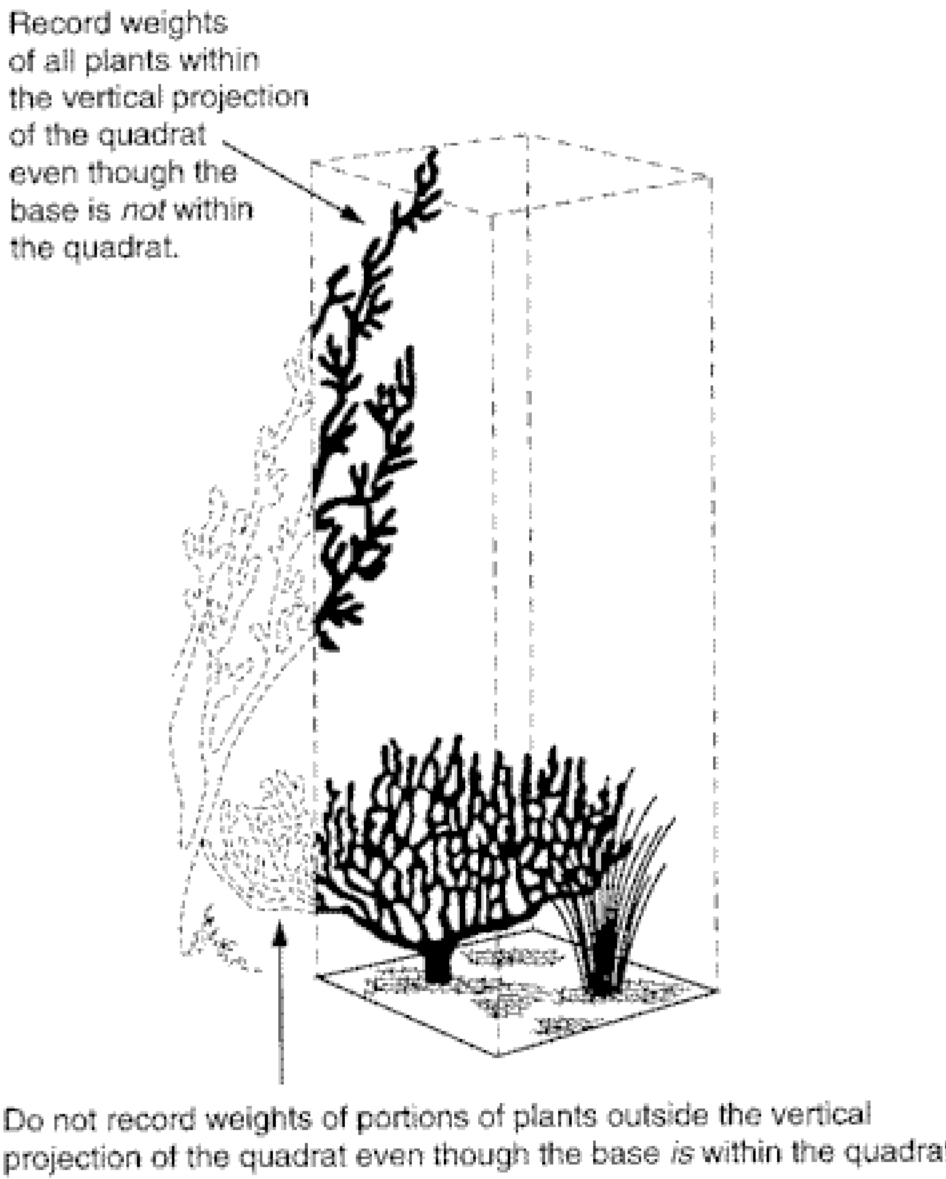
Production

Study Number	Date	Examiner	Allotment Name & Number	Pasture
Transect Location			Quadrat Size	Transect Bearing

Plant Name	Plant Symbol	Estimated or Clipped Weight Per Species (Circle Plots that are Clipped) (3)										Wt Clipped Plots			QCF	%Dry Wt	Wt All Plots	Avg Yield	Pct Comp
												Est	Clip	Dry					
(1)	(2)	P-1	P-2	P-3	P-4	P-5	P-6	P-7	P-8	P-9	P-10	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Totals																			

Notes (use other side or another page)

Weight Estimate Quadrat



COMPARATIVE YIELD METHOD

---

1. General Description This method is used to estimate total standing crop or production of a site. The total production in a sample quadrat is compared to one of five reference quadrats; relative ranks are recorded rather than estimation the weight directly.

It is important to establish a photo plot and take both close-up and general view photographs. This allows the portrayal of resource values and conditions and furnishes visual evidence of vegetation and soil changes over time.

2. Areas of Use This method works best for herbaceous vegetation but can also be used successfully with small shrubs and half-shrubs. As with most production estimates, the comparative yield method can be used to compare relative production between different sites.

3 . Advantages and Limitations The advantage of the comparative yield method is that a large sample can be obtained quickly. Total production is evaluated, so clipping calibration on a species basis is not needed. The process of developing reference quadrats for ranking purposes reduces both sampling and training time. This technique can be done in conjunction with the frequency, canopy cover, or dry weight rank methods. Identification of individual species is not required.

Large shrub communities are not well suited for this technique. If used in conjunction with other techniques (frequency and dry weight rank), the quadrat size may need to be different. This technique can detect only large changes in production.

4. Equipment The following equipment is needed.

A. Study Location and Documentation Data form
B. Comparative Yield form
C. Five sampling quadrat frames
D. Clippers
E. Paper bags
F. Kilogram and gram spring-loaded scale with clip
G. One stake: 3/4- or I -inch angle iron not less than 16 inches long
H. Tally counter (optional)
I. Hammer
J. Permanent yellow or orange spray paint
K. Compass
L. Steel post and driver

5. Training Examiners must calibrate their estimates when sampling situations change (i.e., different sites, time of day, or season).

6. Establishing Studies Careful establishment of studies is a critical element in obtaining meaningful data. Depending on the objectives, comparative yield data can be collected on permanent transects or in a random or systematic design.

A. Site Selection The most important factor in obtaining usable data is selecting representative areas (critical or key areas) in which to run the study . Study sites should be located within a single plant community within a single ecological site. Transects and sampling points need to be randomly located within the critical or key areas.

B. **Pilot Studies** Collect data on several pilot studies to determine the number of samples (transects or observation points) and the number and size of quadrats needed to collect a statistically valid sample.

C. **Selecting Quadrat Size** The criteria for selecting the proper size quadrat is the same as any weight estimate procedure.

(1) Determine the proper size quadrat(s) to use by doing preliminary sampling with different size frames.

(2) Use the same size quadrat throughout a study and for rereading the study.

D. **Number of Transects** Establish one transect on each study site; establish more if needed.

E. **Study Layout** Production data can be collected using the baseline, macroplot, or linear study designs. The linear technique is the one most often used.

F. **Reference Post or Point** Permanently mark the location of each study with a reference post and a study location stake.

G. **Study Identification** Number studies for proper identification to ensure that the data collected can be positively associated with specific sites on the ground.

H. **Study Documentation** Document pertinent information concerning the study on the Study Location and Documentation Data form.

7. Taking Photographs Establish photo plots.

8. Sampling Process In addition to collecting the specific study data, general observations should be made.

A. A set of reference quadrats must be established. The sample quadrats will be compared and rated back to these reference quadrats. The reference quadrats represent the range in dry weight of standing crop that will be commonly found during sampling.

(1) Five reference quadrats are subjectively located. References 1 and 5 are located first. The first quadrat (reference 1) is placed in a low-yielding area which represents the low-yielding situations commonly encountered on the site (avoid bare or nearly bare quadrats). Reference 5 is determined by placing a quadrat on a high-yielding area, excluding unusually dense patches of vegetation which would have a rare chance of being sampled. The examiner should make a

mental note of the amount of production in each of the reference quadrats. These references are then clipped and weighed. If the clipped weight in reference 5 is more than five times the weight found in reference 1, then two new sites should be selected as references 1 and 5. In establishing the initial reference quadrats, the weight in reference 5 is usually too high and the weight in reference 1 is too low. Make sure reference 5 does not represent a rare situation. When references 1 and 5 have been selected, reference 3 is located by placing a frame in an area considered to have a yield halfway between references 1 and 5. References 2 and 4 are located the same way by selecting the midpoint yield between references 1 and 3 and references 3 and 5, respectively.

(2) All five reference quadrats are clipped and weighed to compare the reference quadrats to a linear distribution of quadrat weights. This process is repeated by clipping additional quadrats until the weights of the five reference quadrats are approximately linear and observers are confident in their ability to rank quadrats relative to one of the five references. If the rankings are not linear, the precision of the method will be reduced. If more than five percent of the quadrats have no production, then a larger quadrat frame should be used.

(3) In areas with less than 500 lb/ac, small quadrats are difficult to evaluate. In these situations, larger quadrats should be used or three reference quadrats should be established instead of five.

B. **Collecting the Data**

(1) Start a transect by randomly locating the first quadrat along the transect bearing.

(2) Read additional quadrats at specified intervals. To change the length of the transect, increase the number of paces between quadrats.;

(3) For each quadrat, compare the total yield in the quadrat to the references and record the appropriate rank by dot count tally. It is appropriate to assign intermediate ranks if the yield is at the midpoint between two references. For example, if a quadrat has a yield between references 1 and 2, assign a rank of 1.5. If a quadrat yield greatly exceeds the yield of reference 5, then a higher rank may be estimated. For example, if a quadrat is 50% greater than reference 5, a rank of 7 could be recorded. If more than five percent of the quadrats are ranked above 5, the references were not properly selected.

(4) To calibrate the ranks, several quadrats representing each reference should be clipped and weighed independently of the transect. The total yield in each quadrat is determined without regard to species. Be sure to save all clipped material. The reference quadrats can be used as part of these clipped quadrats. The more quadrats clipped, the better the calibration. Each distinct sampling period should have a separate calibration. Bags can be weighed in the field to determine green weight and then saved and dried to determine dry weight. These weights are then used to determine average weight per reference.

9. Calculations The number of quadrats tallied for each ranking on the Comparative Yield form is totaled and multiplied by the ranking (column 1).

Rank x Tally = Weighted ranking

These weighted rankings (column 3) are summed and divided by the number of total quadrats. This indicates the average ranking for the site.

Total rank / Total number of quadrats sampled = Average ranking for the site

The average yield may be estimated with a ratio estimate (described below) or a least-squares regression technique. The ratio estimate is good for quick field calculations, but the least-squares regression should be used for final data analysis.

To use the ratio estimate technique, calculate the average rank and average clipped weight of the harvested quadrats by dividing the total of the clipped rankings and the total clipped weight by the number of harvested (clipped) quadrats (column 4 and 5).

Total of clipped rankings / Total number of clipped quadrats = Average rank of clipped quadrats

Total clipped weight / Total number of clipped quadrats = Average weight of clipped quadrats

The average clipped weight is then divided by the average rank to determine the average rank interval.

Average weight of clipped quadrats / Average rank of clipped quadrats = Average rank interval (ARI)

The average ranking for the site-which is based on the estimated, not clipped, quadrats-is then multiplied by the average rank interval to estimate the average yield per quadrat for the site.

Average ranking for the site x Average rank interval = Average yield/Quadrat.

The average yield in grams per quadrat obtained above can be converted to either pounds/acre or kilograms/hectare.

To convert to kilograms per hectare, first determine the number of quadrats in a hectare by dividing the number of square meters in a hectare (10,000m2) by the total area (in square meters) of the quadrat. Then divide the number of quadrats in a hectare by 1,000 to arrive at the conversion factor used to convert grams per quadrat into kilograms per hectare.

For example, if the quadrat size is 40 X 40 centimeters (0.4 X 0.4 meters), then the quadrat area would be 0.4 multiplied by 0.4, or .1 6M2. The number of quadrats in a hectare is calculated by dividing 10,000 by .1 6, which works out to 62,500 quadrats per acre. Dividing this number by 1,000 results in the conversion factor, which is 62.5 . e final step is to multiply the average yield per quadrat obtained from the final equation above by 62.5 to arrive at kilograms per hectare.

10. Data Analysis For trend analysis, permanent sampling units are suggested. If permanent transects are monitored, use the appropriate paired analysis technique. If the transects are not permanently marked, use the appropriate nonpaired test. When comparing more than two sampling periods, use repeated measures ANOVA.

Page ___ of ___

Comparative Yield

Study Number	Date	Examiner	Pasture

Allotment Name & Number	Number of Quadrats	Quadrat Size

Study Location

Sampled Quadrats			Harvested Quadrat	
Rank (1)	Tally (2)	Rank x Tally (3)	Clip Rank (4)	Clip Weight (5)
0				
.5				
1				
1.5				
2				
2.5				
3				
3.5				
4				
4.5				
5				
Total				
Average				

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STRUCTURE

1. **Description** Structure of vegetation primarily looks at how the vegetation is arranged in a three-dimensional space. The primary use for structure measurements is to help evaluate a vegetation community's value in providing habitat for associated wildlife species.

Vegetation is measured in layers on vertical planes. Measurements generally look at the vertical distribution by either estimating the cover of each layer or by measuring the height of the vegetation.

2. **Advantages and Limitations** Structure data provide information that is useful in describing the suitability of the sites for screening and escape cover, which are important for wildlife. Methods used to collect these data are quick, allowing for numerous samples to be obtained over relatively large areas. Methods that use visual obstruction techniques to evaluate vegetation height have little observer bias. Those techniques that estimate cover require more training to reduce observer bias. Structure is rarely used by itself when describing trend.

3. **Techniques**

- Primary attributed that the technique collects.
  - **Cover Board**
  - **Visual Obstruction - Robel Pole**

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VISUAL OBSTRUCTION METHOD

Robel Pole

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1 . General Description This method is used for determining standing plant biomass on an area. It has primarily been used to determine the quality of nesting cover for birds on the Great Plains and is commonly referred to as the Robel Pole Method. This method is applicable to other ecosystems throughout the western U.S. where height and vertical obstruction of cover are important. The following vegetation attributes are monitored using this method:

A. Vertical cover
B. Production
C. Structure

It is important to establish a photo plot (see Section VA) and take both close-up and general view photographs. This allows the portrayal of resource values and conditions and furnishes visual evidence of vegetation and soil changes over time.

2. Areas of Use The Robel Pole Method is most effective in upland and riparian areas where perennial grasses, forbs, and shrubs less than 4 feet tall are the predominant species.

3. Advantages and Disadvantages Robel Pole measurements are simple, quick, and accurate. This method can be used to monitor height and density of standing vegetation over large areas quickly. Statistical reliability improves because numerous measurements can be taken in a relatively short time. Limitations of the method may stem from infrequent application in a variety of rangeland ecosystems. While the Robel Pole Method has been used with great success on the Great Plains, there needs to be more research in a variety of plant communities.

4. Equipment The following equipment is needed.

A. Study Location and Documentation Data form
B. Robel Pole form
C. Cover classes for the area or plant community
D. Robel pole
E. One stake: 3/4- or I -inch angle iron not less than 16 inches long
F. Hammer
G. Permanent yellow or orange spray paint
H. Compass
I. Steel post and driver

5. Training The accuracy of the data depends on the training and ability of the examiners. They must receive adequate and consistent training in laying out transects, determining cover classes, and reading the Robel pole.

6. Establishing Studies Careful establishment of studies is a critical element in obtaining meaningful data. Select study sites that are representative of much larger areas in terms of similar cover levels.

A. **Site Selection** The most important factor in obtaining usable data is selecting representative areas (critical or key areas) in which to run the study. Study sites should be located within a single plant community within a single ecological site. Transects and sampling points need to be randomly located within the critical or key areas.

B. **Pilot Studies** Collect data on several pilot studies to determine the number of samples (transects or observation points) and the number and size of quadrats needed to collect a statistically valid sample.

C. **Vertical Cover Classes** Establish the number of vertical cover classes and height limits for each class based on objectives. These cover classes must be developed locally for each ecological site or plant community. The following is an example of cover classes established for upland bird nesting cover on the Fort Pierre National Grasslands:

Cover Classes	Visual Obstruction Height
1	0.0 - 1.9
2	2.0 - 2.9
3	3.0 - 3.9
4	4.0 +

D. **Number of Transects** Establish the minimum number of transects to achieve the desired level of precision for the key species in each study site.

E. **Number of Observation Points** The number of observation points will depend on the objectives, level of precision required, etc.; however, it is recommended that a minimum of 50 be read per transect. Additional observation points should be read, depending on the pilot study.

F. **Study Layout** Data can be collected using the baseline, macroplot, or linear study designs. The linear technique is the one most often used.

G. **Reference Post or Point** Permanently mark the location of each study with a reference post and a study location stake.

H. **Study Identification** Number studies for proper identification to ensure that the data collected can be positively associated with specific sites on the ground.

I. **Study Documentation** Document pertinent information concerning the study on the Study Location and Documentation Data form.

7. Taking Photographs Establish photo plots.

8. Sampling Process In addition to collecting the specific studies data, general observations should be made of the study sites.

This technique is most effectively accomplished with two individuals.

A. Determine the transect bearing and select a prominent distant landmark such as a peak, rocky point, etc., that can be used as the transect bearing point.

B. Start a transect by randomly selecting a point along the transect. Two Visual Obstruction (VO) measurements are taken at each observation point from opposite directions along the contour. One examiner holds the Robel pole at the observation point, while the second examiner holds the end of the cord perpendicular to the transect. The Visual Observation (VO) measurement is made by determining the highest 1 -inch band totally or partially visible and recording the height on the Robel Pole form (Illustration 25).

C. Continue the transect by taking readings at specified intervals along the transect bearing until the transect is complete. The distance between observation points can be increased to expand the area sampled.

9. Calculations

A. Total the visual obstruction measurements on the Robel Pole form for both readings at each observation point and record at the bottom of the form. Add these two totals and divide by the total number of readings. This will yield the average visual obstruction.

B. The average height or visual obstruction value can be used to determine the cover class.

10. Production Data from the Robel pole method can be correlated to forage production or standing crop. This correlation can be established by clipping and weighing the standing crop within; a specified quadrat frame directly in front of the Robel pole after the readings are made. Depending on the vegetation community approximately 25 quadrat frames need to be clipped to get a good correlation between visual obstruction readings and standing crop. Note that this will be an estimate of standing plant biomass. It will include not only this year's production, but also herbage remaining from prior years. After the correlation is made between the pole readings and production, the pole can then be used to quickly estimate production across the entire plant community.

11. Data Interpretation The average Visual Obstruction value can be used to determine success at meeting objectives. The average Visual Obstruction value determined from the Robel Method form is compared with the cover classes and the residue levels to determine if overall objectives have been meet.

12. Data Analysis This technique involves destructive sampling (clipped plots), so permanent transects or quadrats are not recommended. Since the transects are not permanently marked, use the appropriate nonpaired test. When comparing more than two sampling periods, use ANOVA.

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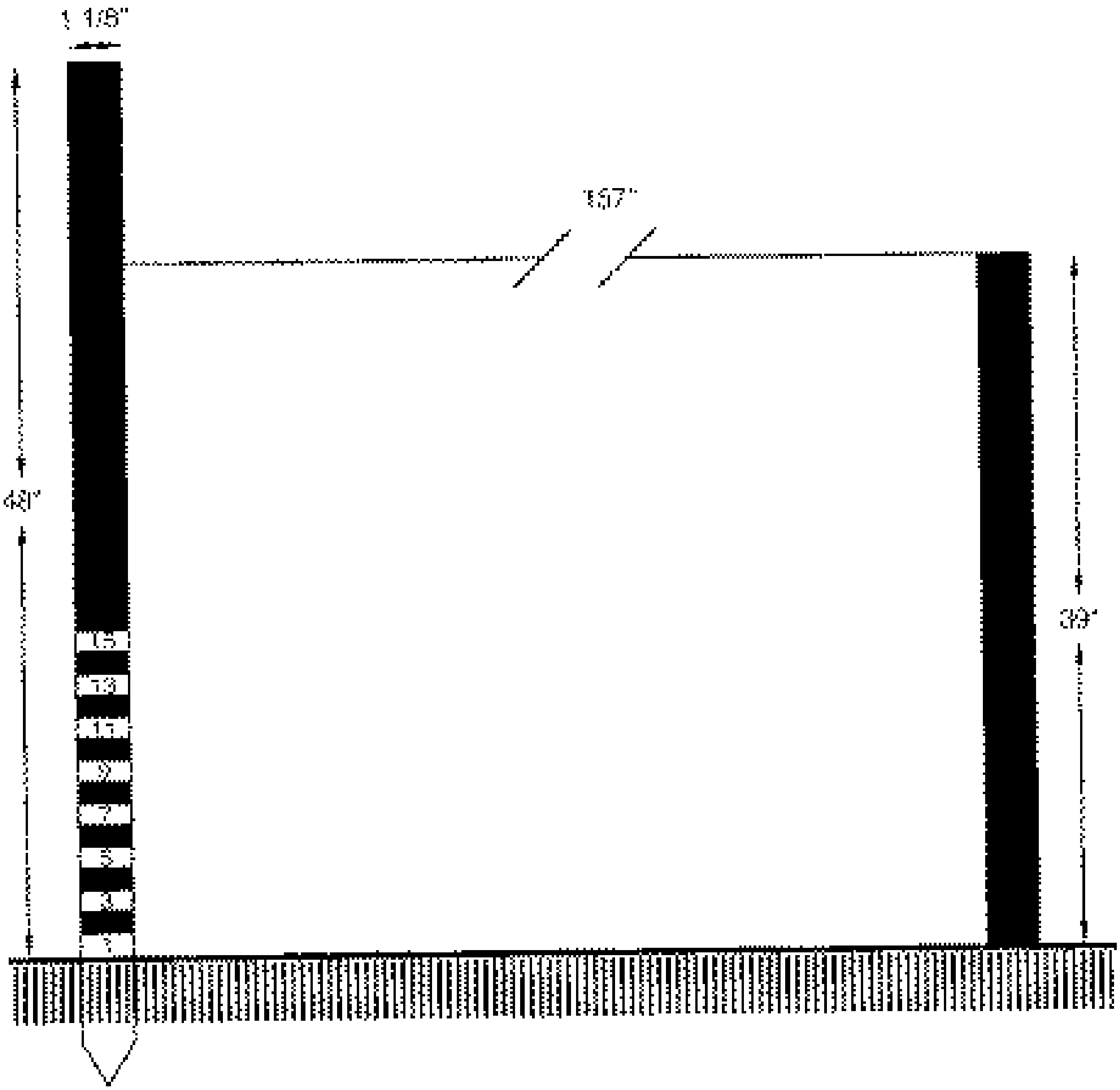
Robel Pole

Study Number	Date	Examiner
Allotment Name & Number	Pasture	
Sampling Interval	Study Location	

Transect	#- 1		#-		#-		#-	
Station	VO	VO	VO	VO	VO	VO	VO	VO
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
21								
22								
23								
24								
25								
Total								
Grand Total								
Average								

Robel Pole



1. Pole is 1.125 inches in diameter and 48 inches long.
2. Pole is painted with alternating 1-inch bands of flat white and gray colors, starting with white on the bottom. Alternating 1-inch bands can be extended to the top of the pole if needed.
3. A single 157-inch (4m) cord is attached to the pole at a height of 39 inches (1m) to standardize the distance and height at which readings are taken.
4. Narrow black numbers corresponding to the number of bands are painted on the white bands. For example, the bottom white band is "1," the next white band is "3," and so on.
5. A spike is attached to the bottom of the pole so that it can be pushed into the ground, allowing one examiner to make the readings. The spike can be removed if not needed.

5. A spike is attached to the bottom of the pole so that it can be pushed into the ground, allowing one examiner to make the readings. The spike can be removed if not needed.

U.S. Fish & Wildlife Service

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COMPOSITION

1. **Description** Composition is a calculated attribute rather than one that is directly collected in the field. It is the proportion of various plant species in relation to the total of a given area. It may be expressed in terms of relative cover, relative density, relative weight, etc.

Composition has been used extensively to describe ecological sites and to evaluate rangeland condition.

To calculate composition, the individual value (weight, density, percent cover) for a species or group of species is divided by the total value of the entire population.

2. **Advantages and Limitations**

a. Quadrats, point sampling, and step point methods can all be used to calculate composition.

b. The repeatability of determining composition depends on the attribute collected and the method used.

c. Sensitivity to change is dependent on the attribute used to calculate composition. For instance, if plant biomass is used to calculate composition, the values can vary with climatic conditions and the timing of climatic events (precipitation, frost-free period, etc.). Composition based on basal cover, on the other hand, would be relatively stable.

d. Composition allows the comparison of vegetation communities at various locations within the same ecological sites.

3. **Techniques**

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- Primary attribute that the technique collects. Species composition is calculated using production data. Frequency data should not be used to calculate species composition.
  - **Dry Weight Rank**
- Secondary attribute that can be collected or calculated.
  - **Daubenmire**
  - **Line Intercept**
  - **Step Point**
  - **Point Intercept**
  - **Density**
  - **Double Weight Sampling**
  - **Harvest**
  - **Comparative Yield**

This page was last modified 05/31/01

PHOTOGRAPHS

1. General Description Photographs and videotapes can be valuable sources of information in portraying resource values and conditions. Therefore pictures should be taken of all study areas. Both photographs and videos can be taken at photo plots or photo points. The difference between photo plots and photo points is that, with photo points, closeup photographs of a permanently marked plot on the ground are not taken. Use close-up and/or general view pictures with all of the study methods. Comparing pictures of the same site taken over a period of years furnishes visual evidence of vegetation and soil changes. In some situations, photo points could be the primary monitoring tool. All pictures should be in color, regardless of whether they are the primary or secondary monitoring tool.

