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 management program. Information in the Guide is designed to facilitate 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."

[Water](#)

[Soil](#)

[Air Quality](#)

[Fire Effects Predictors](#)

CREDITS

REFERENCES

NWCG Fire Effects Guide

NPS Fire Monitoring Handbook

FIREMON

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

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 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.

U.S. Fish & Wildlife Service

Fuel and Fire Effects Monitoring Guide

Fire Works!

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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

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

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procedures).

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 consistently 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.

Fire Works!

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Reporting Results

MONITORING ATTRIBUTES

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Plant Mortality
Frequency
Cover
Density
Production
Structure
Composition

Wildlife Populations
Direct Mortality
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?

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

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most efficient for some situations. Nevertheless, the procedures are 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.

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
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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

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establishment. Seedlings present one year may not be persistent the following year. This situation is problematic if data is collected only 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**

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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.

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2. **Advantages and Limitations**

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**

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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

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related to environmental conditions and can often be interpreted erroneously as 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**

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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

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ground. In addition, the animal portion of biomass is rarely obtainable.

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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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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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**

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  - Dissolved oxygen
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- Burn Severity
- Soil moisture
- Soil pH

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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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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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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:

$$fpc = (1 - n/\mathrm{N})$$

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.