2. Equipment The following equipment is suggested for the establishment of photo plots:

A. Study Location and Documentation Data form
B. Photo Identification Label
C. Frame to delineate the 3- x 3-foot, 5- x 5-foot, or I - x I - meter photo plots
D. Four rods to divide the 3- x 3- foot and I - x I -meter photo plot into nine square segments
E. Stakes of 3/4 - or I- inch angle iron not less than 16 inches long
F. 35-mm camera with a 28-mm wide-angle lens and film
G. Hammer
H. Small step ladder (for 5- x 5-foot photo plots)
I. Felt tip pen with waterproof ink

3. Study Identification Number studies for proper identification to ensure that the data collected can be positively associated with specific studies on the ground.

4. **Close-up Pictures** Close-up pictures show the soil surface characteristics and the amount of ground surface covered by vegetation and litter. Close-up pictures are generally taken of permanently located photo plots.

A. The location of photo plots is determined at the time the studies are established. Document the location of photo plots on the Study Location and Documentation Data form to expedite relocation.

B. Generally a 3- X 3-foot square frame is used for photo plots; however, a different size and shape frame may be used. Where new studies are being established, a 1 -meter x I -meter photo plot is recommended. Frames can be made of PVC pipe, steel rods, or any similar material. Illustration I shows a diagram of a typical photo plot frame constructed of steel rod.

C. Angle iron stakes are driven into the ground at two diagonal corners of the frame to permanently mark a photo plot. Paint the stakes with bright-colored permanent spray paint (yellow or orange) to aid in relocation. Repaint these stakes when subsequent pictures are taken.

D. The Photo Identification Label is placed flat on the ground immediately adjacent to the photo plot frame.

E. The camera point, or the location from which the close-up picture is taken, should be on the north side of the photo plot so that repeat pictures can be taken at any time during the day without casting a shadow across the plot.

F. To take the close-up pictures, stand over the photo plot with toes touching the edge of the frame. Include the photo label in the photograph. Use a 35-mm camera with a 28-mm wide-angle lens.

G. A step ladder is needed to take close-up pictures of photo plots larger than 3- x 3-foot.

5. General View Pictures General view pictures present a broad view of a study site. These pictures are often helpful in relocating study sites.

A. If a linear design is used, general view pictures may be taken from either or both ends of the transect. The points from which these pictures are taken are determined at the time the studies are established. Document the location of these points on the Study Location and Documentation Data form to expedite relocation .

B. The Photo Identification Label is placed in an upright position so that it will appear in the foreground of the photograph.

C. To take general view pictures, stand at the selected points and include the photo label, a general view of the site, and some sky in the pictures.

D. A picture of a study site taken from the nearest road at the time of establishment of the study facilitates relocation.

6. Photo Points General view photographs taken from a permanent reference point are often adequate to visually portray dominant landscape vegetation. It is important that the photo point location be documented in writing and that the photo include a reference point in the foreground (fencepost, fence line, etc.), along with a distinct landmark on the skyline. Photographs taken from photo points should be brought to the field to assist in finding the photo point and to ensure that the same photograph (bearing, amount of skyline, etc.) is retaken. The photograph should be taken at roughly the same time each year to assist in interpreting changes in vegetation. As always, recording field notes to supplement the photographs is a good idea.

Photo points are especially well adapted for use by external groups who are interested in monitoring selected management areas. Photo points require a camera, film, and local knowledge of photo point location; given these, they are easy to set up and retake. Agencies can encourage participation by external groups or permittees by providing the photographer with film and development. Double prints allow the agency and photographer to keep copies of photographs for their files. Negatives should generally be kept and filed at the agency office.

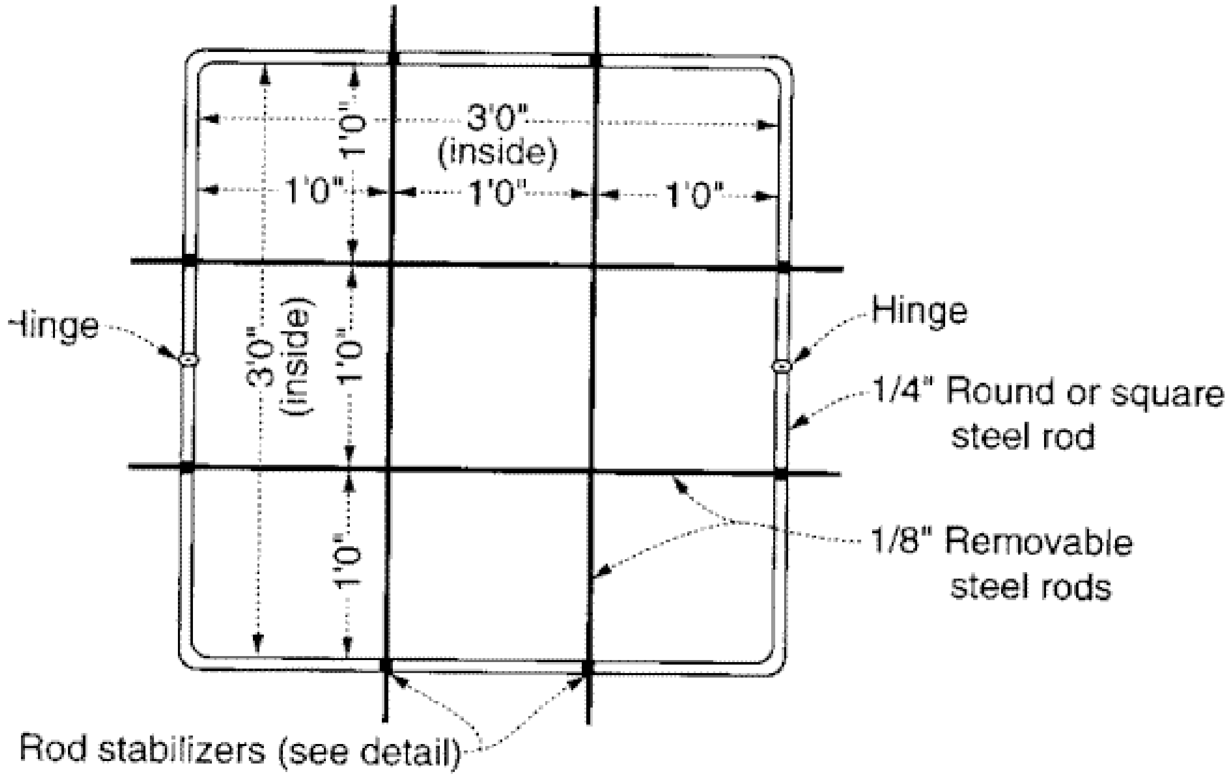
7. Video Images Video cameras, i.e., camcorders, are now available and are able to record multiple images of landscapes for monitoring. While video images provide new ways to record landscape images, limitations in their use should also be considered. Video tapes, especially the quality of the image, may begin to deteriorate within 5 years. These images can be protected by conversion to digital computer images (expensive) or re-recording the original tape onto a new blank tape.

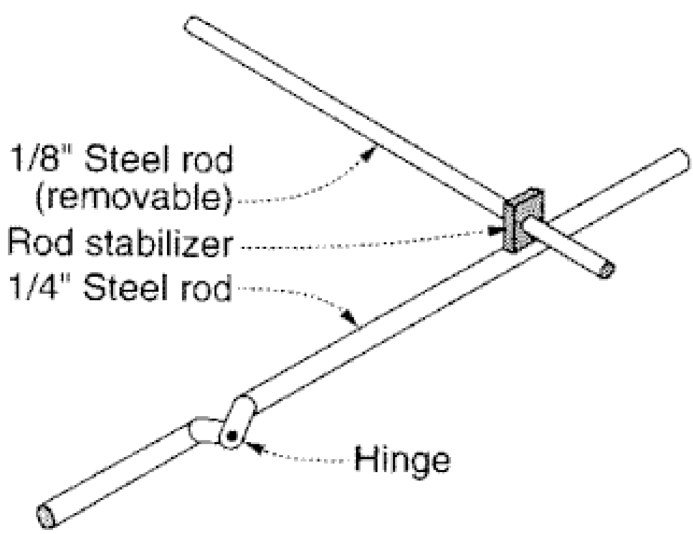
Comparing repeat video images is difficult, especially if the same landscape sequences are not repeated in the same way on subsequent video recordings. Video cameras are also more susceptible to dust and heat damage and cost considerably more than 35-mm cameras. Advantages and disadvantages of video cameras should be carefully considered prior to implementing a video monitoring system.

8. Repeat Pictures When repeat pictures are taken, follow the same process used in taking the initial pictures. Include the same area and landmarks in the repeat general view pictures that were included in the initial pictures. Take repeat pictures at approximately the same time of year as the original pictures.

9. General Observations General observations concerning the sites on which photographs are taken can be important in interpreting the photos. Such factors as rodent use, insect infestation, animal concentration, fire, vandalism, and other site uses can have considerable impact on vegetation and soil resources. This information can be recorded on note paper or on study method forms themselves if the photographs are taken while collecting other monitoring data.

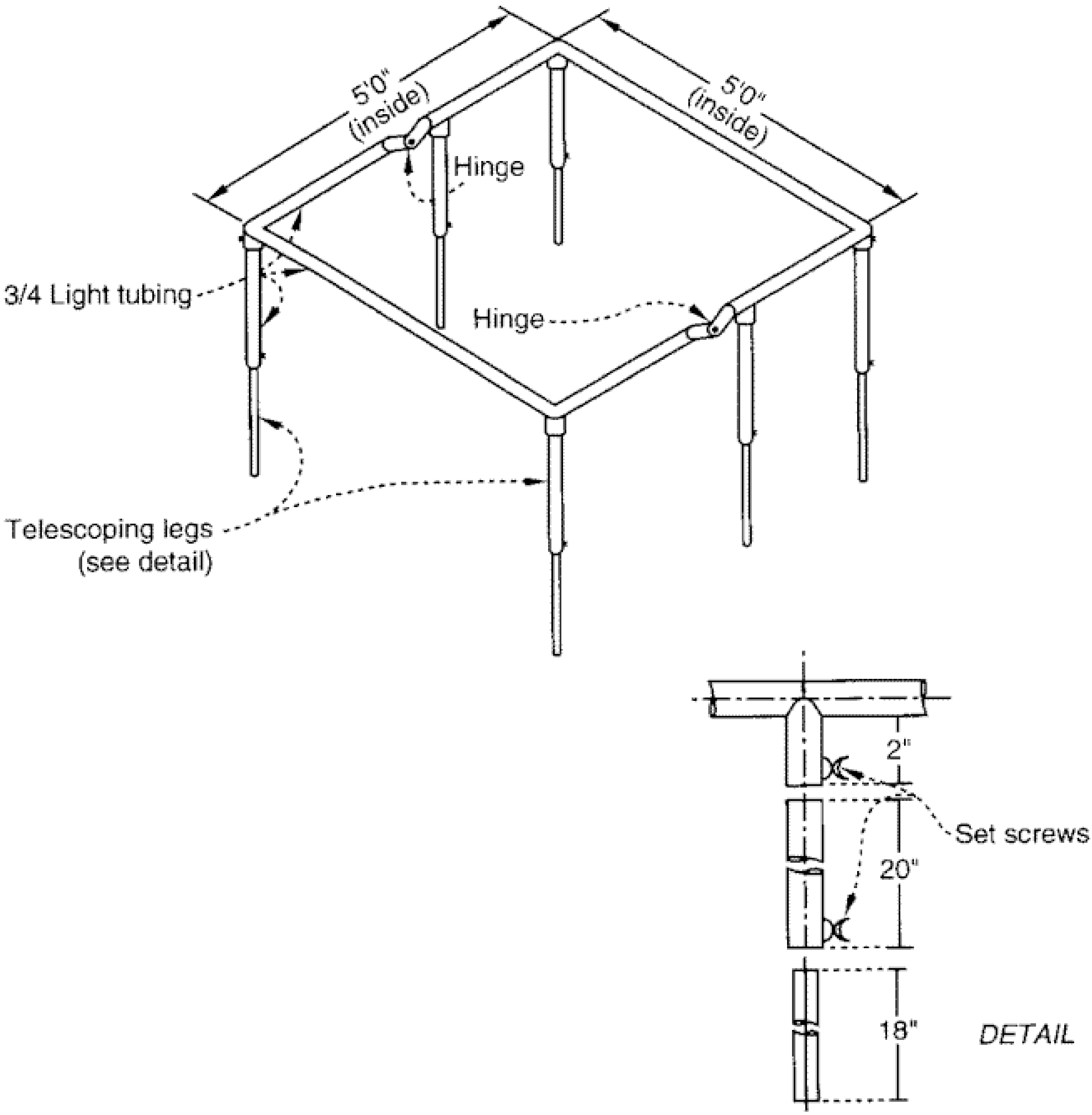
Photo Plot Frame - 3- x 3-foot



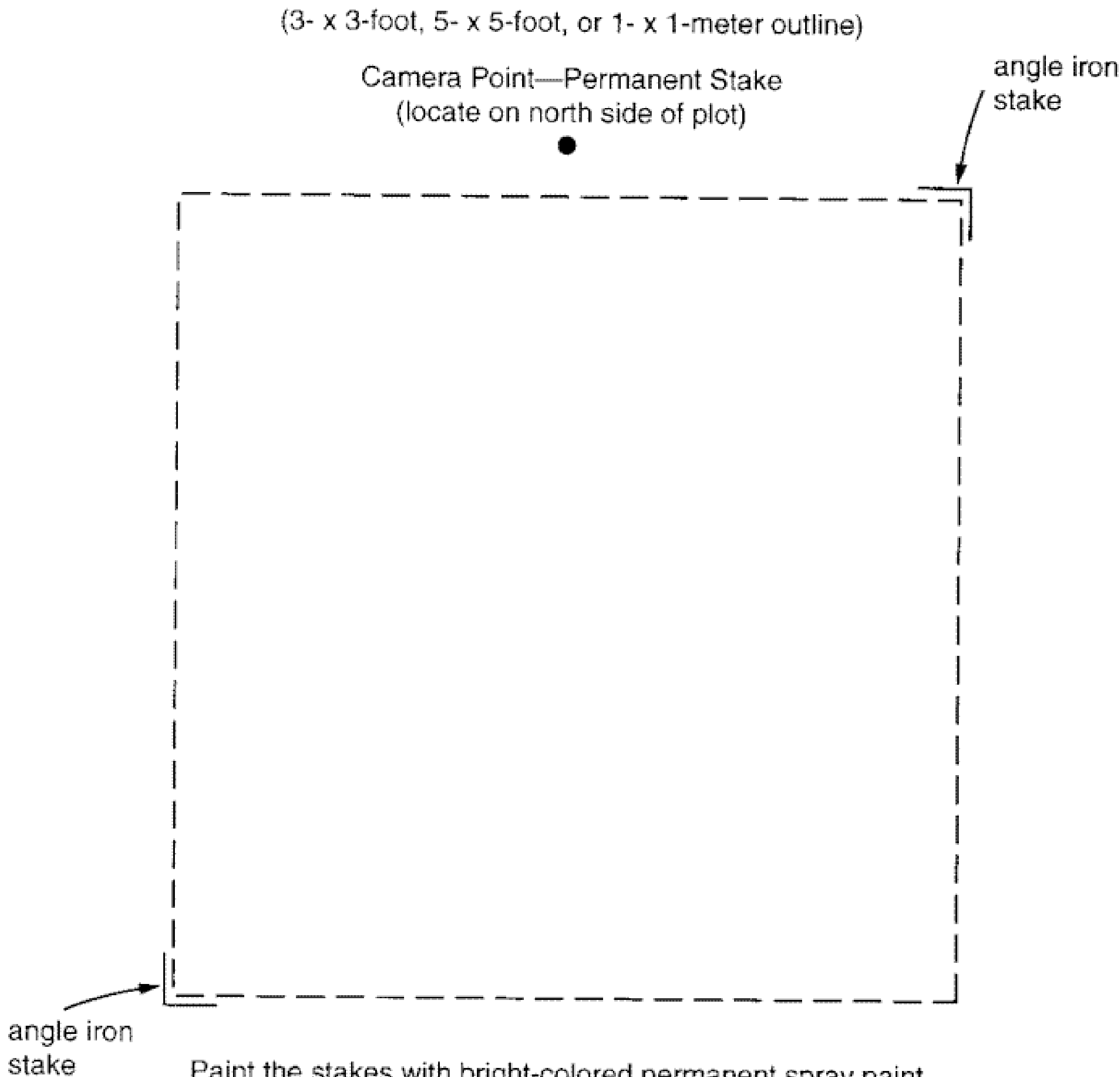


DETAIL

Photo Plot Frame—5- x 5-foot



Permanent Photo Plot Location



Paint the stakes with bright-colored permanent spray paint (yellow or orange) to aid in relocation. Repaint these stakes when subsequent photographs are taken.

HARVEST METHOD

1. General Description The concept of this method is to determine the amount of current-year above-ground vegetation production on a defined area. The following vegetation attributes are monitored:

A. Peak standing crop, which is the above-ground annual production of each plant species.

B. Species composition by weight.

It is important to establish a photo plot (see Section VA) and take both close-up and general view photographs. This allows the portrayal of resource values and conditions and furnishes visual evidence of vegetation and soil changes over time.

2. Areas of Use This method can be used in a wide variety of vegetation types. It is best suited for grasslands and desert shrubs. It is not well suited to large shrub and tree communities.

3. Advantages and Limitations

A. The harvest method measures the attribute historically used to determine the capabilities of an ecosystem.

B. It provides the basic data currently used for determining ecological status.

C. Seasonal and annual fluctuations in climate can influence plant biomass.

D. Measurements can be time-consuming.

E. Current year's growth can be hard to separate from previous years' growth.

F. Accurate measurements require collecting production data at peak production periods which, are usually short, or using utilization and phenology adjustment factors.

G. Green weights require conversion to air-dry weights.

H. In most areas, the variability in production between quadrats requires the sampling of large numbers of quadrats in order to detect reasonable levels of change.

4. Equipment The following equipment is needed (see also the equipment listed in Section VA, page 3 1, for the establishment of the photo plot):

A. Study Location and Documentation Data form
B. Production form
C. Sampling frames or hoops
D. One stake: 3/4- or 1 -inch angle iron not less than 16 inches long

E. Herbage Yield Tables for Trees by Height, DBH, or Canopy
F. Clippers
G. Paper bags
H. Kilogram and gram spring-loaded scales with clip
I. Tree diameter measuring tape
J. Steel post and driver
k. Oven for drying vegetation
L. Air-dry weight conversion tables
M. Rubber bands
N. Compass

5. Training The accuracy of the measurement depends on the training and ability of the examiners. Examiners must be able to identify plant species and determine current year's growth.

6. Establishing Studies Careful establishment of studies is a critical element in obtaining meaningful data.

A. **Site Selection** The most important factor in obtaining usable data is selecting representative areas (critical or key areas) in which to run the study. Study sites should be located within a single plant community within a single ecological site. Transects and sampling points need to be randomly located within the critical or key areas.

(1) Select transects at random.

(2) The number of quadrats selected depends on the purpose for which the estimates are to be used, uniformity of the vegetation, and other factors.

(3) Adapt the size and shape of quadrats to the vegetation community to be sampled.

B. **Pilot Studies** Collect data on several pilot studies to determine the number of samples (transects or observation points) and the number and size of quadrats needed to collect a statistically valid sample.

C. **Study Layout** Production data can be collected using either the baseline, macroplot, or linear study designs. The linear technique is the one most often used.

D. **Reference Post or Point** Permanently mark the location of each study with a reference post and a study location stake.

E. **Study Identification** Number studies for proper identification to ensure that the data collected can be positively associated with specific sites on the ground.

F. **Study Documentation** Document pertinent information concerning the study on the Study Location and Documentation Data form.

7. Taking Photographs Establish photo plots.

8. Sampling Process In addition to collecting the specific studies data, general observations should be made of the study sites (see Section II.F).

A. Determine the transect bearing and select a prominent distant landmark such as a peak, rocky point, etc., that can be used as the transect bearing point.

B. Randomly select the starting point along the transect bearing. Take the specified number of paces and read the first quadrat.

C. Record weights by clipping and weighing all vegetative material for each species occurring in the quadrat. Samples should be bagged and saved for determining air-dry weights. Samples from subsequent quadrats should be kept separate. The following information should be record on each bag: Date, Transect Number, Quadrat Number, and Species.

When harvesting plants, include all parts of all plants within the quadrat. Exclude all parts of herbaceous plants and shrubs outside the vertical projection of the quadrat, even though the base is within the quadrat.

D. Continue the transect by establishing additional quadrats at specified intervals. To change the length of the transect, adjust the number of paces between quadrats.

E. Oven-dry samples at 60'C for 24 hours to determine air-dry weight.

9. Calculations The weights collected for each species per quadrat placement are recorded on the Production form.

A. The green weight for each species is totaled for the entire transect and shown in column 5.

B. Column 6 is the total dry weight for each species. This column is totaled at the bottom of the form for the composition totals.

C. Percent composition (Column I 1) is calculated by dividing the total dry weight of each species by the composition totals.

D. Columns 4, 7, 8, 9,and 10 are used only for double sampling.

E. If plant biomass is collected in grams, it can be easily converted to pounds per acres if the total area sampled is a multiple of 9.6 ft'.

10. Data Analysis This technique involves destructive sampling (clipped plots), so permanent transects or quadrats are not recommended. Since the transects are not permanently marked, use the appropriate nonpaired test. When comparing more than two sampling periods, use ANOVA.

U.S. Fish & Wildlife Service

Fuel and Fire Effects Monitoring Guide

WATER QUALITY MONITORING

Methods Overview

- Water Quality
  - Temperature
  - pH
  - Dissolved oxygen
  - Total Dissolved Solids (TDS)
  - Turbidity
- Water Quantity

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WATER TEMPERATURE

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1. General Considerations

A. **Equipment Selection and Data Sources**

Water temperature is usually measured in situ rather than from water collected with sampling devices; but, if the water sample is at least 500 ml and the temperature is measured immediately, loss of heat will be minimal. Pocket and electronic thermometers are appropriate for measuring temperature in water samples and water surface temperatures.

Depth-temperature profiles are obtained with maximum-minimum, electronic or reversing thermometers or with a bathythermograph. A continuous permanent record of temperature changes at one or two locations can be obtained with a thermograph; sophisticated models of electronic thermistors can record temperature at several locations at specific times.

Water resources records of the U.S. Geological Survey or state stream and lake surveys can provide temperature data for some studies. Care must be exercised to be certain that the records reflect current stream or lake conditions. Dams, channelization, and changes in irrigation diversions and other watershed uses change the temperature regime. Water temperature data collected before such events will not accurately reflect current conditions. Brown (1972) designed a model to predict temperature changes in small streams following clearcut forestry practices. Furthermore, the actual site of temperature collection measurements may not be suited to the needs of your study. Often gaging stations are near upstream tributaries, where mixing is not complete, or near reservoir releases, where the temperature is not representative of downstream reaches.

B. **Site Selection**

Several characteristics of a river must be identified and measured so that the sampling locations best meet the study objectives. Temperature heterogeneity is most likely to occur during low flows because of localized heating or during snowmelt where tributary water enters the mainstream. River zones that receive spring water, water that has flowed through slow-velocity areas, or industrial effluent will exhibit different temperature gradients. In addition, temperatures of a regulated stream may not have the same seasonal trends that a free-flowing stream follows. To determine the degree of temperature variation, measure temperature at selected depths across the river.

In selecting a lake or reservoir sampling site, consider the shapes of the lake surface and bottom the inflow and outflow patterns, the prevailing winds, the accuracy requirements for the data, the species of concern, and the specific study objectives. Wind-protected lakes with large littoral areas and embayments usually have large horizontal and vertical temperature variations. Many sampling sites may be required to obtain a representative average temperature.

2. Pocket Thermometers (Dialhead or Armored Glass)

A. **Field Use**

Glass thermometers are generally more accurate than dialhead thermometers and can be used to calibrate other instruments. They are the simplest device for measuring surface water temperature by boat or wading. Only glass thermometers calibrated for full immersion should be used. Standard procedure is to take the surface temperature in the shade produced by a person or boat. Immerse the thermometer in the water for at least 60 seconds, until the temperature is constant. Read the temperature without removing it from the water. Record the temperature, the site, and the time of day for each location.

B. **Equipment**

Dialhead or armored glass thermometer
Water-sampling apparatus, if necessary
Waders (optional)
Watercraft, if necessary
C. Training
Five minutes to become familiar with the scale.

3. Maximum-Minimum Thermometers

A. **Field Use**

This is an inexpensive instrument that records maximum and minimum water temperatures over a given period of time. The mercury displaces magnets to the points of highest and lowest temperature. The thermometer is reset by repositioning the magnets to the level of mercury with another magnet.

Encase the thermometer by placing it in a 1-ft length of accommodating-diameter galvanized pipe. Close the pipe ends with perforated caps or crossbolts. Suspend it by a cable from an anchored float or anchor it to the stream bottom.

On retrieval, be careful not to jar the magnets from position. Read the temperature scale at the lower end of the magnet. Record the maximum and minimum readings and the time interval between readings.

If water temperatures are expected to decrease from surface to bottom, it is possible to obtain a temperature profile with a vertical string of submersible maximum-minimum thermometers from the surface to the bottom. Attach a thermometer to a cable or rope at various depth intervals, depending on the total depth. Make a mark on the cable for zero depth (surface) to help position the depth of the cable. Set the magnets to the level of mercury. Carefully lower the cable, deepest thermometer first, to the bottom or fixed depth and leave submerged for1 to 2 min. Retrieve the cable and record the minimum temperature from each depth. If there is enough current to displace the line from the vertical, a weight at the end of the cable should be sufficient to maintain a perpendicular line. The temperature profile will be incorrect if, instead of continuously decreasing, the temperature at any depth is higher than the temperature of any water layer above that depth; temperature inversions can occur under ice or within a water layer where increased salinity or a heavy plankton bloom absorbs and holds a disproportionate amount of heat.

B. **Equipment**

Submersible maximum-minimum thermometer
Galvanized pipe of sufficient diameter to hold the thermometer, 1 ft
Perforated caps or bolts and nuts
Cable or rope
Anchor (boat anchor, concrete block, cement-filled can with U-bolt or eye embedded in the top to attach the line or cable)
Weights for cable, if necessary.

C. **Training**

One field trip to become familiar with the equipment and procedures.

4. Electronic Thermometers (Thermistor Type)

A. **Field Operation**

See calibration procedures

Thermistors are accurate, convenient, and simple to use because the sensor can be placed remotely from the readout instrumentation. Allow the instrument to warm up as directed by the manufacturer. Lower the probe to the desired depth as indicated on the cable, and read the meter when it has stabilized.

For lake temperature profiles, readings are usually made every 1-2 m, with shorter intervals in the thermocline. Accurate data can be obtained if the readings are repeated as the probe is brought to the surface. The two readings at each depth are averaged. For very deep work, a cable-compensation factor may be required; these are available from the manufacturer. Analytical units are available that measure and record temperature and other water-quality variables at predetermined time intervals at as many locations as there are sensors.

B. **Equipment**

Temperature readout unit (potentiometer)
Thermistor probe suitable for use with a readout unit with a range of -10 C to +50 C.
Sufficient cable for the sampling site-
C. Training
One-half hour or one field trip to become familiar with the calibration and particular operating procedures of the instrument.

5. Continuous-Recording Thermographs

A. **Field Operation**

Liquid-filled thermographs provide a continuous recording of water temperature, usually within 5 m of the recording unit. Maximum, minimum, and average temperatures are obtained. Follow manufacturer's instructions for operation of the thermograph. House the recording unit, cable, and sensor in a waterproof box, plastic or metal pipe, and perforated pipe, respectively, when used for stream measurements. If the thermograph is mounted on an anchored raft for lake or reservoir measurements, protect the recording unit in a sturdy water-proof housing. Water-proof thermographs can be attached at a specified depth to a weighted line connected to an anchored buoy, or they can be simply anchored to a cement block if bottom measurements are required. These thermographs are much less conspicuous and subject to vandalism than non-waterproof types. They should be recalibrated with a glass thermometer each time the chart in the unit is replaced.

B. **Equipment**

Thermograph
Housing
Capillary and sensor and pipe to house sensor and capillary (streams or lake bottom)
Raft (e.g., wooden platform on oil drums) and hardware to attach housing to raft
Raft or buoy anchor (e.g., Danforth) Rope to anchor raft
Cement block and chain or cable with hardware to anchor waterproof thermograph (streams or lake bottom)
Cable, rope, and hardware for suspending waterproof thermograph from a buoy
Anchored buoy to support and locate thermograph.

C. **Training**

One hour to learn to insert chart paper, fill and adjust recording pens, and calibrate the instrument and one preliminary field trip.

6. Bathythermograph (BT)

A. **Field Operation**

Follow the manufacturer's instructions for operation of the BT. The following instructions are adapted from the Kahlsico BT manual as a guide.

The following list of cautions should be reviewed before lowering the instrument into the water:

(1) Speed of ship not to exceed 18 knots.

(2) Make a sound cable hitch to shackle of instrument.

(3) Check the operation of the hoist and its actuating clutch.

(4) Check lubrication of the hoist and moving parts.

The following steps are necessary to prepare a bathythermograph instrument for lowering:

(1) Remove bathythermograph from container and slide the window cover towards nosepiece end. This will expose the slide ports.

(2) Check the grooves of the slide holder to be sure they are clean and free of foreign material. The curved spring at top of slide holder will hold the glass slide securely in the grooves.

(3) Looking into the port hole, check the stylus point to be sure it is clean and sharp. If it needs cleaning, do not exert any undue force on the stylus or the stylus arm. This might affect the calibration. The stylus should be clean to produce a fine, cleancut line on the glass slide.

(4) Next insert the coated slide into the grooves. Remove a slide from the container, holding it between thumb and forefinger at the edges to prevent touching the coated face. Insert the slide into the grooves of the slide holder so that the edge with the chamfered corners enters first and the chamfer is at the top, or forward, end of slide holder. Push the slide in the grooves under the spring until it rests firmly against the stop pin. This is an important step because errors will be encountered in the readings if each slide is not positioned firmly against the stop pin.

(5) Pull the sleeve down towards the fins. This will trip a stylus lifter arm, lowering the stylus onto the glass slide. Lock the sleeve with the screw near the guard fins. The BT is now ready for lowering.

(6) Determine the approximate depth of the water in the area of the lowering. This is obtained with a fathometer, sonar soundings, or chart. Secure the cable hitch to the bathythermograph and gently release when cable slack has been tightened on the cable drum.

(7) Swing the BT outward from the rail and release clutch, lowering the instrument into the water. Hold the instrument just under the surface of the water for approximately 30 sec to enable the BT to adjust to the temperature of the surface water. Record the temperature of the surface water by retrieving the water in a bucket and measuring the temperature with the thermometer furnished with the BT. This temperature check of surface water should be made as rapidly as possible when the water is retrieved.

(8) To lower the instrument, release the clutch handle into the neutral position and allow the cable to pay out freely and rapidly. If the winch has an indicator for feet of cable paid out and, as the proper indicator depth reading is approached, apply the winch brake smoothly to prevent stopping with a sudden jerk. A sudden jerk may snap the cable, causing loss of the instrument.

(9) Engage the clutch for hoisting the instrument, watching the indicator to check the amount of cable still out. When the BT arrives at the surface of the water, operate the winch to minimize swinging of the instrument under the boom. Hoist the BT to within 4 ft of the boom and retrieve the instrument by swinging the cable towards the boat rail with a convenient cable hook. The BT can now be removed from its cable or remain on the cable for subsequent lowerings.

(10) Move the window sleeve forward to check to make sure that the stylus is free of the slide. Remove the slide by pushing against its edge with a forefinger or pencil through the ejecting port. Handle slide with fingers at edges to prevent damage to the coated surface with its inscribed record.

(11) Always protect BT from hot sun. Cover the instrument with wet cloth if it is to be used immediately. Do not let the BT exceed 105º F or fall below 20º F.

(12) With the slide removed, check for a suitable trace. If the slide has been damaged, make another test with a new slide.

(13) With a sharp point, record the necessary data onto the grid coating, being careful not to damage the temperature scribe made by the instrument. Include the BT serial number date and time on each slide.

(14) Gently rinse the slide and place into storage container for safekeeping until data processing.

(15) To read the slide, insert it into the slide holder with the coated surface towards the grid, which is fastened to the grid viewer. Avoid scratching the coated surface. Insert the slide until it rests firmly against the stop pin furnished at the opposite edge of the grid holder. This procedure is important to obtain accurate readings from the grid calibrated to this particular instrument.

(16) Focus the grid viewer and read the slide scribe as it if portrayed on the crosslines of the grid. Usually the temperatures are read to the nearest 0.1º and the depths read to within approximately 1% of total depth. The center of the trace mark on the slide is the point at which a reading on the grid should be taken.

(17) If, during the course of a lowering, the BT has hit bottom, an underwater object, the side of the ship, or was dropped aboard, it will probably need to be recalibrated by the manufacturer or a qualified laboratory.

B. **Storage and Maintenance**

Since the BT is a delicate instrument, storage and maintenance of this device are extremely important to ensure long life. Following a good cleaning procedure is especially important. Thoroughly rinse the BT with fresh water internally and externally so as to remove residue that can corrode or affect any of the moving parts.

Tilt the BT to remove as much excess water as possible, and place it into its cushioned container to protect it from handling shocks and ship vibrations. Store the BT in its container within a safe temperature range.

Approximately once a week, rinse the interior of the BT with a cupful of rust-preventive compound. Pour the compound into the port, close the sleeve, and, covering the other openings, tilt the BT several times to thoroughly rinse the interior surfaces. Then open sleeve and let compound drain from the interior. Do not oil the BT.

Preventive maintenance will ensure additional life for the BT.

C . **Equipment**

Bathythermograph

Accessories furnished with new BTs:
Gold- or smoke-coated slides
Mounted grid
Grid viewer
Case for the BT
Shackle
Swivel
Winch and crane assembly
Cable

D. **Training**

At least 2 hr in the field is required to become familiar with operating procedures and to practice lowering and raising the BT in a consistent fashion. If inexperienced personnel need to practice raising and lowering the BT, a dummy BT should be used for the first few runs.

7. Reversing Thermometers (RT)

A. **Field Operation**

Reversing thermometers are usually in brass tubes or water sampling bottles, but they can be attached to the line of reversing frames and operated independently. The brass tubes are cut away so that the thermometer scale can be read, and the tube ends are constructed to hold the thermometers firmly in place and to eliminate shock. Frames attached to bottles are fixed if the bottle reverses (Nansen bottles) for sampling or are rigged to reverse upon closure of a nonreversing bottle.

Thermometers are sent to the required depth. Mercury supplied in the larger reservoir fills the capillary to a height above the constriction, depending on the temperature. Upon reversal, the mercury column breaks at the constriction and runs down to a smaller bulb filling the graduated capillary. The loop in the capillary catches any mercury forced past the constriction if the temperature has been raised after reversal. An auxiliary thermometer mounted alongside the RT shows the temperature at the time of reading; this temperature is required to correct the reading of the RT. The heavy glass tube surrounding reversing thermometers eliminates the effects of hydrostatic pressure. Reversing thermometers unprotected from the effects of pressure give a temperature reading dependent on depth, and this characteristic is used to determine depth at reversal. These instruments are usually designed so that the apparent temperature increase attributable to pressure is about 0.01oC per meter.

Reversing frames vary in style with manufacturer. Generally, the lower end is clamped to a cable by a wing nut and the top is attached to the cable by a spring-loaded clamp or wire catch. This catch is released when it is hit by a messenger traveling down the cable. Some frames are constructed so that when the messenger hits the bottom clamp of the frame, another messenger is released to travel down the cable to a deeper RT; in this way a series of measurements can be taken.

B. **Calculations**

The RT reading must be corrected for changes caused by differences between the temperature at reversal and the temperature at which the RT is read. The formula is

ÅT = [(T'-t) * (T'+V_o) / K] 1+[(T'-t) * (T'+V_o) / K]+I

where
ÅT = the correction factor to be added to the uncorrected reading
T' = the uncorrected reading of the RT
t = the temperature at which the RT is read (from the auxiliary thermometer)
V_o = the volume of the small bulb and of the capillary up to the 0º C gradation in degree units of the capillary
K = a constant that depends on the relative thermal expansion of mercury and the type of glass (for most RT, K = 6100)
I = the calibration correction, which depends on T' and is supplied by the manufacturer.

For convenience, prepare graphs or tables for T' and t for each thermometer for any values of T' and t, or prepare a tape for a programmable calculator.

C. **Equipment**

Protected reversing thermometer
Unprotected reversing thermometer if concurrent depth measurement is desired
Regular (auxiliary) thermometer
RT frames for independent operation or for attachment to sampling bottle
Messenger(s)
Sufficient cable for sampling depth
Winch and crane assembly

D. **Training**

During a field trip, practice handling the thermometers, placing them in the tubes, attaching the frame to the bottle or line, and lowering and tripping the frame with a messenger.

8. Calibration

Calibration certificates are available for the better mercury glass thermometers. Two waterbaths are required, one at 5º C, the other at 20º C, to calibrate other instruments. The temperature of these waterbaths should be monitored to the nearest 0.1º C with a certified thermometer.

Most temperature-measuring systems have two calibration adjustments. These are the zero setting, which moves the temperature scale (or pen position) up or down, and the span setting, which expands or contracts the length of the temperature scale (or pen movement). For mechanical instruments, the zero setting is made by raising or lowering the pen arm, and the span setting is made by moving the position of the pen-arm pivot; for electrical instruments, the zero setting is made by changing the d.c. voltage-bias potentiometer, and the span setting is made by changing the voltage-gain potentiometer (volts per º C).

A. **Water Bath Calibration**

(1) Place sensor in the 5º C waterbath and adjust the zero setting until the instrument indicates the temperature of the waterbath.

(2) Place sensor in the 20º C waterbath and overcorrect the instrument by an amount equal to the difference between the temperature of this waterbath and the temperature indicated by the instrument (error) with the span setting.

(3) Repeat steps 1 and 2 until the error is at or near zero. The instrument should now indicate the temperature of both waterbaths within 0.5oC.

When using calibrated portable systems in the field, batteries and electrical connections should be periodically checked. Water temperatures indicated by these systems should be periodically compared with calibrated liquid-in-glass thermometer readings. These checks are important when unusual conditions occur and ensure that the system is indicating accurate water temperatures.

B. Calibration of In Situ Recording Thermometers

(1) Measure the temperature of the water near the sensor with certified mercury thermometer.

(2) Record this temperature, the temperature indicated by the thermograph, date, and the time on the temperature chart.

(3) Adjust the recorder-chart time and the zero and span settings if necessary. Changes of less than 1º C should not be made in the recorder setting unless the apparent error is observed by two or more field checks.

(4) Check and clean sensors. Refill recording pens if necessary.

(5) Adjust final data records by the differences observed between the mercury thermometer and the thermograph,

WATER pH

1. General Considerations

pH is a measure of hydrogen ion activity or concentration and is expressed mathematically by

$$pH = \log (1/[H^+] = -\log \{H^+\}$$

Because water is a weak electrolyte, small numbers of water molecules dissociate into ions: H20 = $H^+ + OH^-$. At 25ºC, 0.0000001 g of H^+ and 0.0000001 g of OH^- ions are liberated per liter of pure water. Since equal amounts of H^+ and OH^- are released, neutrality exists, and

$$pH = -\log [10^{-7}] = 7$$

below the neutral value of pH 7, a solution is acidic; above pH 7, a solution is alkaline. A change of one pH unit indicates a tenfold change in hydrogen ion concentration.

Water dissolves mineral substances it contacts, picks up aerosols and dust from the air, receives man-made wastes, and supports photosynthetic organisms, all of which affect pH. The buffering capacity of water, or its ability to resist pH change, is critical to aquatic life, as it determines the range of pH. Generally, the ability of aquatic organisms to complete a life cycle greatly diminishes as pH becomes >9.0 or <5.0.

Photosynthesis by aquatic plants removes CO_2 from the water, which can significantly increase pH. Therefore, in waters with plant life (including planktonic algae), especially low-velocity or still waters, an increase in pH can be expected during the growing season. Eutrophic lakes and isolated backwaters often exhibit marked pH increases resulting from photosynthesis. Furthermore, in the depths of a eutrophic lake, pH will drop because of decomposition of settling debris and the consequent increase in $C0_2$.

The turbulence of flowing water promotes gaseous interchange between the atmosphere and water. The $C0_2$ content of water in rivers and streams is less likely to change, but be aware of other events in the watershed that may affect pH. Increased leaching of soils or mineral outcrops during snowmelt or heavy precipitation affects pH downstream. Human activities (e.g., accidental spills, agricultural runoff (pesticides, fertilizers, soil leachates), sewer overflow--may also change pH.

2. Sample Collection

Water for pH measurements should be analyzed within 2 hr of collection, preferably immediately. Biological activity in the sample water and loss of gases can change pH. If possible, use water from the sample collected for other analyses (e.g., oxygen and total dissolved solids).

3. Colorimetric Method With Paper Indicators

A. **Procedure**

Test papers for pH are used by dipping a strip in a water sample and comparing the resultant color to a chart which comes with the paper. Test papers come in wide ranges graduated in 1.0 pH units, and narrow ranges graduated in 0.25-0.5 pH units. Wide range test papers are used to determine the approximate pH value, and the appropriate narrow range papers give a more accurate pH estimation. Weakly buffered water requires special test papers.

B. **Accuracy and Precision**

Sharp color changes assure reasonably high precision, but the true pH value can be estimated only to the nearest 0.5 pH unit with the narrow range papers. pH test papers can be unreliable to test waters of low buffering capacity or with interfering substances.

C. **Equipment**

Test paper dispenser
Wide range, 15 ft $ 3.25
Short range, 15 ft 3.25
Set; 1 wide range, 20 short range papers, each 15 ft
Low buffer paper, 30 ft; pH 5.0-9.0
Sampling equipment

D. **Training**

Fifteen minutes in the laboratory.

4. Colorimetric Method With Hydrogen Ion Comparators

A. **Procedure**

The color of a small quantity of water sample mixed with a pH indicator solution is compared to a color standard. Quantities of water sample used in the test and indicator solution are specified by the manufacturer. Compare the color of the test water with the colored standards. The standard pH solution the test water most resembles is the estimated pH of the water sample. Wide- and narrow-range pH comparators are available. Wide-range comparators have color standards that differ by one pH unit; narrow-range color comparators measure 0.5-0.1 pH unit.

B. **Precision and Accuracy**

This method is precise because differences in the color are distinct if there is sufficient light. Under ideal conditions, the narrow-range comparators are moderately accurate (±0.2 pH unit). However, accuracy can be lowered by interference by color, turbidity, salinity, colloidal matter, and dissolved compounds. The color standards and the indicators are subject to deterioration. The indicators may actually change the pH of water with a low buffer capacity. The method is useful only as a rough estimation of pH.

C. **Equipment**

LaMotte wide range block comparator, 3-10.5 pH; ±0.25 units accuracy, or
Hellige pocket model housing: Color disc; each covers 1.6 pH range; Indicator solution, 16 oz 14.59
Hach test kit: Wide range, 100 tests or Narrow range, 2 pH unit range

D. **Training**

Fifteen minutes in the laboratory is adequate.

5. Electronic pH Meter

A pH meter is a sensitive potentiometer; it measures voltage without creating an electrical current. An electrochemical cell is created with the sample, the two electrodes (or one if it is a combination electrode), and the meter (Fig. 10.1). The glass (indicator) electrode is permeable only to H^+ ions, and the potential developed at this electrode depends on the H^+ concentration. The potential changes 59.16 mV per pH unit at 25º C. This potential is measured by comparing it against the reference electrode of known potential. The difference in potential between the two electrodes is indicated as pH on the scale or readout of the meter.

The reference electrode completes the electrical cell by allowing a constant flow of electrolyte (usually KC1) to flow to the sample through a small opening at the bottom of the electrode. The electrical connection (junction) is thus formed independently of the pH of the water sample. A reference electrode that does not require continual refilling should be suspected of blockage.

Reference electrodes commonly consist of Hg in a slurry of Hg_2CI_2 in contact with saturated KC1 (calomel type), or Ag in a solution of AgCl. Electrodes that combine the glass (indicator) and reference electrode into one unit are recommended. Compared with glass bodies, epoxy bodies lessen the possibility of damage. Gel-filled electrodes are nonrefillable and used on many of the field, hand-held meters.

The major differences in pH meters are accuracy, readout form (analog or scale, and digital), and accessories. Accuracy of most pH meters is high enough for field work; the digital readout is advantageous in the field, particularly on a rocking boat. Light-emitting-diode (LED) readouts are useful in dim light, while liquid crystal displays (LCD) use much less electricity--a consideration when the meter is battery operated. Analog displays often have an expanded scale option for greater accuracy. Some pH meters accept automatic temperature compensators and probes that analyze specific ions, such as ammonia, cadmium, fluoride, and sodium.

A. **Procedure**

(1) Meter and Probe Preparation

(a) Prepare new electrodes by soaking the tips over night in distilled water or buffering solution recommended by the manufacturer. In addition to the soaking step, reference electrodes that have not been in use will probably need to be refilled with the recommended electrolyte.

Thereafter, keep the electrode tips in water when not in use.

(b) Open the vent of the reference electrode to allow the electrolyte to flow freely, unless it is a non-refillable type.

(c) Because most meters require that the unknown sample be within 2-3 pH units of the pH value at which the meter was standardized for maximum accuracy, first estimate the pH of the sample with pH test paper. Prepare a buffer solution with a pH near the expected pH of the sample; 50-100 ml of buffer solution in a 250-ml beaker is a convenient routine. Buffer solutions are available in many forms, or solutions may be prepared.

(d) Set up the instrument for line or battery operation and install the electrodes according to manufacturer's instructions.

(e) Make sure the meter is set to "zero" or "standby," and turn it on. Refer to the instructions for required warm-up time.

(f) Turn the knob to "zero." Adjust the zero knob so that the needle is centered at the zero mark. Avoid parallax by aligning the needle with its image in the mirror.

(g) Remove the electrodes from their soaking solution and rinse with distilled water from a squeeze-bottle. Wipe the tips with a soft paper such as Kimwipes.

(h) Measure the temperature of the buffer solution and set the compensation dial to that temperature.

(i) Immerse the electrode(s) into the buffer solution a turn the selection knob to "pH." Allow the system to stabilize (the needle will stop drifting). Adjust the standardize knob until the needle or readout reads exactly the pH of the buffer. Wait 2 min and restandardize. Repeat until no drift is observed.

(j) Turn the function knob to "zero" or "standby", remove the electrodes from the solution, and rinse and wipe them. Never remove the electrodes from any solution with the function knob the "pH" position.

(k) Standardize the meter each time it is turned on or ever one or two hours. Restandardize with an appropriate buffer if the sample is not within the accuracy range of the meter standardized at some other pH value.

(2) Sample Measurement

(a) Rinse a beaker several times with sample water and fill it with about 100 ml of sample water.

(b) Measure the temperature of the sample and adjust the temperature compensation knob to match the sample measurement. For highest accuracy, sample temperature should be within 10ºC of the standardization temperature.

(c) Immerse the electrode(s) in the sample and very gently swirl the sample.

(d) Turn the function knob to "pH" and allow the needle or readout to stabilize. The meter may be slow in coming to a steady reading because water samples of the natural environment are usually relatively unbuffered.

(e) Record the indicated pH, temperature and sample location.

(f) Remove the electrode(s), rinse and wipe dry.

(g) When the analyses are finished, close the vent and immerse the electrode(s) in water or recommended buffer.

(3) Special Considerations

(a) Be careful not to scratch the sensitive surface of the glass electrode. Damage may cause erratic meter fluctuations.

(b) If either electrode becomes plugged, the following, increasingly severe cleaning procedures may clean it:

i. Soak in hot distilled water.

ii. Soak in 0.1 N HCl for a few hours.

iii. Immerse in 2% hydrofluoric acid for a few seconds, rinse with water, then rinse with 0.1 N HCl.

(c) After cleaning the electrodes, coat them with Desicote (Beckman Instrument Co.) to eliminate the rinse and dry step.

B. **Precision and Accuracy**

High precision and accuracy are achievable with proper technique. The pH meter method is the standard procedure of APHA (1980).

C. **Equipment**

pH meter
Celsius thermometer
Beakers, 250 ml, 12
Kimwipes, 60 boxes
pH buffer

> Capsules, 10
> Tablets, 12
> Solution

Electrode filling solution: KCl, 32 oz; KCl Ag/AgCl, 100 mls
Desicote@ (Beckman Instrument), 50
Sampling Equipment

D. **Training**

Allow one to two hours to become familiar with all aspects meter operation and care and to analyze some practice samples.

DISSOLVED OXYGEN

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1. General Considerations

Dissolved oxygen (DO) is one of the most important indicators of the quality of water for aquatic life. Oxygen dissolves freely in water as a result of photosynthesis, community respiration, diffusion at the air-water interface, and wind-driven mixing. Temperature, pressure, and salinity determine the amount of DO water can hold, or its saturation level. Dissolved-oxygen concentrations below 3.0 mg/l are generally considered harmful to aquatic life, but requirements vary according to species, temperature, life stage, activity, and concentration of dissolved substances in the water. Embryonic development demands the highest DO concentration of all life stages.

2. Sample Collection (Analytical Field Kit and Winkler Titration Technique)

Water for dissolved oxygen (DO) analysis must be carefully collected for the field kit and Winkler titration techniques, so that the DO in the sample is representative of the water from which it was taken. Changes in DO are likely to occur if the sample is agitated or exposed to air.

Rinse the sample bottle twice with water from the sample location. When collecting samples by hand, hold the bottle upside down until it is submerged, then turn it at an angle to fill completely. Cap the bottle under water. Fill three bottles with water from each sampling position. Record the bottle number for each position.

Use a Kemmerer or Van Dorn (alpha)-type sampler (see sampling equipment) when hand sampling is not possible. Place the delivery tube at the bottom of the Biological Oxygen Demand (BOD) bottle. Carefully fill to overflowing, avoiding turbulence and bubble formation. Overflow for about 10 sec or three times the bottle capacity. With flow continuing, gently withdraw the delivery tube and stopper the bottle. Record the bottle number for each sampling position.

3. Analytical Field Kits

A. **Procedure**

The technique used with field kits is a modification of the Winkler analysis for DO. The modifications that make field kits suitable for field use by untrained personnel also allow only a relatively rough estimate of DO. Follow the manufacturer's instructions.

B. **Precision**

Each drop of reagent equals one mg DO per liter. Precision can be high, but accuracy is low (± 1 mg DO/1) and the technique is not approved by the American Public Health Association (APHA).

C. **Equipment**

DO analysis kit:

75 tests 50.00 VWR Scientific
bottle 10.00 VWR Scientific

D. **Training**

Up to one hour to become familiar with the sampling procedure and calculations and to practice stoppering the bottle without entraining air.

4. Oxygen Meter

A. **General Instrument Preparation and Care**

Follow the manufacturer's instructions for preparing the instrument and the probe and for zeroing and calibration. Nearly all instruments are operated similarly. When voltage is applied across a polarographic sensor, the sensor becomes polarized. An oxygen-permeable membrane covers the sensor. Oxygen that has passed through the membrane reacts at the cathode end of the sensor, causing a current to flow. The membrane passes oxygen at a rate proportional to the difference in DO concentration between the water and the inside of the sensor. If the oxygen pressure increases (more oxygen in the water), more oxygen diffuses through the membrane and more current flows through the sensor. Lower pressure creates a lower current.

New or unused probes will need to be filled with an electrolyte recommended by the manufacturer until a meniscus completely covers the gold cathode. The membrane is then replaced by holding one end of it against the probe with the left thumb. Stretch the free end up, over, and down the other side of the probe. Secure the membrane by rolling an 0-ring over the end of the probe. There should be no trapped air bubbles or wrinkles in the membrane. Handle the membrane material with care, and touch it only at the ends. Membrane lifetime is usually 2 to 4 weeks, depending on use. Replace the membrane if the membrane is damaged, if erratic readings are observed, or if calibration is not constant.

Store probes in a moist environment, such as a plastic bottle with a moist sponge on the bottom. Storage containers are supplied by the manufacturer. If the electrolyte is allowed to evaporate, so that bubbles form under the membrane, the electrolyte must be replenished and the membrane replaced. Keep the gold cathode bright and untarnished by wiping with a clean, lint-free cloth or hard paper. Rinse the probe with the electrolyte, refill, and install a new membrane. Return tarnished probes to the manufacturer for refinishing.

B. **Calibration**

The choice of calibration technique depends on the circumstances. The Winkler titration is accurate and does not require salinity, temperature, or barometric pressure values but is more tedious and time consuming. Tables or nomograms are required for air or air-saturated water calibration methods. For highest accuracy, the calibration temperature must be within a range about the water temperature specified by the manufacturer. Air calibration is easy but may not be as accurate as the air-saturated water technique.

Calibration is required each time the instrument is turned on and following sets of measurements. The operator should become familiar enough with the instrument that he knows how often it needs recalibration.

(1) Winkler titration

Average three DO measurements obtained by the Winkler method. If one of the values differs from the other two by more than 0.5 parts per million (ppm), discard that value and average the remaining two.

Place the probe in the body of water sampled at the depth from which the samples for the Winkler analysis were drawn. Set the salinity dial at zero or salinity corresponding to that of the water. Adjust the temperature dial if the probe is not automatically temperature compensated. Switch to the desired parts-per-million range and adjust the calibration control to the average value determined above. Allow the probe to remain in the water for at least two minutes before setting the calibration value and leave it in the water for an additional two minutes to verify stability. Readjust if necessary.

(2) Air-saturated water

Saturate a sample of water with air by stirring for 15 min, or supersaturate it by bubbling air through the water and then allowing 5 min for equilibration. While waiting for the sample to equilibrate, determine the oxygen content by using the nomogram. Values for barometric pressure (millimeters Hg), or altitude (kilometers), and temperature (C) of the water sample are necessary to determine oxygen content. Place the probe in the water sample and adjust the calibration control until the meter reads the oxygen content you have calculated for the air-saturated water.

The nomogram has a temperature scale that displays the corresponding concentration of oxygen (C*) in water in equilibrium with water-saturated air at standard pressure (Pst @ 760 mm Hg, or 101,325 Pa ; altitude, h = 0). The fan of scales is used to correct the oxygen concentration, C*, for nonstandard pressures.

On the temperature scale, find the temperature of the water for which you are determining the oxygen concentration. Opposite the temperature, read and mark the corresponding oxygen concentration (note that the oxygen scale increases from right to left). On the fan of scales are lines for temperature in 5º increments radiating from zero altitude, or standard pressure (Pt-), and vertical lines representing atmospheres in 0.01 increments. Pressure may also be expressed as mm Hg (top scale) or altitude, km (bottom scale). Find the pressure of the water sample location on one of these scales and move in a direction parallel the nearest vertical line to the point on the diagonal line corresponding to the water temperature. Mark this position and measure the distance from it to zero with a ruler. On the oxygen-concentration scale, move this distance to the right of the oxygen concentration you marked for the temperature of the water sample. Read the new oxygen concentration, now corrected for nonstandard pressure.

This procedure is for altitudes greater than sea level. If the water sample is below sea level, use the small fan to the left of zero and move the correcting distance to the left of the oxygen concentration marked on the temperature-oxygen scale.

ln DO = 7.7117 - 1.31403 In (t + 45-93 + 5.25 ln (1 - h/44.3)

where
DO = concentration of dissolved oxygen measured at equilibrium temperature per unit volume of water when it is in equilibrium with an atmosphere of standard composition and saturated with water vapor at a total pressure of one atmosphere; it is expressed in mg/dM3, equivalent to mg/l.
t = Oc
h = altitude, km

(3) Air calibration

Place the probe in moist air of either a calibration chamber (available from some manufacturers) or the probe storage bottle with a few drops of water, or wrap loosely in a damp cloth, taking care that the membrane is untouched. Switch the DO meter to temperature, wait 10 min, and read the temperature. Determine the oxygen content of the air using or above equation and known values for barometric pressure (mm Hg), altitude (km), and the temperature of the air (C). Adjust the calibration control so that the meter reads the oxygen content you have calculated.

C. **Dissolved Oxygen Measurement**

Place the probe in the water to be measured. Switch on the submersible stirrer. If there is no submersible stirrer, raise and lower the probe about one foot per second.

Set the salinity knob to the salinity of the water being measured. Allow time for a constant meter reading. Read DO from the appropriate scale if the meter has multiple scales. Parallax and incorrect readings are avoided if the needle is aligned with its image in the mirror, so that only the needle is seen. If there is no salinity-compensation dial on the instrument, the DO value must be adjusted by the salinity of the sample (Mortimer 1981). Record the probe position, DO value (uncompensated and compensated DO values, if compensation is made by calculation), and salinity of the water.

D. **Precision and Accuracy**

If the user carefully follows the manufacturer's instructions and practices the procedures in the field several times, he can obtain an accuracy of ±O.l mg per liter DO and a precision of ±0.05 mg per liter with most systems.

E. **Equipment**

Dissolved oxygen meter and probe
Sufficient cable for water depth encountered
Thermometer if the DO meter has no temperature readout
Winkler titration equipment if this is the choice of calibration
Caliibration chamber or other probe holder for air calibration
Vessel to hold water sample for air-saturated water calibration
Extra membranes, 0-rings, and electrolyte solution

The simplest meters have no salinity compensation dial. If brackish or saline waters will be analyzed for DO with a meter, the salinity dial will save a great deal of time that would otherwise be necessary to adjust DO values by calculation. A DO range of 0 to 15 ppm will cover nearly any environmental situation but is slightly less accurate than the 0 to 10 ppm range offered on multiple-range instruments.

Instrument costs are greatly increased by a digital readout and a system approach that may incorporate multiple sensor, printouts, and capabilities for automatic, timed measurements. Probes with stirrers, if available for the instrument of choice, are desirable. Purchase two probes, so that sampling is not delayed by a lost or broken probe.

F. **Training**

One hour should be sufficient for the user to become familiar with instrument preparation and calibration procedures, unless the Winkler calibration method is used. An additional hour to learn the Winkler calibration is necessary. Membrane replacement is the most difficult procedure and may require practice to become proficient. Allow another half hour to practice the method in the field.

5. Winkler Titration (Azide Modification)

This technique is based on oxidation of a floc of manganous hydroxide that has been added to the sample by the oxygen present in the sample. When oxidation occurs, the sample has been "fixed" because the oxygen is "trapped" by its reaction with the floc. When the sample is acidified, the floc is dissolved and iodine is liberated (from potassium iodide previously added). The quantity of iodine liberated is equivalent to the quantity of oxygen in the sample. The iodine is titrated with sodium thiosulfate or phenylarsine oxide (PAO) and a starch indicator [see Wetzel and Likens (1979) for a detailed explanation of the reactions]. Interference by nitrites is prevented by addition of sodium azide.

A. **Procedure**

Sample collection procedure.

(1) Sample Treatment ("Fixing")

a. Add 2 ml MnSO4 reagent with a pipette or precise-volume dispenser.

b, Add 2 ml alkaline iodide azide reagent in the same way.

c. Carefully stopper the bottle without introducing any air bubbles and mix by inverting ten to twenty times. When mixing, avoid splattering the liquid at the top of the BOD bottle on your clothes or skin.

d. Allow the floc to settle until at least 1/3 of the bottle is clear and then mix again.

e. When the floc has settled to the bottom 1/3 of the bottle, add 2 ml of concentrated HISO4 below the surface with a pipette. Carefully restopper and mix until the floc has dissolved.

f. Samples can be held for 4 to 8 h if kept cool (e.g., in an ice chest) or up to 3 days under refrigeration if there are no interfering substances in the water.

(2) Titration

a. Measure out 100 ml (200 ml if 0.025 N titrant is used) of the sample with a volumetric pipette an-d transfer to a 250-ml Erlenmyer flask. Touch the pipette tip to the side of the flask to remove the last drop. [Note: For highest accuracy, the volume used should correspond to 100 ml of the original sample after correction for loss of sample by displacement with the reagents (2 ml each of MnSO4 and alkali iodide azide): 200 x 300/(300 - 4) = 101.5. This is unnecessary for routine work.]

b. Fill an automatic buret with 0.0125 N standardized sodium thiosulfate (Na2S203) or PAO (titrant). Add titrant (titrate) to the sample until a very pale yellow ("straw") color appears. Mix the solution while titrating by swirling or with a magnetic stirrer.

c. Add two drops (1 ml) of starch indicator, mixing to get a uniform blue color.

d. Titrate carefully until the first disappearance of color. Do not overshoot the endpoint. The blue color should return on standing in 10 to 15 seconds. If it does not, too much titrant was added, and the result is inaccurate. Record the number of milliliters of titrant used.

e. Since I ml of 0.0125 N Na2S203 or PAO is equivalent to 0.1 mg DO, each milliliter of titrant used is equivalent to I mg DO per liter when a volume of 100 ml is titrated.

f. The sample may be titrated with a digital titrator. Follow manufacturer's instructions.

(3) Reagent Preparation

a. Manganous sulfate: Dissolve 400 g MnSO4-2H20 or 365 g MnSO4-H20 in I 1 of distilled water.

b. Alkaline iodide azide: Dissolve 400 g NAOH in 500 ml boiled and cooled distilled water in a 1-1 volumetric flask, cool slightly, and then dissolve 900 g NaI in this solution. Dissolve 10 g NaN3 in 40 ml distilled water and add the above solution. Add distilled water to the mark to make I liter.

c. Concentrated H2SO4 (no preparation necessary).

d. Starch indicator: Make a cold-water suspension of 5 g arrowroot (or soluble starch) and add to about 800 ml boiling water, stirring. Dilute to I liter and let settle 8 to 12 hours. Use the clear supernatant. Preserve with 1.25 g salicylic acid per liter or by adding a few drops of toluene.

e. Standardized sodium thiosulfate:

i. 0.1 N stock solution: Dissolve 12.41 g Na2S203-5H20 in boiled and cooled distilled water, dilute to 500 ml. Preserve by adding 2 g borax (Na2B407-IOH20) or 0.5 g NAOH, or 2.5 ml chloroform.

ii. 0.0125 N: -Measure 125 ml of 0.1 N stock solution into a 1-1 volumetric flask. Dilute to the mark with distilled water.

iii. 0.025 N: Dissolve 6.205 g Na2S203-5H2) in one liter of boiled and cooled distilled water.

(4) Standardization of Sodium Thiosulfate

a. Place exactly 25.00 ml of standard KI03 in 250-ml Erlenmyer flask and add 75 ml distilled water.

b. Dissolve 2 g potassium iodide (KI) in this solution.

c. Add 10 ml of 3.6 M H2SO4 (carefully dilute 200 ml concentrated H2SO4 to 1 liter).

d. Allow to stand at room temperature in the dark for 2 to 5 min.

e. Titrate as for DO.

f. Actual normality of the sodium thiosulfate is

> N = 25 / ml Na2S203 used in titration * 0.0125 N ,
>
> Normality of thiosulfate solution = (ml of KI03 solution)/ (ml of thiosulfate solution used) * Normality of KI03 solution

g. Adjust the actual normality of the sodium thiosulfate solution to the desired normality by adding distilled water or stock thiosulfate, depending on whether the normality is too high or too low, or

h. Multiply the DO values by a correction factor calculated by

> Correction factor = actual normality of solution / specified normality

(5) Special Considerations

a. Rinse the buret and tubing with distilled water after use. Fill and purge the buret with titrant three times before using. Bubbles should not be present in the buret.

b. Shake the thiosulfate solution before use.

c. If the starch indicator begins to show a reddish color when added to the sample, a new batch should be prepared.

d. Refer to APHA (1980) for modifications of the procedures when ferrous iron or interfering suspended solids are present. Ferrous iron exists only in acid to neutral water that is low in oxygen and has a low redox potential (200 to 300 mV), such as the hypolimnion of a stratified eutrophic lake. Interfering suspended solids are indicated by high turbidity.

e. High concentrations of bicarbonate-carbonate (above 1500 mg/1) cause volatilization of the iodine and thus low readings. The Winkler method cannot be used at alkalinities higher than this.

f. Organic substances can interfere with this method.

B. Precision and Accuracy

With care, an accuracy of 1% and a precision of ±0.05 mg/l can be attained.

C. Equipment

A wide selection of devices, prepackaged reagents, and prestandardized titrants greatly facilitates this method. The titration is field adaptable under some conditions, and the equipment can be set up in the laboratory, which allows processing of samples in a nearly assembly-line manner. Reagents are available in aliquots packaged for individual samples. Precise-volume dispensing bottles are even more convenient because a simple squeeze dispenses the correct quantity of reagent and no litter is produced. A digital titrator (Hach Company) is transportable and easy to use in the field and the laboratory.

The equipment list provides for different options: making reagents buying prepared solutions and standardized solutions, reagents packaged for each sample, traditional glass buret or the digital titrator (Hach Company). The list is intended mainly as a checkoff reference, not for establishing a laboratory. It is assumed that the user has access to facilities for making distilled water, cleaning glassware, etc.

Sampling Equipment

Sampling Bottle
Messenger
Braided polyester, line 3/16, various lengths, 100 feet
Tubing
BOD bottles with glass stopper, 300 ml (24)
Bottle-carrying rack
Precise-volume dispensing bottles (3)
Winch and boom or crane (optional)

Glassware or plastic ware

Automatic-zeroing buret, 10 ml, 0.05-ml subdivisions
Digital titrator (optional)
Erlenmyer flasks, 250 ml (12)
Dropping bottle for starch indicator, or use 1-ml dispensing bottle, or automatic dispensers
Volumetric pipet, 100 ml (2)
Volumetric flasks with glass stopper, 100 ml (for making reagents)
Wash bottles (for rinsing buret tip and stir bars), 250 ml

Polyethylene bottles (for holding reagents) 1 liter (6)

Chemicals (reagent grade)

Manganous sulfate (MnSO4-H20),

powder, 500 g
solution, 32 oz
"pillow" prepackaged powder, 100

Alkaline iodide azide

NAOH, 454 g
NaI, 10 g
NaI, 454 g
NaN3, 100 9
solution, 32 oz
solution, 473 ml
"pillows," 100

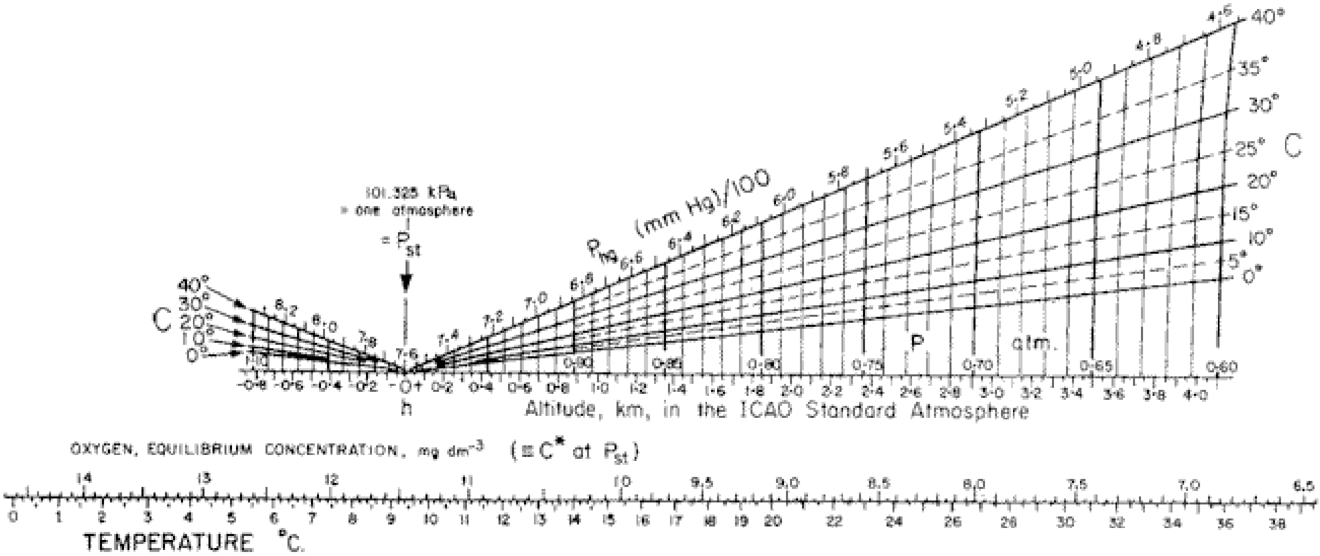
Concentrated sulfuric acid (H2SO4), 500 ml
Sulfuric acid, powder pillows, 25
Sodium thiosulfate (NaS2033 -5H20), powder, 454 g, 0.1 N solution, 2 pt, cartridge for digital titrator
Standard potassium iodate (KI03), 0.025 N solution, 16 oz (dilute 1:1 for 0.0125 N)
Potassium iodide (KI), 100 g
Phenylarsine oxide, 0.025 N solution, 3.78 1 (dilute 1:1 for 0.0125 N) cartridge for digital titrator
Soluble starch, 250 g 6r starch indicator solution, 16 oz Salicylic acid, 1 lb

Miscellaneous equipment (*optional)

Buret reader*
Buret support
Lighted stirrer*: stir bar assortment and stir bar retriever
Stir plate with holder for use with digital titrator*
Analytical balance, if making own reagents, 0.01 mg precision

E. Training

The analyst should have some knowledge or experience with analytical chemistry techniques. He or she can then become familiar with the Winkler technique within one hour and proficient with one-half hour practice.


101.325 kPa
= one atmosphere
= P st
P Hg (mm Hg)/100
P atm.
C
h
Altitude, km, in the ICAO Standard Atmosphere
OXYGEN, EQUILIBRIUM CONCENTRATION, mg dm-3 (≡ C* at P st)
TEMPERATURE °C.

TOTAL DISSOLVED SOLIDS (TDS)

1. General Considerations

Total dissolved solids (TDS; total filterable residue) is a common measurement of freshwaters. When TDS is determined by summing the results of separate analyses for all major ions, it is analogous to salinity. When TDS is measured gravimetrically (by weight), it can be greater or less than salinity, depending on whether loss of bicarbonate (H2CO3) in the gravimetric analysis is more than offset by the presence and, consequently, measurement of dissolved organic carbon. A gravimetric measurement of TDS in water in an alkaline lake would probably indicate lower TDS than if TDS were measured by summation, or salinity because not enough organic matter would be present in the water to make up the H2CO3 weight loss. In contrast, a mountain bog lake would have few ions but its high organic matter would contribute to TDS measured gravimetrically, and the TDS reading would likely be higher than that estimated by the summation method.

2. Conductivity

Measuring conductivity to obtain TDS is nearly identical to the conductivity method for salinity. For highest accuracy and convenience, prepare a regression of conductivity on TDS with data previously collected from the water body to be sampled. Alternatively, prepare a regression as for salinity by measuring TDS gravimetrically or by summation to obtain a conversion factor. Galat (unpublished data) found a correlation (r) of 0.99 between TDS measured by summation and conductivity in 14 western U.S. lakes of widely differing chemistry. The regression equation was TDS (mg/l) = 0.77 (conductivity üS) + 36.46. Williams (1966) found a very high correlation (r = 0.94) between conductivity and TDS measured gravimetrically from 40 Australian sodium chloride lakes. The regression equation was TDS (mg/1) = 0.6656 + 0.0000034 (conductivity).

Electrical conductivity is a measure of the ability of a solution to carry a current and depends on the total concentration of ionized substances dissolved in the water. Although all ions contribute to conductivity, their valences and mobilities differ, so their actual and relative concentrations affect conductivity. When the concentration of ions is high, conductivity is high, and the resistance to electrical passage is low.

The mho, or siemen (S), is the unit of measurement for conductance; it is the inverse of resistance (ohms). Resistivity (ohms x unit length) is defined as the resistance between opposite faces of a rectangular prism. Conductivity (mho per unit length) is the reciprocal of resistivity. Specific conductance (S/cm) is numerically equivalent to conductivity. For water analyses, conductivity is usually expressed in micromhos/cm (ümhos/cm) or microS/cm (üS/cm). The specific conductance of distilled water is about I üS/cm, which is low, and that of seawater is about 50,000 üS/cm.

Conductivity meters measure resistance using a source of alternating current, a Wheatstone bridge, a null indicator, and a conductivity cell. The voltage of the a-c source varies, depending on the accuracy and sensitivity of the meter. Choice of frequency of the bridge current depends on the solution to be measured; for measurements on high resistance solutions, such as demineralized water, a lower frequency (60 Hz) is desirable, whereas a higher frequency (1 kHz) is advantageous in highly conductive solutions. Most meters have several ranges, which are selected with a switch or dial, in conjunction with the appropriate conductivity cell.

The conductivity cell typically consists of two metal plates or electrodes firmly placed within an insulating chamber that isolates a portion of the sample. The cell constant is dependent on the area (size) of the electrodes and the distance between them. A cell with a relatively low constant (K = 0.1/cm) has large electrodes close together and is suitable for measuring low-conductivity samples. Cells are usually offered with constants of 0.1 to I.0. A properly chosen cell causes the resistance of a water sample to be measured within the middle of a relatively narrow detection range. Most meters are calibrated to read directly with a cell of constant K = 1.0; if using a different cell, multiply the reading by the cell constant.

Temperature of the solution affects ionic velocity and, consequently, specific conductance. Conductivity increases 2-3% per degree Celsius. Therefore, temperature measurements and records must be accurate. Most conductivity values for aquatic measurements are corrected to 18^{o}C or are corrected on the meter to the ambient temperature.

Temperature compensation is possible on most conductivity meters either by dialing in the temperature of the sample (manual compensation) or by installing a thermistor with the conductivity cell to provide automatic compensation. Meter costs are significantly increased by a temperature compensator because it must be highly accurate for the total measurement system to remain acceptably accurate. Furthermore, the temperature compensator characteristics should be compatible with the temperature coefficient of the solution under analysis. Most meters with temperature compensation are compatible for water analyses.

The polarizing effect of the current passing between electrodes is greatly reduced by a deposit of black platinum, which must be replaced when readings become erratic. Electrodeless cells require no maintenance. The liquid to be measured is contained in a closed loop of nonconductive metal coil. The solution couples two transformer coils with constant voltage input, and the reading from the output is proportional to the conductivity of the solution.

A. **Preparation of Conductivity Cell (Platinum Electrodes)**

(1) Cleaning. Clean electrodes with chromic-sulfuric acid. (Caution: Extremely caustic; use gloves and eye protection.)

(2) Platinizing. Replatinize electrodes when the readings become erratic, when a sharp reading cannot be obtained, or if any platinum black has flaked off.

To prepare platinizing solution, mix 1g chloroplatinic acid (H2ptCl6-6H.0) and 10 to 20 mg lead acetate [Pb(CH3COO)21 in 100 ml water.

To replatinize:

a. Immerse the electrodes in the solution.

b. Connect both electrodes to the negative terminal of a 1.5 V battery.

c. Connect one end of a platinum wire to the positive terminal and dip the other end in the solution.

d. Continue the electrolysis until both electrodes are coated with platinum black. Only a small amount of gas should be evolved.

e. Keep the solution for later use.

B. **Calculation of Cell Constant**

It is best to follow the manufacturer's instructions; but, if they are not available, the following may be used:

(1) Prepare potassium chloride standards:

a. For conductivity water, pass distilled water through a mixed-bed deionizer; discard the first 1000 ml.

b. For 0.01 M KC1 standard, dissolve 745.6 mg anhydrous KCl in conductivity water in a 1000-ml volumetric flask.

c. Add conductivity water to the 1000-ml mark. Keep in a clean glass-stoppered, labeled reagent bottle.

d. The specific conductances of different molarities of KCl solutions at 25ºC are:

Concentration (M)	Specific conductance (ümho/cm)
0.0001	14.95
0.0005	73.90
0.001	147.0
0.005	717.8
0.01	1413.0
0.02	2767
0.05	6668
0.1	12900
0.2	24820

e. Prepare other molar concentrations of KCl from this standard if other ranges of conductivity are to be used: For a 0.005 M solution, add 50 ml of the 0.01 M solution to a 100-ml volumetric flask and add conductivity water to the mark; for 0.001 M, mix 10 ml of standard and 90 ml of conductivity water to a 100-ml volumetric flask, etc. Higher concentrations are prepared similarly with a stock solution of higher molarity. Mix 7.456 g KC1 in 1000 ml distilled water for 0.1 M, etc.

f. Alternatively, use standard NaCl solution (1000 üS/cm), available from Hach Company.

(2) Maintain the standard solutions at 25º C ±0.1 C.

(3) Rinse the conductivity cell two or three times with solution and place it in a beaker with sufficient solution to cover the cell.

(4) If the meter has a manual temperature compensator, adjust the temperature dial to 25ºC and select the appropriate conductivity range

(5) Adjust the conductivity dial until the null (zero) indicator is centered, or read the scale directly if applicable.

(6) Calculate the cell constant (C):

C = (specific conductance of standard solution at 25ºC)/ (specific conductance of standard solution indicated by the meter)

C. **Conductivity Measurement**

Manufacturers of conductivity meters offer a variety of features, including multiple ranges, manual and/or automatic temperature compensation, range finding, coarse and fine adjustments, and any combination of the above to measure conductivity:

(1) Select the appropriate conductivity range on the meter.

(2) Measure temperature and set manual temperature compensation dial, if applicable. Record temperature.

(3) Rinse the conductivity cell twice with sample water, or lower the cell to the proper depth and position.

(4) Adjust conductivity dial until the null indicator is centered and read the conductivity from the dial, or

(5) Turn knob to operate and read conductivity from the analog scale or digital readout.

(6) Record the conductivity with the temperature.

(7) If the meter has no temperature compensation, convert the conductivity to the conductivity at the temperature used for calibration

(8) Calculate salinity of the sample from the salinity:conductivity regression equation above and the conductivity measurement.

E. **Accuracy and Precision**

With good equipment, a trained analyst should obtain conductivity within 1% of the true value. Results from APHA (1982) tests had an 8% standard deviation.

F. **Equipment**

Conductivity or salinity meters
Thermometer accurate to ±0.10C
KC1, anhydrous, 1 lb or Standard NaCl solution (Hach Company), 118 ml
Deionized, distilled water
Chloroplatinic acid, H2PtCI6-6H20, 1 9
Lead acetate, Pb(CH3COO)2-3H20, 1 lb
Chromic-sulfuric acid cleaning solution (chromerge)
Volumetric flask, 1000-ml
Volumetric flask, 100-ml
Beakers, 250-ml 30.00/12
Glass-stoppered reagent bottles, 1000-ml 16.00

G. **Training**

At least 3 hours will be required to become familiar with all aspects of this method and additional hours of proficiency.

3. Gravimetric Analysis of TDS

In this method, water that passes through a glass-fiber filter is dried and weighed. The amount of TDS in the water is calculated from this dry weight.

A. **Sampling**

Use resistant-glass or plastic bottles to hold collected water samples, and analyze the samples promptly.

B. **Procedure**

(1) Apparatus Preparation

a. Wrap several glassfiber filters in aluminum foil.

b. Place filter packages and evaporating dishes in a muffle furnace at 550'C for I hr.

C. Cool and store in a desicator. If several packages and dishes are prepared at once, you will be prepared for future analyses.

(2) Sample Analysis

a. Try to approximate the TDS content from previous data or from waters of the region.

b. Weigh the evaporating dish and record weight.

c. Using forceps, place a prepared filter in the filtering apparatus.

d. Shake the sample well and measure into a graduated cylinder an aliquot that will yield no more than 200 mg of filterable residue. Record the amount of sample used.

e. Pour the sample into the filtering apparatus and turn on the vacuum pump. Filter until the filter paper is dry.

f. Pour the filtrate into a prepared evaporating dish.

g. Rinse the flask three times with distilled water before using it again.

h. Dry the sample (approximately I hr) at 180 C t2oC, cool in the desiccator, and weigh.

i. Repeat drying and weighing until the weight is the same twice in a row or until the weight loss is less than 0.5 mg. Record the weight.

C. **Calculations**

TDS (mg/l) = ([final weight dried residue + dish (mg)] - initial dish weight (mg)) / milliliters filtrate used * 1000

D. **Accuracy and Precision**

Precision was estimated by APHA (1980) to be 10%. Accuracy determinations have not been made.

E. **Equipment**

Muffle furnace
Drying oven
Analytical balance accurate to ±0.l mg
Vacuum pump
Glassfiber filters, GFC
Graduated cylinder, 250-ml
Evaporating dishes, 150- to 250-ml
Desiccator, plastic or glass
Desiccator plate
Indicating desiccant, 1-lb
Filter funnels/holder, 300-ml
Filter flasks, 1000-ml
Filter forceps
Filter funnel manifold for filtering three samples at once (optimal)

F. **Training**

A person qualified to perform chemical analyses should be able to easily learn this method. It is simple, but an accurate weighing technique is essential for good precision.

4. Summation Method

A full-scale review of the procedures of this method of measuring TDS is beyond the scope of this reference guide. It would require an analysis for each of the major ions found in water, principally chloride, bicarbonate, carbonate, sulfate, sodium, calcium, magnesium, potassium, and perhaps boron, iron, iodine, or bromine. The sum of the concentrations of each of these ions give the TDS. Many of the analyses require sophisticated equipment and highly trained personnel. Only trained, qualified technicians, with proper facilities, should perform this analysis. One solution is to contract a laboratory to perform either this method or the gravimetric method on a few water samples during the sampling season to calibrate the conductivity technique that would be used for most of the samples.

TURBIDITY

1. General Consideration

Turbidity is an "expression of the optical property that causes light to be scattered and absorbed rather than transmitted in straight lines through the sample" (APHA 1980). Factors such as particle size distribution, shape, refractive index, and absorptivity affect light scattering, so it is impractical to consider relating scattered light measurement to the concentration of suspended solids. In clear, brightly lit streams, some turbidity can enhance photosynthesis by lowering light to less inhibiting levels. More often, photosynthesis is reduced; and, if it is caused by inorganic particulates, turbidity can interfere with the filter apparatus of invertebrates, the gills of fish, and the foraging success of sight feeders. Within a specific water body, turbidity is a seasonal phenomenon depending on stream discharge, biotic activities, wind circulation, and chemical changes. A "parts per million silica" standard concentration scale was once used but was abandoned in 1955. Turbidity standards prepared with formazin (hydrazine sulfate and hexamethylene tetramine) are precise and accurate. Units of turbidity measurement with formazin as the primary standard are formazin turbidity units (FTU).

Visual turbidity measurements are made by observing the extinction of the image of a special candle as the amount of sample between the candle and the observer is increased (Jackson Candle Turbidimeter). A variation of this method uses a special lightbulb and the disappearance of the image of a black spot by turning a dial. The scale is in Jackson turbidity units (JTU), which are graduations equivalent to parts per million of suspended silica turbidity. This method is imprecise because it is dependent on human judgment to determine the exact extinction point. Moreover, turbidities lower than 25 JTUs or caused by dark particles, such as charcoal, cannot be measured, and the method is insensitive to fine-particle suspensions.

Measurement of the attenuation of light transmittance through a sample with a spectrophotometer is precise but not a true measure of turbidity as defined. Transmittance measurements are insensitive at low turbidities, whereas at high turbidities, multiple scattering interferes with measurement of light transmitted directly through the sample. The nephelometer detects light scattered 90' from the incident light beam because a 90' angle is considered least sensitive to variations in particle size. This method is precise and sensitive. Turbidities derived from nephelometric measurements are expressed in nephelometric turbidity units (NTU) (analogous to FTU) and are only approximately correlated with JTU.

For models calling for turbidity in parts per million, it is recommended that a new HSI curve be drawn using NTU, so that meaningful and accurate measurements of turbidity may be used. Data in JTU are acceptable if a candle turbidimeter is available; but, if a turbidimeter is purchased, it is recommended that a nephelometer be chosen and the curve reconstructed in NTU.

2. Visual Method (Comparison with Standards)

A **Procedure for Standard Preparation**

(1) Prepare suspensions of kaolin (see following steps) for calibration with a candle turbidimeter for JTU, or use formazin for FTU [18.4.B(2)).

(2) Add about 5 g kaolin to 1 liter distilled water and mix thoroughly. Let stand for 25 hours.

(3) Prepare dilutions of these standards in the desired range.

(4) Determine the turbidity in JTUs with a Jackson Candle Turbidimeter (section 18.3).

(5) Preserve these standards with I g mercuric chloride per liter.

B. **Procedure for Visual Comparison**

(1) Have the sample and standards in bottles of the same size, shape, and type. Leave enough air in the bottle to allow shaking.

(2) Arrange artificial light above or below them, so that direct light does not shine in your eyes.

(3) Shake the bottles and look through them at the same object, such as newsprint.

(4) Record the sample turbidity as that standard that appears most like the sample.

C. **Accuracy and Precision**

Accuracy depends on the range between standards used to compare with the sample. The smaller the range, the higher the accuracy. For high precision, the lighting must be in the same relative position and comparisons made within the same length of time after shaking.

D. **Equipment**

Turbidity standards
Reagent bottles, 300-ml $ 3.75 each
Kaolin, I lb 11.24
Mercuric chloride crystal, 0.25 lb 22.38

E. **Training**

Learning the technique requires virtually no training, but preparing standard solutions can be time consuming, and considerable experience may be needed to estimate the range of standards required for a particular sample.

3. **Visual Methods (Jackson Candle Turbidimeter)**

A. **Procedure**

(1) Shake sample and pour into the glass tube until the image of the candle flame just disappears from view. You should have a uniformly lit field with no bright spots.

(2) Remove enough sample with a pipet until flame image reappears.

(3) Add small amounts of the sample until the flame image disappears again.

(4) Record the JTU indicated on the tube at the meniscus level of the sample.

(5) If turbidity exceeds 1000 JTU, dilute the sample with distilled water.

(6) Calculate JTU for diluted samples (volume in milliliters):

JTU = ((JTU in diluted sample) * (volume of dilution water)+ (sample volume)) / sample volume taken for dilution

B. Precautions

(1) Avoid drafts to prevent the flame flickering.

(2) Burn the candle for only a few minutes at a time.

(3) Remove any charred wick that can be easily broken off before relighting the candle.

(4) Keep the tube clean and free of scratches.

C. Accuracy and Precision

Not available.

D. **Equipment**

Jackson turbidimeter.

E. **Training**

One hour to obtain repeatable results.

F. **Hellige Turbidimeter**

This meter operates on the same principle as the Jackson Candle Turbidimeter but uses opal bulbs instead of a candle. Also the sample volume remains constant but a dial is adjusted until the shade of a spot equals that of the sample. The scale readings are calibrated by the manufacturer to ppm SiO, and are read from graphs supplied with the meter. Each meter and tulb has a different set of graphs.

Because each meter is unique and requires specific graphs, follow the manufacturer's instructions.

4. **Light Transmittance**

The amount of light that can be transmitted through a sample is not a true measure of turbidity, which is an expression of light scattering. Transmittance can be related to turbidity by using a conversion table or by preparing calibration (regression) curves.

Jackson Units (450 nm, 1-inch test tube)

Meter reading (% transmittance)	0	1	2	3	4	5	6	7	8	9
10	395	380	360	350	335	320	310	300	290	280
20	273	265	258	250	245	240	233	228	222	217
30	211	206	200	197	193	188	184	180	175	172
40	168	164	160	157	153	150	147	144	140	137
50	134	131	128	125	123	120	117	114	112	109
60	106	104	101	99	97	85	92	90	88	86
70	84	81	80	77	75	73	71	68	65	64
80	61	59	56	54	51	49	47	44	42	39
90	36	32	30	26	22	20	16	12	8	4

This method is offered because spectrophotometers are more commonly available in laboratories than turbidimeters are, but do not buy a spectrophotometer instead of a turbidimeter specifically for turbidity measurements.

A. **Procedure for Obtaining Sample Data in JTU**

(1) Use matched sets of cuvets (18.4B).

(2) Add distilled water to a clean, dry cuvet (blank).

(3) Close spectrophotometer cover, set wavelength to 420 nm, and align needle to the zero mark on the left side of the scale.

(4) Wipe blank with a Kimwipe and insert into holder.

(5) Close cover and align needle to the zero mark on the right side of the scale.

(6) Shake sample, fill a cuvet with sample. Remove the blank and insert the sample into the holder. Record transmittance.

(7) Convert transmittance to JTU using Table 18.1.

B. **Procedure for Obtaining Sample Data in FTU**

(1) Prepare Matched Sets of Spectrophometric Cells (Cuvets)

a. Matched (of similar transmittance) cuvets may be purchased or made with the procedure in Lind (1979).

b. Cuvets must be handled with great care to avoid marring their surface '. Clean individually with gentle cleanser and do not allow them to touch each other, wire, or metal. Use cuvet holders or a cloth towel.

(2) Prepare Turbidity Standards

a. Hydrazine stock: In 100-ml volumetric flask, dissolve 1.00 g hydrazine sulfate [(NH2)2-H2SO41 in distilled water. Add distilled water to make 100 ml.

b. Tetramine stock: In a 100-ml volumetric flask dissolve10.00 g hexamethylenetetramine [(CH2)6N4] in distilled water. Add water to make 100 ml.

c. Turbidity standard:

i. In a 100-ml volumetric flask, mix 5.0 ml hydrazine stock and 5.0 ml tetramine stock.

ii. Let stand at room temperature for 24 hr.

iii. Add distilled water to 100 ml and mix. The turbidity is 400 FTU.

iv. Make a series of lower turbidities by diluting this standard. Mix 10 ml standard with 90 ml distilled water to make a suspension of 40 FTU; mix I ml standard in 99 ml distilled water for 4 FTU, etc.

v. The standard can be kept no longer than one week.

(3) Prepare Spectral Transmittance Curve

a. Transmittance measurement

i. Add the appropriate amount of distilled water to a clean dry cuvet of the size required by your spectrophotometer (e.g., 5 ml to a 1-cm cuvet for Spectronic 20). This is the blank cuvet. Add the same amount of a turbidity standard to another cuvet.

ii. Set wavelength scale to 400 nm. Close cover and set needle to the left zero-transmittance line with the left knob.

iii. Wipe blank cuvet with a Kimwipe and insert into holder. Set needle to zero absorbance with right knob.

iv. Remove and insert the turbidity standard. Record absorbance.

v. Turn down right knob and set wavelength to 425 nm.

vi. Remove sample. Close cover and make sure needle is aligned with left zero mark.vii. Increase the wavelength 25 nm, to 450 nm, and repeat steps 3, 4, 5, and 6 until 700 nm is reached.

viii. At 625 nm the blue phototube must be replaced with a red-sensitive phototube and a red filter inserted, both of which must be absolutely clean.

b. Transmittance graph

i. Plot transmittance on the ordinate and wavelength on the abscissa, using linear graph paper.

ii. Find region of rapid change in transmittance with wavelength.

iii. Smooth out the curve by repeating the procedure in a (above) using 10 rim instead of 25 nm.

iv. Choose the best wavelength to determine transmittance of formazin standards.

c. Prepare standard curve

i. Set the wavelength at that determined by the above procedure.ii. Adjust left zero with a distilled-water blank.

iii. Mix formazin standard by inversion. Fill a cuvet and wipe dry.

iv. Remove blank and insert the formazin standard. Record percent transmittance.

v. Plot transmittance on the ordinate and formazin turbidity units on the abscissa, or calculate a regression equation. A regression would more accurately relate sample transmittance to the standard transmittance and permits calculation of confidence.

vi. Plot new standard curves twice a month.

d. Measure sample turbidity

i. Insert blank and adjust left zero.

ii. Shake sample and fill a cuvet. Wipe with Kimwipes.

iii. Remove blank and insert sample cuvet- Record transmittance.

iv. Calculate FTU with the regression equation or use the standard curve.

C. **Equipment**

Spectrophotometer

Blue-sensitive phototube
Red-sensitive phototube
Matched cuvets
Cuvet holder
Volumetric pipets, l-, 5-, 10-, 25-, 100-ml
Hydrazine sulfate (NH2-H2SO4), 0.25 lb
Hexamethylenetetramine [(CH2)6N4], 500 g
Reagent bottles, 125 ml
Distilled water
Kimwipes
Graph paper or statistical calculator

D. **Accuracy and Precision**

Precision can be high if the technician is diligent in keeping the cuvets and filters free of scratches and smudges, in checking how well his cuvets match, and in zeroing the meter. Accuracy depends on the spectrophotometer model (the Spectronic 20 has an accuracy of ±2.5 rim) and the number of standards used to prepare the regression. Accuracy of converting transmittance to JTU is unknown.

E. **Training**

Allow at least three hours to prepare reagents and practice the technique.

U.S. Fish & Wildlife Service

Fuel and Fire Effects Monitoring Guide

SOIL PROPERTIES MONITORING

Methods Overview

- Soil Temperature
- Soil Erosion
  - Depth-of-Burn Pins
- Hydrophobicity
- Burn Severity
- Soil moisture
- Soil pH

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HYDROPHOBICITY

1. Introduction

When an area is burned, soil in parts of the burned area may become water repellent (hydrophobic). Fire induced hydrophobicity is usually only associated with high bum intensity areas. When evaluating the effects of fire on burned watersheds it is important to be able to identify the presence of hydrophobic layers, the degree of repellency, and the aerial extent of the repellent layers. Ibis information helps to evaluate the hydrologic response and hazard of the burned watershed.

2. Cause of Hydrophobic Layer Development

Some areas may have naturally occurring hydrophobicity. This is especially in true is true fir and chaparral vegetation types. Fire induced hydrophobic soils are created when waxy organic substances produced by plants and organisms present in the soil surface and duff layer are burned at high temperatures. High temperatures causes volatilization of these organic compounds and the heated gasses move down into the soil. With cooling temperature gradients in the soil, the gasses re-condense on mineral particles to form a water repellent coating. This phenomenon occurs at and below the soil surface.

3. Factors Affecting Development of Water Repellent Soils

A. Fire temperatures - A heat source is needed to volatilize the organic substances. Generally, very intense repellency is formed when the soil containing hydrophobic substances are is heated between 176º and 204º C. Hydrophobic substances are generally destroyed when heated over 288º C. In general soil hydrophobicity only develops significantly in high bum intensity.

The duration of soil heating has an effect on the formation and the depth of repellent layers. Longer duration of the heat source may create deeper layers.

B. Organic Matter Source - There must be an organic matter source to develop a water repellent layer. Sources include litter/duff deposits, very fine roots, fungi and other micro-organisms. Soil organic matter can be a source if the soil surface is heated enough. The higher the wax and oil content of the organic source, the higher the potential is for development of water repellent layers. The amount of wax and oils also effects the degree of repellency.

C. Surface Soil Textures - Coarse textured soils are generally more susceptible to water repellency because the heated gasses can move more readily through the larger pore spaces and the organic matter coats soil particles more completely. Finer textured soils are more resistant because of their larger amount of particle surface area.

D. Soil Moisture Content - Dry soils are most susceptible to repellency. Less soil heating occurs when soils are moist.

4. Identification of Hydrophobic Soils

A. **Identification**

Water repellent soil layers can be identified only by sampling in the field. Tests can be integrated into a fire effects monitoring plan or done independently. Walk through the burned area and do spot checks in several locations. Pay attention to changes in soil, burn severity, vegetation types, etc.

To test for water repellent soil conditions you need to have a water bottle with a small hole in the cap or some way of dispensing small amounts of water and a small trowel or other small digging tool. Basically, you want squirt water on different depths of soil to identify the depth, thickness, and degree of water repellency. I use the following two methods most often.

(1) Dig a shallow trench with a diagonal wall and apply water droplets from the surface down in centimeter increments. Droplets that do not go into the soil indicate that the layer is repellent. Repellent layers should be noted for the degree of repellency (how long does the water take to soak in), the depth at which the repellent layer starts, and the thickness of the repellent layer.

(2) Gently dust away the surface ash till you expose the mineral soil surface, being careful not to break through or into the soil. Squirt a few drops of water from a water bottle onto the soil. Note if the water remains on the surface without soaking in, and if so, how long it remains (degree of water repellency). If it soaks in carefully scrape the soil back to the depth that the water soaked in. Add a few more drops of water. If it soaks in keep repeating.

Once a repellent layer is located scrape thin layers of soil back to expose progressively deeper portions of the topsoil and test each time. Keep going deeper until you no longer observe any water repellency (usually only a few centimeters-maybe more in coarse-textured soils). The depth and thickness of water repellent layers determines the class of water repellency. After you've done this in a few places you will begin to get a feel for the extent of the hydrophobicity in your bum area and can test subsequent areas very quickly.

Record how long the droplets remain on the ped before soaking in.

Record the depths where the repellent layer starts and ends. This gives depth and thickness of the layer.

Be careful when applying the water. If the water droplet touches the side of a ped, a root or ? it may give a false impression of soaking in.

B. **Rating Water Repellent Soils**

Classes of water repellency are based on time required for the adsorption of a drop of water on a dry soil surface.

1. Slight: Less than 10 seconds
2. Moderate: Between 10 and 40 seconds
3. Strong: Greater than 40 seconds

Water Repellency Rating:

1. Low: No strong repellency except at immediate soil surface and no moderate repellency below 0.5 inches. Repellency is very spotty in occurrence.
2. Medium: Some moderate repellency below 0.5 inches, but no strong repellency below I inch.
3. High: Moderate repellency between 3 and 6 inches or strong repellency below I inch. This degree of repellency is uniform in extent.

C. **Estimate the aerial extent of the repellent soil conditions.**

This can be done by idenitrifying the conditions and bum intensity that developed the repellent layers, extrapolating these conditions to areas with similar characteristics and spot checking enough areas to feel comfortable with this extrapolation. There is no predetermined amount of sampling that is needed to determine the aerial extent of the repellency. You should sample as much as possible to be sure that the condition that you are describing occurs where you would guess it would occur and doesn't occur where you would guess that it doesn't occur. This is usually a lot of sampling at first, then less as you gain confidence.

Note: It is important that if more than one person is sampling for hydrophobic conditions that all samplers be standardized. This can be accomplished by taking the time to do some initial sampling of the different burn intensities as a team. This will help ensure that the information gathered is uniform.

5. Management Implications

A. Large areas of water repellent soils could significantly increase the runoff potential.

B. Severe repellency will increase sedimentation and erosion in burned watersheds.

C. Soil repellency naturally breaks down. It can last from months to several years depending on fire severity and soil properties.

U.S. Fish & Wildlife Service

Fuel and Fire Effects Monitoring Guide

AIR QUALITY MONITORING

- Air Monitoring for Wildland Fire Operations
- When and How to Monitor Prescribed Fire Smoke: A Screaning Procedure (requires Adobe Acrobat Reader) - Monitoring particulate matter concentrations in the air (and indirectly, visibility) in sensitive communities and Class I areas before, during and after prescribed understory burning operations.
- Smoke Signals
- Highway Minimum Acceptable Visibility Standards

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AIR MONITORING FOR WILDLAND FIRE OPERATIONS

J. Kennedy and G. Guay

The following are recommendations for conducting an ambient air monitoring program in support of wildland fire operations. These guidelines are designed to assist public land management agencies, Tribal authorities, and private land owners in the assessment of smoke impacts from wildland fire activities. It generally describes important differences between wildland fire monitoring and monitoring for compliance with national ambient air quality standards (NAAQS), how air monitoring can support development and assessment of smoke management plans, and how air agencies and fire/land management agencies can collaborate to conduct monitoring where needed. Information on types of monitors available, cost estimates, and suggestions for operational guidelines are also provided.

What are the differences between wildland fire and NAAQS compliance monitoring? The primary purpose for monitoring wildland fire impacts is to support the smoke management planning process, primarily in wildland-urban interface and Class 1 areas. Uses include: 1) as a tool in assessing smoke management program effectiveness, 2) to assess smoke impacts on sensitive receptors, including firefighter safety, and visibility impacts to Class 1 areas, and 3) for input and validation of modeling studies and other research on smoke behavior. These additional points will help to further clarify the differences between recommended wildland fire air monitoring and monitoring for compliance with the NAAQS:

NAAQS Monitoring:

- Monitoring for NAAQS compliance requires a long-term fixed network which meets the State and Local Air Monitoring Station (SLAMS) criteria of 40 CFR Part 58 and appendices). Criteria include: quality assurance, monitoring methodology, siting, etc.
- Monitoring for NAAQS compliance requires the use of federal reference or equivalent methods pursuant to 40 CFR Parts 50 and 53.
- Monitoring for NAAQS compliance is generally done in high population areas and is primarily filter-based. Data from filter-based monitors is collected every 24 hours and then must be weighed. This delay is obviously an impediment to providing burn managers and air quality managers with the information they need to respond in a timely manner to unacceptable smoke impacts.

Fire Monitoring

- States are responsible for deployment of SLAMS networks. A state may decide to locate a SLAMS or special purpose monitor (SPM) in any populated area where repeated or anticipated levels of smoke exposure from fires is high. Should the NAAQS be violated at a fixed SLAMS or SPM site (that meets CFR guidelines) due to smoke impacts, that violation is considered valid under the Clean Air Act.

- Monitoring for smoke impacts from wildland fire will, in most cases, include short-term monitoring of fire events with portable, or semi-portable instruments. While such short-term monitoring should follow established protocols (e.g., siting design, operational procedures, quality assurance, etc.), federal reference method and SLAMS requirements would not need to be strictly adhered to. Therefore, except in cases where SLAMS and federal reference methods are being utilized, this program cannot be used to determine compliance with the NAAQS.

- Monitoring of wildland fire is usually done to measure smoke impacts in a quantitative sense without regard to comparisons with the NAAQS. One example of such monitoring is a real-time nephelometer network established by the State of Oregon to monitor burning activity in the Blue Mountains. This method is far more effective than filter-based monitoring since the feedback from the monitors is instantaneous and so burning can be modified or terminated where unacceptable smoke impacts are occurring.

Monitoring to support smoke management programs

Air monitoring can be used to support a number of objectives in the smoke management planning process. For a small project where smoke sensitive receptors are not expected to be impacted and the NAAQS is not approached, visual monitoring of the direction of the smoke plume may be sufficient. Posting personnel on potentially affected roadways to monitor for smoke and to initiate safety measures for motorists, using aircraft to track the progress of the smoke plume, continued tracking of meteorological conditions during the fire, and a network of persons at the various sensitive receptors visually monitoring for smoke impacts are examples of monitoring techniques. Ambient monitoring may be warranted for projects which are expected to be multiple day events and/or may potentially cause the NAAQS to be approached in smoke sensitive areas.

Most wildland and prescribed fires will take place in remote areas, however, some do occur at the wildland/urban interface. Since most ambient air monitoring takes place in urban population centers, States/Tribes should consider establishing monitoring sites, in addition to those in the current monitoring network, near sensitive receptors at the wildland/urban interface during fire seasons. When the State/Tribe determines that additional monitoring is warranted, the following elements should be considered:

- type and size of fires requiring special air monitoring,
- where monitors should be located,
- type of monitors that will be used at each location,
- sampling time duration and frequency,
- sample analyses required,
- storage and use of monitoring results.

Public Notification and Firefighter Safety

There are real limitations on the use of ambient monitoring data for real time decision making for the purpose of protecting public and firefighter health. The 24-hour NAAQS for particulate matter (PM-2.5 and PM-10) Federal reference (or equivalent) monitors operate on a 24-hour schedule and are therefore not appropriate for real time decision making. On the other hand, non-filter based real time samplers provide a instantaneous reading of increasing PM levels and thus can be used for public notification, fire management, or firefighter safety purposes . Ambient monitoring can be useful for multi-day events where mid-stream fire management decisions are possible, either to change the prescription or to issue an air quality advisory to nearby communities. It will be up to the judgement of the burn boss and/or local air quality officials to determine when to issue an air quality advisory. Where smoke impacts to downwind communities may be of concern, measuring air quality levels can help provide assurance to those communities that a fire is being carefully "monitored". Where SLAMS sites exist in downwind communities, compliance with the NAAQS can be tracked.

Evaluating Smoke Management Plan Effectiveness

Monitoring is one tool which can determine how well a smoke management plan is working with regard to the concentration levels of harmful pollutants impacting firefighters or sensitive populations. The design of any given monitoring network depends on the purpose for which it is being conducted. If, for example, the use is to determine the distance or direction of smoke travel for purposes of developing or assessing smoke management plans, a series of monitors at various downwind distances would be appropriate. Monitoring frequency should also be often enough to determine smoke travel under various conditions or to determine the duration of smoke exposure to receptors. Where post-burn analysis is being conducted, the sampling design might call for samplers to gather data at various locations to assess if the smoke management measures are successful. Having good data is essential in post-burn analysis to aid in improving smoke management plans.

Monitoring for smoke management plan effectiveness can be limited by: the vagaries of fire/smoke behavior and monitor siting options; not having enough monitors for the application; budget constraints; coordination with fire managers; inadequate training or knowledge of monitoring methods; unclear sampling objectives or inadequate network design.

Partnerships

Joint monitoring efforts among stakeholders (including public land management agencies, Tribal authorities, state/ local air agencies, non-governmental agencies, and private land owners) can greatly increase collaboration, reduce costs, and take more advantage of air monitoring as a useful tool in assessing air quality impacts of smoke. A number of collaborative monitoring arrangements already exist across the country, which can provide useful lessons for future collaborative efforts. For example, the state of Oregon in cooperation with the Forest Service and the Bureau of Land Management entered into an agreement to establish a real-time air quality monitoring network to minimize prescribed burning impacts originating in the Blue Mountains and protect air quality in NE Oregon, SE Washington and Western Idaho.

State/local air agencies play a key role in this process by providing technical assistance, training, and sometimes instrumentation to stakeholders. They can also activate idle network samplers to support smoke tracking efforts. Local air agency personnel are often willing to operate and maintain instrumentation, assist in data analysis and reporting, and issue health advisories when requested. MOU's between stakeholders (such as the one between Oregon and the federal government) can be a good vehicle for detailing what services would be provided and who would pay for salaries and per diem.

Another very important aspect to partnerships is the smoke management planning and negotiation process among stakeholders. The greater the understanding and collaboration that can be achieved among the various governmental agencies in this process, the more sharing of technical assistance, personnel and monitoring resources can take place to achieve mutually desired goals.

What type of monitors are available?

Two general types of ambient air quality monitors are available for use in sampling prescribed fire emissions; those which have been certified as federal reference method monitors (FRMs) and those which show comparable results, but have not been certified. The FRMs are more commonly associated with fixed SLAMS sites. These samplers are large, not easily transportable, require line power and are labor intensive. The current PM-10 and PM-2.5 samplers are available in both continuous and manual configurations. Manual samplers are collect particles on a filter medium and are designed to give 24 hour measurements. The continuous sampler provides data hourly in addition to providing a 24 hour average and is better suited for indicating changing levels of particulate on an hour-by-hour basis. Filter-based samplers allow for speciation analysis of soil, organics (carbon), metals, and other compounds - analyses which also help to validate modeled estimates of these components.

For prescribed burns where smoke changes direction frequently or the duration of the burn is short, a portable sampler is more desirable. Two types of portable monitors are currently available, filter based and non filter based. In general, the filter based sampler is similar to the FRM sampler while the non filter based monitor (integrating nephelometers) correlates back scattering of light off the particles in the gas stream to produce a concentration. One of the newer technologies combines a nephelometer with a portable particulate sampler to provide a real-time continuous monitor with a filter collection capability. The advantage is instantaneous data readout with the ability to do filter speciation later. The limitation of these portable samplers is that they may not be as accurate as the FRMs and their data could not be certified for determining compliance with the particulate standard- shortcomings which are not believed to be critical for this application.

Finally, there are monitors available which combine different measurement parameters such as for aerosols (e.g., nitrates, sulfates and carbon compounds), fine and coarse particulates, some gaseous pollutants, and visual (camera) components . IMPROVE sites are probably the best example, and certainly most widely used, sampler of this type which are used primarily for monitoring visibility impacts in Class 1 areas. The Interagency Monitoring of Protected Visual Environments (IMPROVE) network is a cooperative effort among several agencies, including NPS, EPA, NOAA, USFS, STAPPA, FWS, WESTAR, BLM, and NESCAUM. The IMPROVE program was designed in 1985 and initiated at 20 locations in 1987. The objective of the program is to monitor visibility in Class I visibility protected areas (156 national parks and wilderness areas nationwide). Several additional agencies have adopted the instrumentation and protocols developed for IMPROVE for use in their programs, bringing the number of IMPROVE look-alike sites to more than 40 in this country and nearly 60 worldwide.

How much do samplers cost?

Monitors cost between $2000 and $20,000 with fixed site continuous samplers and remote-operated integrated meteorological/particulate samplers priced at the upper end of the range. Fixed site installations cost approximately $10,000 depending on the type of shelter and local power requirements. A basic portable nephelometer costs around $5000 with the sampler version around $8000-$10,000. The capital costs of filter handling and weighing is approximately $20,000 - 30,000 if a microbalance balance is needed to be purchased. Operating and data analysis are in addition to the above capital costs.

How often should sampling be done?

The standard sampling duration for FRMs is a twenty-four hour period starting at midnight and ending at midnight the following evening. For the purpose of smoke management plans, the monitoring times can be adjusted to what makes sense. Start times may be shifted to early in the morning; sampling duration may be adjusted to shorter periods to facilitate advisory updates. When basing action on continuous sampler readings, the recommended sample period should be at least 3-6 hours.

How should data be analyzed?

Data analysis depends on the intended use. Where immediate operational decisions and public notification are being based on the data results, only real time monitoring information should be used. In a post burn analysis mode, the entire data set, including filter analyses and meteorological data, can be used to assess smoke dispersion patterns, validate air quality models, fine tune action plans to improve public notification systems, and revise smoke management plans. Laboratory support is essential for filter weighing and speciation.

Monitoring Protocols

Protocols should be developed and agreed upon before conducting a monitoring program or project. Protocols should include siting design and rationale for monitor placement; routine quality control check procedures against certifiable standards (traceable to National Bureau of Standards where possible); quality assurance procedures on instruments and data, data analysis procedures, QC and QA; data storage and accessibility, and reporting (to whom, how often, what format, etc). The Federal monitoring guideline in 40 CFR 58 can provide some framework for developing a monitoring protocol, as well as other existing field and research study protocols.

References

Code of Federal Regulations, Title 40, Parts 50, 53, 58, and Appendices.

Prescribed Fire Understory Burning Smoke Monitoring Plan, USDA Forest Service, Pacific Northwest Region. Prepared by CH2MHill. Contract # 53-82-FT-03-2. Draft April 1, 1997.

U.S. Fish & Wildlife Service

Fuel and Fire Effects Monitoring Guide

IMPORTANT FIRE EFFECTS PREDICTORS

Several fuel conditions, weather factors, and weather indices are highly correlated to fire effects.

- Live fuel moisture
- Drought
- Evaluating fire danger rating index performance

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This page was last modified 05/30/01

LIVE FUEL MOISTURE STUDY SITE DESCRIPTION FORM

Instructions: Complete this site description form ONLY after the site has reached full greenup. Take 35 mm slides of the area on the same day the site is described. The best slides are taken on bright overcast days.

1. Enter the date of this observation: month/day/year as mm/dd/yy

2. Enter the observer's name so we have a contact if we have questions.

Enter site identification information including:

3. Agency by code

4. Forest or State by code

5. District or organizational unit by code

6. Site Name descriptive of location (for example Belle Creek) or site number.

7. and 8. Enter latitude and longitude as displayed by GPS or as determined from a map. Please include units such as -105.2425 degrees or -105º 14.55 mins or -105º 14 min 33 sec.

9. Enter the names of the predominant species on the site and the approximate percent canopy cover of each for the following: trees, shrubs, and herbaceous (grasses and forbs). Leave blank if type isn't present. For example, if there are no trees, skip the section on trees. If there are more than four species of a type on site, enter the percent coverage of all the remaining species of that type. Also enter the percent cover of bare soil at this time of year, that is soil that is not covered by either live or dead plant material.

10. Enter the color of the soil moist and dry. You do not need to refer to a soil color chart, but may select white, tan, yellow, red, brown or black.

11. Enter the general aspect of the site as N, NW, W, SW, S, SE, E, NE.

12. Enter the average or most common percent slope on the site.

13. Enter the site's elevation in feet.

14. Enter the NFDRS fuel model that best represents the vegetation on the site.

15. Enter the NFDRS or RAWS weather station number associated with the site.

16. Describe the general condition of the vegetation layer that is being sampled for moisture contents: average height in feet, an estimate of the average percent dead material in the plants, the continuity of the plant layer (continuous, patchy, isolated individuals), disturbance in more than 20% of the plants (insects, disease, browsing, wind damage, fire, other). Include any other information about the condition of this layer that may not be obvious in the photos,

17. Note the slide numbers and a brief reference to the scene pictured.

LIVE FUEL MOISTURE SAMPLING PROCEDURES

1. Site Selection

Sites are selected with interagency partners so that significantly different fuels and/or geographic variation are sampled. The intent is for area coverage to be obtained through interagency coordination and collection, to prevent duplication of efforts, and minimize travel.

A particular site should be representative of the live fuel complex of concern. The site should be relatively undisturbed, such as by heavy browsing or breakage of shrubs, unless that is highly representative of the fuel complex. The species collected should be the one that carries the fire or the one that is felt to be representative of all the species in a complex. If two species are a concern, they should perhaps both be sampled for the first or several years, to determine if the moisture cycle of one represents both. Because moisture cycles of deciduous leaved shrubs are very different from evergreen leaved shrubs, both in terms of timing of their seasonal moisture cycles and the actual variation in moisture content, both may need to be collected if well represented on site.

The site should be located near a RAWS station or in an area with weather well represented by a nearby automatic or manual weather station. Location of the site near a weather station allows for study of the long-term correlation of fuel moisture cycles to weather.

The collection site should be about 5 acres in size, and relatively homogeneous in terms of species composition, canopy cover, aspect, and slope steepness. It should be fairly easy to travel to, although collection should occur away from roadsides, streams, and ponds. If the shrub canopy makes walking difficult, a path can be cut to allow movement around the site. Clearance along the path should be the minimum necessary to allow access.

Site naming will be important to maintaining the identity of site and foliar moisture data. Include agency, administrative unit, and state names as will as the local name you choose for the sample area.

The site should be described the first year immediately following full greenup. If a site can be linked to other survey/monitoring areas in which vegetation has been characterized, it will simplify description of the area. Basic site information should be noted on a site description sheet. Information should include: GPS location (or latitude and longitude derived from maps), elevation, aspect, percent slope, percent species composition of dominant shrub or tree species, percent canopy cover of dominant species and average ratio of live to dead material in the species being collected. Note the percent coverage of surfaced vegetation type (annual or perennial herbaceous, or deciduous or evergreen woody plant) present and the percent cover of litter and bare mineral soil. An air photo reference should be obtained for the largest scale of coverage available. Note the distance and direction from the nearest RAWS or other representative weather station.

Site documentation can be enhanced by taking 35mm photographs. Establish a photopoint by placing a permanent steel post at a location within the plot.

Photos should be taken at the time of site description preferably on a bright, overcast day to minimize shadows. Plot identification is important. Use a felt tip pen to write the plot name on a full sized sheet of paper and lay it on the ground. Carefully focus and photograph the plot name. This will identify the next series of photos as belonging to that plot. Photos should be taken of the general setting of the site, looking in the four cardinal directions, from your established photopoint post. Inclusion of a brightly colored, vertically placed meter stick or some other visible object will aid as a size reference for the vegetation. Photos looking downwards toward the fuels in four directions will also be useful for characterizing surface vegetation, litter, and the amount of exposed soil. In some types, both the general setting and vegetation character can be captured in the same frame, requiring only four photos. You may wish to take duplicate photos of each, one for your records and one to be sent to a central collection point. Process the film and label each slide with agency, administrative unit, site name and direction of view. The original copy of the form and slides should be maintained at your field office.

2. Timing and Number of Samples

Live fuel moisture should be sampled at least every two weeks. Weekly sampling may be desired through that portion of the season when live fuel moistures are rapidly changing. The starting and ending dates should be established for each state or geographic area. It is important that live fuel moisture is collected well before the fire season begins, and into the fall, if species trends are to be identified. It is best if sampling occurs throughout the entire growing season, recognizing that some evergreen leaved shrubs will not begin to show new growth until well after deciduous vegetation and grasses have begun to green up.

Samples should be collected between 1100 and 1600 hours. A specific site should be visited at about the same time of day, and at about the same day of the week each time it is sampled to maintain consistency. However, if the foliage is wet with dew, rain or snow, do not sample at all, but return as soon as possible once the area has dried.

Twenty samples of new foliage and 20 samples of old foliage (from twenty plants) should be collected each sampling period during the early part of the season. When there is no more than 5% difference, on average, in moisture content of new and old foliage, just collect twenty composite samples containing both. Sampling density the first year will probably be greater than in future years, because we need to learn how much variation there is among individual plants. Then we can estimate how many plants must be sampled to obtain a truly representative fuel moisture sample.

3. Equipment

A. **Containers**: Containers for fuel moisture samples should have tight-fitting lids and be rustproof, permanently numbered, and of a material that can be put directly into a drying oven. The best containers are drawn aluminum soil sample cans, or nalgene plastic bottles that can tolerate high temperatures. Each have tight fitting lids that prevent evaporation.

'Zip-lock" or self-sealing bags made specifically for fuel moisture sampling are available from commercial forestry suppliers. These bags can be put directly into the oven, although care must be taken that the bags do not tip. These are the ONLY kind of plastic bag that are suitable because moisture can be lost through pores of most plastic materials and other bags may not be able to withstand oven-drying temperatures. Note, these bags can only be used one time for sample collection.

Containers should be marked with sequential numbers. Numbers written with permanent marking pens will last about one field season. Numbers can be etched or stamped on metal containers. Each lid and each container pair should be marked with the same number, as container and lid weights may vary.

B. **Clippers**: Good quality pruning shears with two sharp curved blades are the most effective for clipping live fuels. Appropriate sampling for some vegetation types precludes clipping and foliage must be sampled by hand stripping leaves from stems.

C. **Tape**: The lids of metal cans are sealed by placing one strip of 1/2 inch wide drafting tape around the lid. Drafting tape can be easily removed from the container. Masking tape can be used but it frequently leaves a residue that is hard to remove. Cross sections of bicycle tire inner tubes can also be used to seal cans.

D. **Carrying case**: It is most convenient if a carrying case or backpack is used to carry samples and equipment. Insulated plastic coolers with a handle work well, and can keep samples from being heated on hot or sunny days. Between sampling periods, keep all sampling equipment and extra forms in the carrying case.

E. **Drying oven**: An electric, mechanical convection oven with a built-in fan is the best oven for drying fuel moisture samples. The fan circulates the heated air and ventilates the oven, drying fuels more uniformly and rapidly than a gravity convection oven. The oven must be able to maintain a regulated temperature of 80º C and have adequate volume to allow air to circulate freely around the samples. We DO NOT recommend the use of Computrac moisture analyzers. These moisture devices can handle only one very small sample at a time and can require a relatively long time to obtain a moisture measure, preventing timely collection of the number of samples required to adequately characterize live fuel moisture.

F. **Scale**: A top loading electronic scale capable of accurately measuring to the nearest 0.1 gram is adequate. These scales allow rapid weighing and are inexpensive. Battery operated models for field use are available.

4. General Sampling Procedures

On arrival at the sampling sire, place the sample carrying case in the shade, and prepare the data sheet. Record the site number or name, date, time of day, name of observer and note plant phenology.

Do not collect live fuels if water drops from rain or dew are present on leaves because the presence of free surface water will cause large errors in calculated moisture content. Shaking the sample to remove excess water or attempting to dry the sample in any way is ineffective. If the sample is wet with surface water, do not collect until later in the day when leaves have dried naturally or return to the site on another day.

Randomly locate a plant that has not been recently sampled and that is located at least several paces away from the last plant sampled. Your intent is to characterize the live fuel moisture content for your species of interest on the entire site.

Note each container number on the data sheet prior to collecting material for that container.

Place sample loosely in the container, do not compress. Cut long stems or large leaves into pieces because succulent plant material becomes fairly stiff as it dries and may force material out of the container as it dries in the oven.

Each sample should contain about 40 to 80 grams green weight of plant material from one plant. (Dried plant sample should weigh around 20 to 35 grams.) When sampling a vegetation type for which new growth is obviously different from mature, sample each into separate containers, noting on the data form whether the sample is new or old. Sample new and old as pairs from the same plant and enter them on the data sheet sequentially.

Collect from all sides of the plant and from different heights above the ground, but refrain from sampling deep within the interior of the plant because that foliage may represent senescent or ephemeral foliage. Do not collect diseased or damaged stems or leaves. DO NOT include flowers, fruits or dead twigs or leaves. However, if frost has killed living leaves or for some other reason the entire site has damaged leaves, then collect them and note the cause of damage on the data form.

When each container is full, seal it tightly. Check the numbers on lid and container to see they are the same. If aluminum cans are used, seal them with drafting tape or inner tube bands as you collect them.

If you collect samples in plastic bags, weight these samples in the field as soon as you return to your vehicle. Record the weights and place sample-filled bags together in a larger plastic bag and close tightly. Moisture loss is less likely from sealed aluminum cans or bottles, so they can be weighed when you return to your office or field station. Transport immediately and do not leave samples for extended periods in a closed, heated vehicle.

5. Species Specific Collection Directions

The following directions are for guidance in selecting an appropriate sampling technique based on the type of plant you are collecting. A few plant names are listed as examples. Due to species differences from one region to another and the vast array of growth forms among plants, you may need to use your own judgement in which method is most appropriate. For example, bitterbrush (*Purshia tridentata*) is technically a deciduous-leaved shrub, but its growth form is most like sagebrush, a "broadleaf" evergreen shrub with tiny leaves. Thus it is most appropriate to sample it in the same way sagebrush is sampled.

A. **Deciduous-leaved trees and shrubs:**

(1) Gambel oak, mountain shrubs, swamp cyrilla, honeycup, etc.:

All leaves are produced newly each year. Collection may begin as soon as leaves begin growing and should be continued until leaf drop. Collect only foliage. Collect one set of 20 samples representing 20 individual plants each sampling period.

(2) Broadleaf evergreen shrubs:

Begin collection prior to initiation of new growth and continue sampling throughout both prescribed burning and wildfire seasons. Sampling may continue year-round if that is appropriate to meeting your fire concerns.

(3) Sagebrush:

Two methods of collection have become established. Note the method chosen on the data form and continue with that method throughout the season and in subsequent years. Results from one sampling period to the next, and from one year to the next will be influenced by the sample material you choose to collect.

Technique used at Dinosaur National Monument. For shrubs on which leaves appear on relatively non-woody stems but the current year's growth is not easily distinguishable from the previous year's, collect by clipping both leaves and stems only to the point of stem transition from pliable and green to becoming brown and, lignified. Do not collect any stem material larger than 1/4 inch in diameter. This generally includes only the current year and the previous year's growth. Collect one set of 20 samples representing 20 individual plants each sampling period.

Technique established by the Great Basin Live Fuel Moisture Project. Collect FOLIAGE ONLY by hand stripping leaves from stems. Collect from the outer portion of the plant avoiding reproductive stalks and leaves on old growth material. Collect one set of 20 samples representing 20 individual plants.

(4) California chaparral: chamise-like shrubs:

For shrubs on which leaves appear on relatively non-woody stems, but current years growth is easily distinguishable from previous years, collect both leaves and stem by clipping. Collect 20 samples each of new growth and mature foliage/stem until new growth cannot be distinguished from old in the field or until new and mature moistures are within 5% of each other. Collect one new and one mature sample for each plant and enter as pairs on the data form so identity of the samples as a pair from one plant can be maintained. Later in the season, when new and mature growth are similar, collect 20 samples of the combined foliage/stems.

(5) Arizona oakbrush (Turbinella oak), ceonothus, gallberry, fetterbrush, etc.:

New leaves on these plants appear on new shoots each year that lignify by the end of the season. Mature leaves reside on woody stems. Collect foliage only. Do not clip and collect stems. Collect 20 samples each of new foliage and mature foliage until new foliage cannot be distinguished from old in the field or until foliar moistures are within 5% of each other. Collect one new and one mature foliage sample for each plant and enter as pairs on the data form so identity of the samples as a pair from one plant can be maintained. Later in the season, when new and mature foliage are similar, collect 20 samples of the combined foliage.

B. **Needle-leaved evergreens:**

Prior to onset on new spring growth, collect 20 samples of previous years' growth. Do not include swelling bud in sample. Begin collecting new foliage samples as well once the bud scale covering is lost. Then, collect 20 samples each new and mature growth, one pair per plant, separating current year's growth from that of previous years' throughout the season as these moistures will tend to be remain distinguishable. Maintain samples as pairs on the data form. Collect foliage only of long-needled species. Do not collect foliage that dates back more than 2 growing seasons. Short-needled species can be collected either as foliage-only samples or by clipping foliage and foliage covered twigs less than 1/8 inch in diameter, separating current year's growth, once bud scale is lost from new needle growth, from previous years'. Do not collect growth from more than a few years past. It is critical to note on the sample form whether or not twig material is included and it is equally critical that the same method be maintained throughout the season as twig moistures can vary greatly from foliage. Sampling foliage only is preferred.

6. Weighing and Drying

In order to calculate moisture content, you must know the tare (empty) weight of each container. Aluminum and nalgene containers, with their lids, should be weighed and the weight recorded. Reweigh the containers after about every 5 uses. The weight of plastic bags must be determined before sampling as fragments of sample will cling to the inside of the bag after use, changing the weight. Do not attempt to reuse the bags. Fuel moisture sampling bags tend to be quite uniform in weight. Weigh several new empty bags. If the weights are very close, you can use an average weight as the tare. Tare weights can be written on the bag with a permanent marker. Recheck this average weight with each new purchase of bags.

Preheat the drying oven to 80º C. Though water boils at 100º C, studies have shown that moisture is totally removed from plant material at this lower temperature. The lower temperature also limits weight loss do to degradation of other substances in the plant. Samples collected in self-sealing bags and weighed in the field can be opened and placed upright in the oven. Samples collected in cans or bottles must be weighed before drying. Remove any tape or bands from the container. Place the container on the center of the scale platform and record the 'wet" weight to the nearest 0.1 gram. Check to see that the number on the container matches the number on the lid, and if collecting more than one species, that the species in the container matches that noted on the data sheet.

Remove the lids from containers and place containers in the drying oven. If the lid fits on the base of the container, place it beneath it in the drying oven. Or, place all lids in sequential order in a convenient place so you can easily replace the matching lid when you remove the dried sample from the oven. Space the containers evenly in the oven so that air can circulate freely around them. Record the date and time that the samples were put into the oven.

Dry the samples for 24 hours at 80º C. Do not put additional samples into the oven while drying a set of samples. If you do, the original samples will absorb moisture from the new samples and the entire set must be dried an additional 24 hours.

When you are to remove the samples from the oven, take a few samples from the oven and quickly replace each lid as the container is removed. If using fuel moisture bags, reseal the bag. Do not leave the oven door open for a long time, particularly if the humidity is high, because the samples can quickly absorb moisture from the air. If any sample material falls from a particular container as you remove it from the oven, throw that sample away, unless you are sure exactly what fell and can replace all of it into the container.

Weigh the sample with its lid on as soon as possible after removing it from the drying oven, and record the dry weight to the nearest 0.1 gram. Check the container number and its contents before you record the weight on the data sheet. After each dried sample is weighed and checked, replace the lid tightly on the container and save the sample until the fuel moisture content is calculated. If an obvious error appears in the calculation, reweighing the sample, or double checking the container contents may reveal the cause of the problem.

7. Calculating Moisture Content

The moisture content is the ratio of the weight of the water in the sample to the dry weight of the sample. This is equal to:

> % Moisture Content = (Wet weight of sample - dry weight of sample) / dry weight of sample * 100

It is most easily computed by the following formula:

> % Moisture Content = (Wet sample weight in container - dry sample weight in container) / (Dry sample weight in container - container tare weight)

Record the calculated moisture contents to the nearest tenth of one percent, one decimal place, rather than rounding to the nearest whole percent. This will decrease the error when you calculate an average of all measured values. If you are recording the data on a spreadsheet, a simple program can be written to calculate moisture content. Double check numbers entered in the spread sheet against those recorded on the data sheet. If calculations are performed with a hand calculator, repeat the calculations to ensure that they are correct.

8. Incidental Fire Behavior Observations

The best use of foliar moisture data will be attained as fire behavior observations and foliar moisture observations are compared. Note comments on any prescribed fire or wildfire behavior occurring in the vicinity of sample plots. Place comments on data forms of the appropriate date in remarks box or on a separate, but attached sheet. Helpful comments could include length of burn period, such as "fire continued in shrub crowns only until 1600", or "until late in the evening", or "into the night". Note spread behavior such as spread in crowns only at head, spread at the flanks, or fire backing in crowns. Equally helpful comments include notes on the inability of shrub or tree crowns to carry fire from one crown to the next.

9. Quality Control

Quality control will be the responsibility of the sampling unit. This procedure will take commitment throughout the season and attention to detail by observer and supervisor. The usefulness of foliar moisture data will be highly dependent on the care given to sampling, drying, calculating and reporting.

INSTRUCTIONS FOR LIVE MOISTURE CONTENT SAMPLING DATA SHEET

1. Data Entry

Each form has room to enter 10 samples. You will need 1 copy of Page 1 and 1 to 3 copies of the following page depending upon whether you are collecting new and mature vegetation separately (20 samples each or 4 sheets) or a mixture of new and mature growth (20 samples total or 2 sheets). (Deciduous is all new). Please enter the page numbers sequentially in the blanks to the upper right.

Enter header information on each sample collection form:

- **Agency** code number
- **Forest or State** code
- **District or Unit** code
- **Site name or number**.

Enter **Collection Record** header information

- **Observer** (your) name
- **Date as** month/day/year **as** mm/dd/yy
- **Time** (should be between 1100 and 1600)

Take a few moments to fill out the **Phenological Observations** section. Mark the appropriate boxes in each of the **Leaf/Stem** and **Flowers/Fruits** columns.

Mark the appropriate SAMPLE CONTENTS choice in the box to the right of phenology to indicate whether this sample contains foliage only, or is a clipped sample containing both leaves and small diameter stems.

Note anything unusual or of special interest about the site in the **Remarks** box.

Collect your weather observations if that is a part of your previously established sampling program. If weather collection is not a normal part of your sampling routind, just note percent cloud cover.

Enter the can, bag or bottle number as you select each from your pack or box.

If you are collecting only 1 species, note the species in the fist row under Species heading. If you are collecting more than one, note species in each row.

Note the type or **condition** of each sample you are collecting by marking the correct box for each sample. **New** = this year's growth. **Old** = growth from previous year(s). **Mix** = mixed current and past year's growth, which you collect once the current and past years' leaves and/or stems appear the same.

As you fill each container, double check container number against that entered on the form, then seal securely and stow in an insulated cooler or sample box.

When you finish collecting all samples: If you are collecting samples into plastic bags, return to your vehicle and weigh each immediately to the nearest 0.1 gram. Enter this weight in **Column A (Gross Weight Wet)** on the **Moisture Determination Record** half of your data form. Pack the plastic bags carefully into **a** large plastic bag, seal and store in a cool safe place. If you collect samples in cans or bottles, seal, pack carefully into your box or cooler and place in a secure, shaded location in your vehicle. Return to your office.

Oven Drying procedures are on the back of the next sample form.

2. Oven Drying Procedure

Preheat the drying oven to 800C.

Samples collected in self-sealing bags and weighed in the field can be opened and placed upright in the oven.

Samples collected in cans or bottles must be weighed before drying. Remove any tape or bands from the container. Place container on the center of the scale platform and record the **Gross Wet Weight** to nearest 0.1 gram in **Column A**. Check to see that the number on the container matches the number on the lid and the species in the container matches that noted on the data sheet.

Remove lids from containers. Place lid beneath can if it fits and put sample in the drying oven. Place bottle lids in order in a convenient place so you can easily replace the matching lid and place opened bottle in the oven. Space the containers in the oven so air can circulate freely. Record the date and time the samples were put into the oven.

Dry the samples for 24 hours at 800C. Do not put additional samples into the oven while drying a set of samples. If you do, dry set an additional 24 hours.

Take **a** few samples from the oven and replace each lid as the container is removed. If using fuel moisture bags, reseal the bag. Do not leave the oven door open. If any sample material falls from the container, throw the sample away, unless you can replace all of it.

Weigh the sample with its lid on as soon as possible after removing it from the drying oven, and determine the **Gross Dry Weight** to the nearest 0.1 gram. Check the container number and its contents before you record the weight on the data sheet. Enter weight in **Column B**. Replace the lid tightly on the container and save the sample until the fuel moisture content is calculated in case an error requires rechecking the sample contents or weight.

3. Calculating Moisture Content

Enter Tare Weight in Column C. You may have a standard weight to enter if using bags of uniform size. Or enter the weights of the cans or bottles that had been preweighed empty from your master tare weight list.

Enter Water Weight in Column D: Gross Wet Weight (A) - Gross Dry Weight (B)

Enter Dry Weight in Column E: Gross Dry Weight (B) - Tare Weight (C)

Enter % Moisture Content in Column F: Water Weight (D) / Dry Weight (E)

Record the calculated moisture contents to the nearest 0.1 % If you are recording the data on **a** spreadsheet, a simple program can be written to calculate moisture content. Double check numbers entered in the spread sheet against those recorded on the data sheet. If calculations are performed with **a** hand calculator, repeat the calculations to ensure that they are correct.

Calculate 20-sample averages by adding all New, Old OR Mixed samples and dividing by 20. Enter averages on first page in Calculation Summary box.

Live Fuel Moisture Samples

Page ___ of ____

Agency	Forest/State	District/Unit	Site Name or Number

Collection Record

Observer	Date	Time
	/ /9	

Moisture Determination Record

Observer	Date in	Time in
	/ /9	

Can, Bag or Bottle Number	Species	Condition			A	B	C	D	E	F
	//////////////	New	Old	Mix	Gross Weight		Tare Weight	Water Weight	Dry Weight	% Moist.
	//////////////				WET	DRY				

Phenological Observations

Leaf/Stem stages:
- Dormant [ ]
- Stem / leaf growth [ ]
- Growth complete [ ]
- New stems lignified [ ]
- Leaves curing falling [ ]
- Frosted or frozen [ ]

Flowers/Fruits:
- Buds / flowers present [ ]
- Seeds/fruits developing[ ]
- Seeds/fruits ripe [ ]
- Seeds/fruits falling [ ]
- None [ ]

Weather: Dry Bulb ______ RH ____%
Wet Bulb _____ Cloud Cover ____%

Calculation Summary

A - B = D   B - C = E

(D / E) X 100 = F

Average of 20 Samples: New = XXXXXXX %

Old = XXXXXXX %

Mix = XXXXXXX %

SAMPLE CONTENTS
- Leaf only [ ]
- Leaf & Stem [ ]

Remarks: Enter Phenology, Calculation Summary, Sample Contents and Weather on front page only.

Live Fuel Moisture Study Site Description Form

1. Date ____________ 2. Observer ____________

3. Agency ____________ 4. Forest/State ____________

5. District/Unit ____________ 6. Site Name or # ____________

7. Latitude ____________ 8. Longitude ____________

9. Major Vegetation:

Tree species 1 ____________ percent cover ______
Tree species 2 ____________ percent cover ______
Tree species 3 ____________ percent cover ______
Tree species 4 ____________ percent cover ______
All other trees percent cover ______

Shrub species 1 ____________ percent cover ______
Shrub species 2 ____________ percent cover ______
Shrub species 3 ____________ percent cover ______
Shrub species 4 ____________ percent cover ______
All other shrubs percent cover ______

Grass/forb species 1 ____________ percent cover ______
Grass/forb species 2 ____________ percent cover ______
Grass/forb species 3 ____________ percent cover ______
Grass/forb species 4 ____________ percent cover ______
All other grasses/forbs percent cover ______

Bare ground percent cover ______

10. Predominant soil color: moist ____________ dry ____________

11. Predominant aspect ____________ 12. Predominant % slope ____________

13. Elevation (feet) ____________ 14. NFDRS fuel model ____________

15. Associated NFDRS or RAWS weather station number ____________

16. Vegetation condition description of layer chosen for moisture sampling:

Average height (ft) ____________ Percent dead ____________

Continuity of layer ____________ Disturbance ____________

Other comments ____________

____

17. Slides numbers and descriptions ____________

____

U.S. Fish & Wildlife Service

Fuel and Fire Effects Monitoring Guide

Fire Works!

HOME

WHAT'S NEW

PLANNING

Project Planning
Design & Analysis
Reporting Results

MONITORING ATTRIBUTES

Fuel

Wildlife Habitat
Plant Mortality
Frequency
Cover
Density
Production
Structure
Composition

Wildlife Populations
Direct Mortality
Populations

DROUGHT

1. Introduction

The moisture content of the upper soil, as well as that of the covering layer of duff, has an important effect on the fire management effort in forest and wildland areas. In certain areas of the United States, fires in deep duff fuels are of particular concern to the fire manager. When these fuels are dry, fires burn deeply, soil heating is excessive, and fire extinguishment unduly expensive. Even relatively small fires are costly and risky to manage. As an example, in 1955, 1956, 1981, and 1998, fires in the Southeast each burned thousands of acres. During these years, normally moist areas which usually served as good fire barriers, such as branch heads and bays, became so dry that the fires accelerated through the heavy fuel instead of slowing down.

Certainly, factors in addition to soil moisture influenced the occurrence and behavior of these and other less spectacular fires. However, experience over the years has established the close association of extremely difficult fire suppression with cumulative dryness, or drought.

In fire management, the critical effects of drought are not confined to deep organic soils. Dried-out organic materials are frequently imbedded in the shallow upper layers of mineral soils. These fuel pockets can become a deciding factor in whether or not firelines will hold and a further problem in mopup operations. During extreme drought conditions, the moisture content of living brush and tree crowns may be lowered, fires may crown more readily, and some of the woody vegetation may die. Furthermore, the curing of herbaceous material during the growing season is associated with periods of little or no rainfall. It is important to recognize how drought intensifies the problem of fire management.

Drought development, especially in the early stages, is frequently unrecognized and certainly is not uniformly interpreted. The need for systematic methods of estimating the progress of drought has been

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emphasized by State and Federal fire management officers. This recurring problem stimulated the search for a measure of drought that would be useful in planning fire management operations.

2. General

Drought has been defined in many ways. For fire management, a useful concept of drought is one which treats it as a continuous quantity which can be described in numerical terms. The values would range from zero (soil and duff saturated with water) up to some maximum value which corresponds to an absence of available moisture in the soil and duff. This point of view does not necessarily emphasize the extreme or unusual aspects of the drought concept. However, the upper part of the scale does correspond to those conditions for which many definitions of drought require that the dryness or moisture deficiency be "abnormal" or "unusual."

Drought index is the net effect of evapotranspiration and precipitation in producing cumulative moisture deficiency in deep duff or upper soil layers. Drought index is, thus, a quantity that relates to the flammability of organic material in the ground.

The material may be soil humus, in which case the upper soil may appear to burn if fires occur when the index is high. The organic material may also consist of buried wood, such as roots in varying degrees of decay, at different depths below the mineral soil surface. The relative dryness of these fuels is a direct effect of drought and, because of the problem of firelines noted previously, is of greater significance in fire management than in fire behavior.

There may, however, be important indirect effects of an extended drought on specific fire behavior characteristics, such as rate of spread or energy release, because these variables are affected by the size of the area on fire at one time. Fires may also crown more readily under drought conditions. A prolonged drought influences fire intensity largely because more fuel is available for combustion. The increased intensity, added to the difficulty of holding firelines, greatly adds to the effort required for fire management.

We emphasize that the drought index is not in any way a substitute for the moisture parameters used in the spread phase of the National Fire Danger Rating System. A drought condition is not a prerequisite for the occurrence and spread of fire in any area. The drought index does not replace any NFDRS index, because it represents an entirely different moisture regime in which the response to weather changes is much slower. The purpose of the drought index is to provide fire managers with a continuous scale of reference for estimating deep-drying conditions in areas where such information may be useful in planning fire management operations.

3. Structure of the Drought Index

The physical theory and the general framework for a drought index is that it should operate through a wide range of climatic conditions. The theory and framework are based on the following assumptions:

A. The rate of moisture loss in a forested area will depend on the density of the vegetation cover in that area. In turn, the density of the vegetation cover, and, consequently, its transpiring capacity, is a function of the mean annual rainfall. Furthermore, the vegetation will eventually adjust itself to use most of the available moisture.

B. The vegetation-rainfall relation is approximated by an exponential curve in which the rate of moisture removal is a function of the mean annual rainfall. Therefore, the rate decreases with decreasing density of vegetation, hence, with decreasing mean annual rainfall.

D. The rate of moisture loss from soil is determined by evapotranspiration relations.

E. The depletion of soil moisture with time is approximated by an exponential curve form in which wilting point moisture is used as the lowest moisture level. Thus, the expected rate of drop in soil moisture to the wilting point, under similar conditions, is directly proportional to the amount of available water in the soil layer at a given time.

F. The depth of the soil layer wherein the drought events occur is such that the soil has a field capacity of 8 inches of available water. Although the selection of 8 inches is somewhat arbitrary, a precise numerical value is not essential. Eight inches of available moisture appears reasonable for use in forest fire control because in many areas of the country it takes all summer for the vegetation cover to transpire that much water.

With the exception of assumption A., the basic principles upon which the drought index is based are similar to those upon which Nelson (1959) based his index. However, he used a linear relationship in assumption D. instead of the exponential form. The precise nature of the soil moisture depletion curve is still in doubt, but most investigators now seem to prefer the exponential form.

Current drought index data can be obtained from Wildland Fire Assessment System and NWS Climate Prediction Center on the WWW:

- Keetch-Byram Drought Index (US or AK)
- Palmer Drought Index (US)
- Precipitation Needed to Bring Palmer Drought Index to Near Normal
- Crop Moisture Index
- U.S. Drought Monitor

Site specific drought index data can also be developed.

- Keetch-Byram Drought Index

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KEETCH-BYRAM DROUGHT INDEX COMPUTATIONS

1. Introduction

The drought index can be computed for any desired level of mean annual rainfall, but to simplify the computations for field use, five tables of drought factors were made up. Each table covers a specified range of mean annual rainfall. Drought factor table for areas with mean annual rainfall:

- 10 - 19 inches
- 20 - 29 inches
- 30 - 39 inches
- 40 - 59 inches
- 60 inches or more

The measurements needed for the drought index are (1) the maximum air temperature (or the dry-bulb temperature at time of basic observation) and (2) the total rainfall for the past 24 hours. This information is available at stations that regularly compute NFDRS indexes. These measurements can be recorded on a field recording form.

Only one drought factor table is needed at any selected station. Thus, to compute drought index it is first essential to decide which drought factor table to use. The appropriate table is determined by the long-term mean annual rainfall of the area. Because the range of mean annual rainfall in each table is fairly broad, a reliable estimate applicable to the rating area can usually be obtained from the nearest U. S. Weather Bureau office.

In remote areas it may be necessary to refer to state maps which show lines of mean annual rainfall drawn through points of approximately equal value (called isohyets). These maps are available in the publication, "Climates of the States," which is prepared by the U. S. Weather Bureau and issued separately for each state. Caution should be used in interpolating between the lines on these maps, particularly in mountainous areas.

2. Starting a Drought Index Record

An examination of the drought factor tables makes it clear that, for any given temperature, the drought factor to be added each day depends on the drought index yesterday. This cumulative feature means that an observer starting a drought index record cannot automatically begin at zero. The zero point may have occurred weeks or months before, or even during the previous year. It is necessary to go back in time until a day is reached on which it is reasonably certain that the upper soil layers were saturated, then bring the record forward day by day to the starting date. In areas of heavy snowfall, it is normally safe to assume saturation just after the snow melts in the spring. When starting a record in snowfree areas, it is necessary to go back to a period of abundant rainfall, such as 6 or 8 inches in a period of a week. The index must be very low, if not actually zero, at the end of the rainy period.

When the starting point has been determined and the proper drought factor table has been selected, the computation of drought index each day is a simple bookkeeping procedure. Essentially, there are two steps:

Step 1--Reduce the drought index by the amount of net rain, if any.

Step 2--Increase the drought index by the amount found in the drought factor table.

3. Instructions for Computing Drought Index (refer to sample record)

A. **Column 2 - 24-Hour Rainfall**

Record measured amount of rain to nearest 0.01 inch. Follow standard instructions for melted snow and recording the water equivalent.

B. **Column 3 - Net Rainfall**

Subtract 0.20 from amount in column 2 to obtain net rainfall. Record 0 (zero) if amount in column 2 is 0.20, or less.

Exception: If there are CONSECUTIVE rainy days, with no drying of tree canopy between showers subtract only once, on the day that the cumulative rainfall exceeds 0.20. Thereafter, consider all of the rain in column 2 as net rainfall (and transfer the amount to column 3) until the wet spell ends. Consider wet spell ended on first 24-hour period with no measurable rain. In case of snow--consider no drying as long as snow blankets the fuels, and transfer all measured water equivalent to column 3.

Example 1 - 0.20 was subtracted from each of the individual rains on June 3, 5, 14, and 16.

Example 2--Rains on June 7-8 were consecutive, so the 0.20 was subtracted when total rain exceeded 0.20, which was June 8.

Example 3--Rains on June 29-30 were consecutive, so 0.20 was subtracted on first day, and all of the rain was transferred to column 3 on second day.

C. **Column 4 - Air Temperature**

Record air temperature to nearest degree, rounding fractions of 0.5 or more to next higher number. Place an "x" in appropriate box at head of column to identify the temperature used--whether maximum for the day, or dry-bulb temperature at time of basic observation.

D. **Column 5 - Drought Index yesterday, or as reduced by net rainfall in column 3**

During rainless periods, or when net rainfall in column 3 is zero, enter in column 5 the drought index recorded in column 7 on the previous day. When there is net rainfall in column 3, subtract the number of hundredths inches of rain from the previous day's drought index, and record the reduced drought index in column 5.

Example 1--No net rain on June 2. Drought index was 174 (column 7) on June 1. Therefore, 174 was carried forward to column 5 for June 2.

Example 2--Net rain on June 3 was 46 hundredths. Drought index June 2 was 182 (column 7). Therefore, 182 minus 46 equals 136, the, number to record in column 5 for June 3.

E. **Column 6 - Drought Factor**

Use the appropriate Drought Factor Table as determined by the mean annual rainfall of the rating area. If your area has a mean annual rainfall that seems to fall right on the borderline between tables, such as 19.50 inches or 39.50 inches, use the table with the next higher number. Insert the table number used in the box provided at the top of column 6.

Procedure - refer to Temperature in column 4 and Drought Index yesterday in column 5. Record the drought factor where these numbers intersect in Drought Factor Table.

Example: For June 10, Temperature 70 and Drought Index yesterday 190 intersect at drought factor 6 in the 40 - 59 inches Drought Table 4.

F. **Column 7--Drought Index For Today**

Add Drought Index yesterday in column 5 to drought factor in column 6 to obtain Drought Index For Today.

Example: For June 10, 190 plus 6 equals 196.

G. **Column 8 - Current Stage of Drought**

Refer to Drought Index For Today in column 7, and determine the drought stage as follows:

Index Stage Index Stage

Index	Stage
0-99	0
100-199	1
200-299	2
00-399	3
400-499	4
500-599	5
600-699	6
700-800	7

Example: The Drought Index For Today on June 10 is 196 (column 7), so the drought stage is 1.

3. Drought Index Interpretation

Because the drought index number expresses moisture deficiency in hundredths of an inch and the index is based on 8.00 inches of water available for transpiration, the index is on a scale ranging from 0 to 800. Zero is the point of no moisture deficiency and 800 is the maximum drought that is possible. At any point along the scale, the index number indicates the amount of net rainfall (in hundredths) that is required to reduce the index to zero, or saturation.

To facilitate the description and to clarify the discussion of drought, the available range of drought has been divided into stages. The zero or incipient stage includes the range from 0 to 99, the first stage from 100 to 199, the second stage from 200 to 299, and so on through the seventh stage from 700 to 800.

Mathematically, the 800 point would require infinite time and, therefore, would never be reached. But by using the rounded off values as set up in the drought factor tables, it is possible to reach 800. Once reached, this maximum cannot be exceeded, because the drought increment at index 800 is zero.

Although the drought index number has a definite meaning in terms of moisture deficiency, the significance of a particular stage of drought for fire management must be determined locally.

In relating drought index to specific locations, we must select the proper drought factor table. This selection is determined by the mean annual rainfall of the area. One simple way to emphasize the importance of selecting the proper table is to compute, according to each of the five tables, the number of consecutive days having a constant maximum temperature and no effective rainfall that must elapse (after starting at zero) before a selected stage of drought is reached. The following tabulation lists the number of days required, according to each of the tables, to reach the fifth stage (500) when the observed temperature each day ranges from 80º to 82º F.

Mean annual rainfall (inches)	Consecutive drying days needed to reach D. I. 500 (number)
10-19	157
20- 29	109
30-39	78
40-59	52
60 or more	36

From the foregoing, two extremes can be represented by the drought factor tables. If the two areas represented by 10-19 and 60 or more table both started with zero drought index on May 31, then the area with heavy rainfall would reach stage 5 in 36 consecutive days, by July 6, and the area of light rainfall would reach stage 5 in 157 consecutive days, by November 4.

In a normal or average year the drought index has a definite trend or cycle of values throughout the year with which the index at any time during a given year can be compared. In the Asheville area, the normal drought index climbs rapidly during June and July, peaks in mid-September, and drops nearly to zero by late February or March. It was found that the normal cycle drought is well understood by fire managers, both State and Federal, and is reflected in fire control action.

Because of higher temperatures and more wind, the spring fires in the Asheville district spread faster, on the average, than those in the fall. But once the average spring fire is stopped, mopup is relatively easy. This is not the case in the fall. The typical fall fire burns in cooler weather; there is less wind, and the rate of spread is less than in the spring. Fall fires are therefore easier to stop. But they burn deeper, firelines are more difficult to build and maintain, and mopup is often an extended operation, soil heating and fire severity is greater. When the drought index climbs into the fifth and sixth stages, as it did in 1951, 1952, and 1953, the control problem is greatly aggravated. In contrast, during the fall of 1959 the index dropped to stage 1 and remained there through the fall season, and firelines were easy to hold.

There was an unusually severe drought near Fort Myers, Florida, starting in September 1961 and persisting through the first 5 months of 1962. Going back to the records for that month, we find that the drought index was in the incipient stage (below 100) at the beginning of September, reached stage 3 on September 20, and edged into stage 4 by the end of the month. This progress seems to agree with drought observations during that period.

Ketchikan, Alaska, where the mean annual rainfall is 151.93 inches, is one of the relatively few areas in the country to which the 60 inches or more table is applicable. In this area of abundant and normally well-distributed rainfall, a drought beyond the incipient stage is unusual. The lowest mean monthly rainfall is 7.34 in June. In the period from 1956 through 1960, 92 percent of the days rated below 100. However, a drought can build up beyond stage 3 in a 30-day summer period with little rain. In 1958, the drought index exceeded 300 from June 20 through July 20 and in the last 3 days of the period was above 500.

The opposite end of the climatic scale is represented by Burbank, California. Long rainless periods are a normal event in an area where the mean annual rainfall is only 13.88 inches. With so little rain, one might suspect that there would be relatively small change in the seasonal level of drought; and the drought index for 1961 seems to bear out this supposition. At the beginning of 1961, the area was in the fifth stage. The seriousness of the drought situation was noted by the local unit of the U. S. Weather Bureau. The moisture deficiency continued to climb throughout the dry summer, reaching a maximum in October well into the seventh stage. The lowest drought index recorded on any day in 1961 was 413, the highest was 743. However, the Burbank weather records from 1956 until they were discontinued in 1966, 1961 was not a typical year. In fact, it was the most persistently dry year in the 11 - year period and averaged the highest drought index. The zero drought index occurred in one or more of the spring months in 6 of the 11 years. In an average year the low point in the drought curve descends into stage 1 in March and April. Thereafter, the index climbs steadily for the next 6 months, peaking just into stage 6 in October. The 1962 drought, a more typical situation than that in 1961. Substantial rains in February brought the index all the way back to zero. Thereafter, the index climbed slowly back to stage 5 at the end of August and into stage 6 by October 31.

A difference in the drought index curves of the magnitude for 1961 and 1962 indicates that soil moisture during the first 10 months of 1961 was markedly lower than for the corresponding months in 1962, at the Burbank station. Additional measurements from several surrounding stations would be needed to determine whether the observed difference in the 1961-62 drought index was localized or was representative of an extensive area.

An interesting comparison can be made, however, with moisture measurements of plant foliage that were taken on the nearby Angeles National Forest. The moisture content of chamise foliage on study plots in the Angeles National Forest has been reported by the Pacific Southwest Forest and Range Experiment Station. These data are contained in a series of 10-day reports on California Fire Weather. A report covering the period from April 10 to October 20 shows the percent moisture content of chamise foliage in 1961 and 1962. The moisture content of the foliage during the period from April to October varied greatly from 1961 to 1962; the distinction was similar to the difference in drought index from 1961 to 1962. In 1962 the lowest moisture content reached by October was about 75 percent (at which time the drought index was in the fifth stage). In 1961 the moisture content reached the 75 percent level in May (when the drought index was in the fifth stage) and then dropped to less than 30 percent in October (when the drought index was in stage 7).

In 1957 there was a drought in Portland, Maine. Starting from stage 1 in June, the drought had reached the sixth stage by late September. In September a water shortage was evident at that time. Copious precipitation in the latter part of October and through mid-December (9.49 inches) brought the drought index back to zero. It is probable that the September drought was indeed over by December, because the rivers rose sharply to normal during that month.

4. Keetch-Byram Drought Index Revisited: Prescribed Fire Applications

5. Keetch-Byram Drought Index Software

Temp °F	Drought Index Yesterday (or as reduced by precipitation) 10-19 inches annual precipitation															
	0-49	50-99	100-149	150-199	200-249	250-299	300-349	350-399	400-449	450-499	500-549	550-639	640-699	700-759	760-799	800
107+	21	19	18	17	15	14	13	11	10	9	7	5	3	2	1	0
104-106	18	17	15	14	13	12	11	10	8	7	6	5	3	2	1	0
101-103	15	14	13	12	11	10	9	8	7	6	5	4	2	1	1	0
98-100	13	12	11	11	10	9	8	7	6	5	5	3	2	1	1	0
95-97	11	10	10	9	8	8	7	6	5	5	4	3	2	1	1	0
92-94	9	9	8	8	7	6	6	5	5	4	3	3	2	1	0	0
89-91	8	8	7	7	6	5	5	4	4	3	3	2	1	1	0	0
86-88	7	6	6	6	5	5	4	4	3	3	2	2	1	1	0	0

83-85	6	5	5	5	4	4	4	3	3	2	2	2	1	1	0	0
80-82	5	5	5	4	4	3	3	3	2	2	2	1	1	1	0	0
77-79	4	4	4	3	3	3	3	2	2	2	1	1	1	1	0	0
74-76	3	3	3	3	3	2	2	2	2	1	1	1	1	1	0	0
71-73	3	3	3	2	2	2	2	2	1	1	1	1	1	1	0	0
68-70	2	2	2	2	2	2	1	1	1	1	1	1	1	0	0	0
65-67	2	2	2	2	1	1	1	1	1	1	1	1	1	0	0	0
62-64	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
59-61	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
56-58	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
53-55	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
50-52	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0

Temp °F	Drought Index Yesterday (or as reduced by precipitation) 20-29 inches annual precipitation															
	0-49	50-99	100-149	150-199	200-249	250-299	300-349	350-399	400-449	450-499	500-549	550-639	640-699	700-759	760-799	800
107+	30	28	26	24	22	20	18	16	14	12	11	8	5	3	1	0
104-106	25	24	22	20	19	17	16	14	12	11	9	7	4	2	1	0
101-103	22	20	19	18	16	15	13	12	11	9	8	6	3	2	1	0
98-100	19	17	16	15	14	13	11	10	9	8	7	5	3	2	1	0
95-97	16	15	14	13	12	11	10	9	8	7	6	4	3	1	1	0
92-94	14	13	12	11	10	9	8	7	7	6	5	4	2	1	1	0
89-91	12	11	10	9	9	8	7	6	6	5	4	3	2	1	1	0

86-88	10	9	9	8	7	7	6	5	5	4	4	3	2	1	1	0
83-85	8	8	7	7	6	6	5	5	4	4	3	2	1	1	0	0
80-82	7	7	6	6	5	5	4	4	3	3	3	2	1	1	0	0
77-79	6	5	5	5	4	4	4	3	3	2	2	2	1	1	0	0
74-76	5	5	4	4	4	3	3	3	2	2	2	1	1	1	0	0
71-73	4	4	4	3	3	3	2	2	2	2	1	1	1	1	0	0
68-70	3	3	3	3	2	2	2	2	2	1	1	1	1	1	0	0
65-67	3	3	2	2	2	2	2	1	1	1	1	1	1	0	0	0
62-64	2	2	2	2	2	1	1	1	1	1	1	1	1	0	0	0
59-61	2	2	1	1	1	1	1	1	1	1	1	1	0	0	0	0
56-58	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
53-55	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
50-52	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0

Temp °F	Drought Index Yesterday (or as reduced by precipitation) 30-39 inches annual precipitation															
	0-49	50-99	100-149	150-99	200-249	250-299	300-349	350-399	400-449	450-499	500-549	550-639	640-699	700-759	760-799	800
107+	41	38	36	33	30	28	25	23	20	17	15	11	6	4	1	0
104-106	35	33	31	38	36	34	33	19	17	15	13	9	5	3	1	0
101-103	30	28	26	24	22	20	19	17	15	13	11	8	5	3	1	0
98-100	26	24	23	21	19	18	16	14	13	11	9	7	4	2	1	0
95-97	22	21	19	18	16	15	14	12	11	9	8	6	3	2	1	0
92-94	19	18	16	15	14	13	12	10	9	8	7	5	3	2	1	0

89-91	16	15	14	13	12	11	10	9	8	7	6	4	3	1	1	0
86-88	14	13	12	11	10	9	8	7	7	6	5	4	2	1	1	0
83-85	11	11	10	9	9	8	7	6	6	5	4	3	2	1	1	0
80-82	10	9	8	8	7	7	6	5	5	4	3	3	2	1	0	0
77-79	8	8	7	7	6	6	5	4	4	3	3	2	1	1	0	0
74-76	7	6	6	5	5	5	4	4	3	3	2	2	1	1	0	0
71-73	6	5	5	5	4	4	3	3	3	2	2	2	1	1	0	0
68-70	5	4	4	4	3	3	3	3	2	2	2	1	1	1	0	0
65-67	4	3	3	3	3	3	2	2	2	2	1	1	1	1	0	0
62-64	3	3	3	2	2	2	2	2	1	1	1	1	1	1	0	0
59-61	2	2	2	2	2	2	1	1	1	1	1	1	1	0	0	0
56-58	2	2	2	1	1	1	1	1	1	1	1	1	1	0	0	0
53-55	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
50-52	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0

Temp °F	Drought Index Yesterday (or as reduced by precipitation) 40-59 inches annual precipitation															
	0-49	50-99	100-149	150-99	200-249	250-299	300-349	350-399	400-449	450-499	500-549	550-639	640-699	700-759	760-799	800
107+	62	58	54	50	46	42	38	34	30	26	22	16	10	6	2	0
104-106	53	50	46	43	39	36	33	29	26	22	19	14	8	5	1	0
101-103	46	43	40	37	34	31	28	25	22	19	16	12	7	4	1	0
98-100	39	37	34	31	29	26	24	21	19	16	14	10	6	4	1	0
95-97	33	31	29	27	25	23	20	18	16	14	12	9	5	3	1	0

92-94	28	27	25	23	21	19	17	16	14	12	10	8	4	3	1	0
89-91	24	23	21	20	18	16	15	13	12	10	9	6	4	2	1	0
86-88	21	19	18	17	15	14	13	11	10	9	7	5	3	2	1	0
83-85	17	16	15	14	13	12	11	10	8	7	6	5	3	2	1	0
80-82	15	14	13	12	11	10	9	8	7	6	5	4	2	1	1	0
77-79	12	11	11	10	9	8	8	7	6	5	4	3	2	1	1	0
74-76	10	10	9	8	8	7	6	6	5	4	4	3	2	1	1	0
71-73	8	8	7	7	6	6	5	5	4	4	3	2	1	1	0	0
68-70	7	6	6	6	5	5	4	4	3	3	2	2	1	1	0	0
65-67	6	5	5	4	4	4	3	3	3	2	2	2	1	1	0	0
62-64	4	4	4	4	3	3	3	2	2	2	2	1	1	1	0	0
59-61	3	3	3	3	3	2	2	2	2	1	1	1	1	1	0	0
56-58	3	2	2	2	2	2	2	1	1	1	1	1	1	0	0	0
53-55	2	2	2	1	1	1	1	1	1	1	1	1	1	0	0	0
50-52	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0

Temp ^{o}F	Drought Index Yesterday (or as reduced by precipitation) 60 inches or more annual precipitation															
	0-49	50-99	100-149	150-99	200-249	250-299	300-349	350-399	400-449	450-499	500-549	550-639	640-699	700-759	760-799	800
107+	91	85	79	73	68	62	56	50	44	38	32	34	14	8	2	0
104-106	78	73	68	63	58	53	48	43	38	33	28	21	12	7	2	0
101-103	67	63	58	54	50	45	41	37	32	28	24	18	10	6	2	0
98-100	57	54	50	46	43	39	35	31	28	24	20	15	9	5	2	0

95-97	49	46	43	40	36	33	30	27	24	21	17	13	8	4	1	0
92-94	42	39	36	34	31	28	26	23	20	18	15	11	7	4	1	0
89-91	36	33	31	29	26	24	22	19	17	15	13	9	6	3	1	0
86-88	30	28	26	24	22	20	18	17	15	13	11	8	5	3	1	0
83-85	25	24	22	21	19	17	16	14	12	11	9	7	4	2	1	0
80-82	21	20	19	17	16	15	13	12	10	9	8	6	3	2	1	0
77-79	18	17	16	14	13	12	11	10	9	8	6	5	3	2	1	0
74-76	15	14	13	12	11	10	9	8	7	6	5	4	2	1	1	0
71-73	12	12	11	10	9	8	8	7	6	5	4	3	2	1	1	0
68-70	10	9	9	8	7	7	6	6	5	4	4	3	2	1	1	0
65-67	8	8	7	7	6	6	5	4	4	3	3	2	1	1	0	0
62-64	6	6	6	5	5	4	4	4	3	3	2	2	1	1	0	0
59-61	5	5	4	4	4	3	3	3	2	2	2	1	1	1	0	0
56-58	4	4	3	3	3	3	2	2	2	2	1	1	1	1	0	0
53-55	3	2	2	2	2	2	2	1	1	1	1	1	1	0	0	0
50-52	2	2	2	1	1	1	1	1	1	1	1	1	1	0	0	0

KEETCH-BYRAM DROUGHT INDEX REVISITED: PRESCRIBED FIRE APPLICATIONS

Mike Melton: District Ranger, Daniel Boone National Forest

In the May, 1988, edition of Fire Management Notes, I wrote an article concerning the Keetch-Byram Drought Index as it related to fire suppression and the resulting problems that could be expected with suppression efforts at different levels of drought as measured by the index. Since that time, I have received many inquiries and comments appreciative of the practical information contained in the article, and it has been used as a training tool in many fire classes.

The drought index levels are calculated as part of the 1988 Revision of the National Fire Danger Rating System. The simplicity of the calculations also lend themselves to being calculated and kept by individuals or field offices that do not have access to NFDRS calculations or are not in proximity to an office which does. All that is needed to calculate the values are a copy of the directions found in the original documentation of the Keetch-Byram Drought Index and a rain gauge. It is then a simple mathematical process to determine the value on a daily basis.

Many people, especially in the Southeastern part of the country, are using the information found in my original article and applying it to prescribed burning. The information contained in the original article is certainly applicable to prescribed fire, however there are some differences that prescribed fire practitioners will find of value to understand. With that in mind, I have decided to expand on the original article and address the Keetch-Byram Index specifically from a prescribed fire perspective. In the following discussion, I have addressed the index and effects on a drought scale difference of 200, which corresponds to the loss of two inches of water from the fuel/soil profile as the drought progresses from one stage to the next.

The seasonal variations in the index generally follow the seasonal temperature pattern. The following discussions will be based on this idea. The index will be low in the winter/spring and increasing into the summer and early fall and then tapering off again into winter. At the conclusion of the article, I will discuss some of the variations found when the index departs from normal, some things to be expected on rising/falling indexes and the days since rain concept.

Keetch-Byram Index 0-200

Much of the understory prescribed fire work is done at this level, especially in the South. This level basically corresponds to the early Spring dormant season conditions following winter rains. Soil moisture levels are high and fuel moistures in the 100 and 1000 HR fuel classes are sufficiently high that these larger fuel classes do not significantly contribute to prescribed fire intensity in most cases.

Fuel moistures in the 1HR and 10HR classes will vary daily with environmental conditions. Prescribed fires should be planned based on the predicted levels of moisture within these two fuel classes in association with the weather conditions on any particular day. Prescribed Fire Planners should be aware that areas with heavy loading of these two fuel classes such as areas that have not received cyclic burns can exhibit intense behavior resulting from the amount of fuel to be consumed. Also, areas that are slope/aspect influenced can give erratic and intense fire behavior from the preheating effects. Southerly aspects can produce intense fire behavior while northern aspects of the same unit may have difficulty carrying the fire.

At this level, nearly all soil organic matter, duff, and the associated lower litter layers are left intact. These layers, even though they may not be soaking wet, will be protected by the insulating properties of the moist layer below and will retain moisture levels close to extinction and resist ignition. Patches of unburned fuel can be expected to give the "mosaic" effect pattern of burned/unburned fuels over the burn unit, often a preferred result. The typical situation on burns implemented in this stage are a relatively fast head/strip head fire or a backing fire that consumes the upper litter layers. Once the fire passes, remaining embers extinguish quickly and within a few minutes the area is completely extinguished and smoke free. Mop up efforts required on most burns are at a minimum level.

Examples of burns that can be successfully implemented at this stage are fuel reduction, range improvement, wildlife habitat, or any burn that does not require a deep burning, organic/duff reduction type fire.

Smoke management concerns are primarily centered around the smoke generated during the burn and not from large smoldering materials following the completion of the burn.

Natural features such as creeks and drainages can be used as control lines. Most agencies/companies will use mechanized equipment to construct lines, but adequate lines can be constructed with hand tools. "Wet lines" can also be used in some fuel types.

A word of caution is needed at this point. This part of the index represents the "wettest" part of the scale. However, this should not be taken as an indicator of fuel moisture (1HR and 10HR) in the upper layers of the fuel complex. These fuel moisture levels are almost totally dependent on fluctuations in daily weather variables. Dry air masses or frontal passages that pass over an area may have an insignificant effect on the drought index but can lower fuel moisture to critically low levels. It is the responsibility of every Prescribed Fire Planner to make sure acceptable fuel moisture measurements are accounted for prior to ignition, regardless of the drought index levels.

Keetch-Byram Index 200-400

In normal years, this level would represent conditions found in a late spring and early growing season situation. Rising temperatures, increased levels of transpiration within the plants, and normal water movement within the soil all contribute to a reduction of moisture within the soil/fuel profile.

Lower litter layers and duff now begin to show signs of water loss and will begin to contribute to fire intensity. Humidity recovery at night will have some positive effect on moisture recovery in the fuel profile, but this will be quickly overcome by daily temperature and humidity variations under normal burning conditions.

Fire practitioners should expect an increase in fuel consumption over the area as the index moves into the upper end of this range. The increase in fuel consumption, and resulting intensity can result in heavier fuel classes becoming involved in the burn. Heavier dead fuels such as downed logs and snags will now become a part of the major players in the burn process. Fire planners should also expect that some of the live fuels such as low level brush species, and vines such as honeysuckle, may now receive sufficient heat to burn actively and contribute to control problems if they are close to fire lines.

Patches of unburned vegetation are still common, but these conditions tend to allow for more smoldering/creeping fires that may eventually consume most surface fuels. Fire Planners wanting to initiate a burn over a forested area with the purpose of "blacking it out" should consider this range on the index as conducive for that purpose. Sufficiently intense fires can be generated with most forest fuel types to carry across the area. These conditions also allow for an increase, although not complete, consumption of the lower litter layers and duff which tend to insure the fire carries across the unit.

Under normal conditions, the majority of the duff and organic layer will still be intact following the burn. Soil exposure will be minimal. Smoke management can become a real hazard especially if there is a significant amount of the larger fuel classes available for ignition. Downed logs, stumps and similar material should be expected to ignite and smoulder for a considerable period of time. Expect smoldering and the resulting smoke to carry into and possibly through the night. Smoke sensitive areas should be thoroughly screened and mitigation measures should be implemented when necessary.

Hand lines constructed to hold the fire should be to mineral soil. Natural features used for control lines should be thoroughly checked for drifted debris that could allow fire to creep across. Mechanical lines will need to be patrolled and cleared of any materials left following construction that could ignite. Fire Planners should seriously reconsider line standards under conditions in the upper levels of this range.

Keetch-Byram Index 400-600

These levels are typical of those encountered during the Summer and early Fall conditions.

This level represents the upper range at which most normal understory type burning should be implemented. Very intense fires can be generated with burns ignited in this range of conditions.

Under these levels, most of the duff and associated organic layers will be sufficiently dry to ignite and contribute to the fire intensity and will actively burn. The intensity can be expected to increase at an almost exponential rate from the lower to the upper ends of this range.

Fire Planners should expect a considerable amount of soil to be left exposed following a burn. Much of the site preparation burning done across the southern United States occurs under this set of conditions. Intensity of burns under these conditions are such that most all fuel classes occurring on a unit will ignite and burn. Complete consumption of all but the largest dead fuels can be expected. Larger fuels not consumed may smolder for several days creating smoke and potential control problems.

Expect weathered stumps, downed logs and most snags to be completely consumed over a period of time (possibly several days) within the burn. A significant portion of the duff and organic layer will be consumed resulting in large areas of exposed mineral soil. These areas may be susceptible to sheet erosion with the next heavy rain. This potential varies with soil types.

Smoke management relating to sensitive areas is of critical importance due to the length of time smoke should be expected to result from the burn area. Under normal circumstances, Fire Planners should have a specific resource management objective that requires an intense fire before igniting understory fires in this range. The intense fire and deep burning that often result from these conditions can do serious damage to timber resources, and present an opportunity for insect pests to create additional problems.

Control problems resulting from spotting should be expected.

This point in the index indicates two things are happening. First, deep drying resulting from water loss is occurring in the duff and organic material in the soil. Second, lower live fuel moistures resulting from continued water loss in the soil and the natural physiological process within the plants make understory vegetation susceptible to ignition with a minimum of pre-heating. These two situations amount to an increase in the fuel available for consumption and consequently increase the fire's intensity. Fire planners should consider the outputs from computer programs and nomograms relating to intensities to be under predicted and plan accordingly.

At this level, Fire Planners should seriously begin to reevaluate the line construction and location standards necessary to contain the burn. Reduced runoff levels in some drainages can preclude their use as control lines, or require that they receive some refurbishment treatments. Failure to recognize this can create potential control problems resulting from fires that may now creep across leaf piles, etc. that have drifted in creek channels. This situation will continue to escalate as the index levels increase.

Where practical, use either major natural features or roads that are suitably located. All line construction should be to mineral soil. Removal of duff and organic material from within constructed lines is imperative since this material can provide an avenue for fire to burn across the line. Where practical, consider line locations that should otherwise be used for fire suppression. This can give an added "edge" in maintaining the security of the lines under intense conditions.

Keetch-Byram Index 600-800

This range of the index would represent the most severe drought conditions identified within the index and would result from an extended period of little or no precipitation and high daytime temperatures.

There may be cases when specific management objectives for a given area justify prescribed fire ignitions within this range. These cases, for the most part, will be the exception rather than the rule. Management should consider the mid to upper 600 range the limits of acceptability for igniting prescribed fires of any type unless specific locality conditions dictate otherwise. These levels of the index are often associated with increased wildfire occurrence and many states and municipalities will issue burning bans in response to this situation. These actions should preclude any management decision regarding prescribed fire. Such bans are an acknowledgement of the seriousness of the fire situation.

Prescribed fires ignited within this range will be characterized by intense, deep burning fires. The potential for significant downwind spotting should be considered the rule in planning. Live understory vegetation 2-3 inches in diameter at ground level should be considered part of the fuel complex. Live fuel moistures will be sufficiently low within this vegetation and it will burn easily with a minimum of preheating. The majority of soil organic material subject to ignition will be consumed. Expect stump roots and other subsurface organic material that ignite to be completely consumed. Large fuel classes will burn intensely with almost total consumption once ignited. Expect these fires to be very difficult to contain and control.

It will take an extended period of time (possibly a year or more) for a layer of organic material to be replaced on the area. Resource managers should expect some amount of soil loss from erosion until the area replaces sufficient vegetative cover. The significance of the loss will be determined by the specific soil type and slopes on the area.

Line construction standards should follow the previous discussion standards.

Rising and Falling Indexes

This discussion primarily addresses the effects on the larger dead component of fuel associated with a given fuel model and has its basis in the time lag concept associated with 100, 1000, and 10,000 hour fuel classes.

Indexes that have been low and begin the normal seasonal rise are characterized by the larger fuel classes being damp inside. It is typical for a large piece of woody material to be saturated in the interior and therefore difficult to ignite and sustain combustion. As time progresses the exterior dries but interior fuel moistures still remain high. This situation is sometimes characterized by smoldering logs that have ignited by fire intensities high enough to overcome the surface moisture levels but which later go out due to the high interior moisture levels precluding further combustion.

When this situation occurs, there may be some concern for smoke from the smoldering debris and mop up may be a consideration, but dealing with this situation is relatively easy. Humidity recovery at night can be a major factor in extinguishing this type ignition.

The very opposite situation can be expected on a falling index.

The larger fuel classes have experienced deep drying from a sustained period of little or no precipitation. The exterior surface may have a relatively high fuel moisture level from a recent precipitation event while the interior of the fuel will have lower moistures due to the longer equilibrium time lag. Prescribed fire ignited under these conditions may develop sufficient intensities to break through this outer layer of high fuel moisture. Once this happens, the fire encounters a reservoir of material with comparatively low fuel moisture levels and can be expected to burn for an extended period of time. This could go on for several days within the area and result in a large amount of smoldering material and resulting smoke management problems, depending on the type and amount of fuels on the area. Experience has shown that this material will continue to smolder until it is consumed, mopped up or another precipitation event raises moistures to a level of extinction. The resulting smoke problems can be compounded by fluctuations in wind direction over several days. Mop up operations can be lengthy and expensive.

This situation should be expected for indexes that have been in the 600+ range and have rapidly fallen into the 200-300 range. This could have resulted from one precipitation event, and while the 1 hour and 10 hour classes of fuel are immediately affected, the other fuel classes are slower to react. This is just an example of one of the subtleties noted from actual field experience in dealing with the index values.

Days Since Rain

Finer fuel classes are immediately affected by precipitation of any type, and since fires originate and spread within these classes, we can use this characteristic to accomplish prescribed fire objectives during what might normally be unacceptable drought conditions.

During the first few days following a precipitation event, the surface fuels sill have been saturated and begun to dry out. The lower fuel layers and possibly even the organic layer may still have moisture of extinction levels present. Resource objectives can be accomplished by timing the burn to occur during this time period even though the drought index levels may still be high.

Timing of this situation may be critical and Prescribed Fire Planners should be fully aware of the conditions they are dealing with. Most burns should be accomplished during the first two/three days following a precipitation event. After about four days of continuous drying the effects of the precipitation event will have disappeared from a prescribed fire standpoint.

Prescribed fire personnel should be especially careful in monitoring the amount of precipitation that has occurred. Once fuels have experienced deep drying, it takes a significant rainfall event to dampen conditions to the point where they are reasonably safe for burning. Precipitation amounts in the one half inch range should be considered minimal in most cases.

This situation could be characterized by the type conditions and burning done in the summer growing season throughout much of the southeast. These burns can be accomplished by careful planning and following this general guidance.

Index Readings that Depart from Seasonal Norms

Fluctuations in weather patterns, and variations in temperatures and precipitation levels can all coincide to create a departure from the normal yearly index pattern. An abnormally dry Fall and Winter season could lead into an early Spring season with drought index readings in the 500-600 range. The most recent case of this happening on a broad scale was in 1987 in the southern United States. This situation resulted in a significant drought situation across the southeast. This part of the country experienced a severe Fall fire season and carried Keetch-Byram index readings of 600 into the early months of January and February when the normal reading would be expected less than 100. Since that time other localized drought events have occurred with similar results.

Prescribed Fire Planners must recognize departures from normal readings in planning burns for their particular location. A burn conducted under index levels of 100 in the spring time is not the same as a burn conducted under levels of 500 at the same time. Extreme caution should be used in implementing any burn under this set of conditions. These type conditions should be recognized as those primed for a potential escape situation.

Closing Thoughts

Through the previous discussion I have attempted to qualify and quantify the effects of the Keech-Byram Drought Index as it relates to the application of prescribed fire. The variables within this application are many and their interaction complex. Prescribed fire personnel should always remember that the Keetch-Byram Index is a measure of meteorological drought and reflects water gain of loss within the soil. It does not measure fuel moisture. Prescribed fire application is almost totally dependent on the moisture levels in the 1HR and 10HR fuel classes which must be measured by other means for an accurate assessment of fuel moisture regardless of the drought index readings.

The other situation that needs reinforcing is the additional fuel that becomes available for consumption in the higher levels of the index resulting from the deep drying and reduced soil moisture available for take-up by vegetation. This increased availability of previously "unavailable" fuel may drastically change the fuel complex. This condition is not accounted for in current computer technology such as BEHAVE. Prescribed Fire Planners must be aware of this situation when dealing with the prescribed fire in the mid and upper ranges of the index.

The drought index levels discussed here and the resulting effects on prescribed fires should not be considered hard and fast rules but rather a reflection of my career experiences in dealing with both wild and prescribed fires and the levels of the Keetch- Byram Index. The reader is invited to develop their own guides and apply this information to their particular situation. Variations in fuel types, topography/aspect, geographic location, moisture/temperature regimes and soils types may dictate a variety of effects within the levels of the Keetch-Byram Index. After all, that is why we describe the implementation of prescribed fire as an art, rather than a process.

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sample	sample	sample	June	1966
Agency	District	Station	Month	Year

Day of the Month	24-Hour Rainfall (measured amount)	Net Rainfall (adjusted amount-- see instructions)	Air Temperature [X] maximum temp. [ ] dry-bulb temp.	Drought Index yesterday, or as reduced by net rainfall (col. 3)	Drought Factor From Table [4]	Drought Index For Today col. 5 plus col. 6	Current Stage of Drought
1	2	3	4	5	6	7	8
1		0	79	164	10	174	1
2		0	75	174	8	182	1
3	0.66	.46	70	136	6	142	1
4	T	0	76	142	9	151	1
5	0.23	.03	79	148	11	159	1
6		0	84	159	14	173	1
7	0.16	0	65	173	4	177	1
8	0.09	.05	66	172	4	176	1
9		0	83	176	14	190	1
10		0	70	190	6	196	1
11	0.08	0	67	196	4	200	2
12	0.03	0	65	200	4	204	2
13		0	76	204	8	212	2
14	0.22	.02	69	210	5	215	2
15		0	65	215	4	219	2
16	0.21	.01	75	218	8	226	2
17		0	78	226	9	235	2
18		0	85	236	13	248	2
19		0	88	248	15	263	2
20	0.01	0	79	263	8	271	2
21		0	69	271	5	276	2
22		0	75	276	7	283	2
23		0	84	283	12	295	2
24		0	89	295	16	311	3
25		0	93	311	17	328	3
26		0	92	328	17	345	3
27		0	96	345	20	365	3
28		0	91	365	13	378	3
29	0.25	.05	78	373	7	380	3
30	0.16	.16	83	364	10	374	3
31							

FIRES

Fire Information Retrieval and Evaluation System (FIRES) provides methods for evaluating the performance of fire danger rating indexes. The relationship between fire danger indexes and historical fire occurrence and size is examined through logistic regression and percentiles. Historical seasonal trends of fire danger and fire occurrence can be plotted and compared. Methods for defining critical levels of fire danger are provided.

- Brief information
- Detailed information
- FIRES: Fire Information Retrieval and Evaluation System - a program for fire danger rating analysis
- Download supporting files

U.S. Fish & Wildlife Service

Fuel and Fire Effects Monitoring Guide

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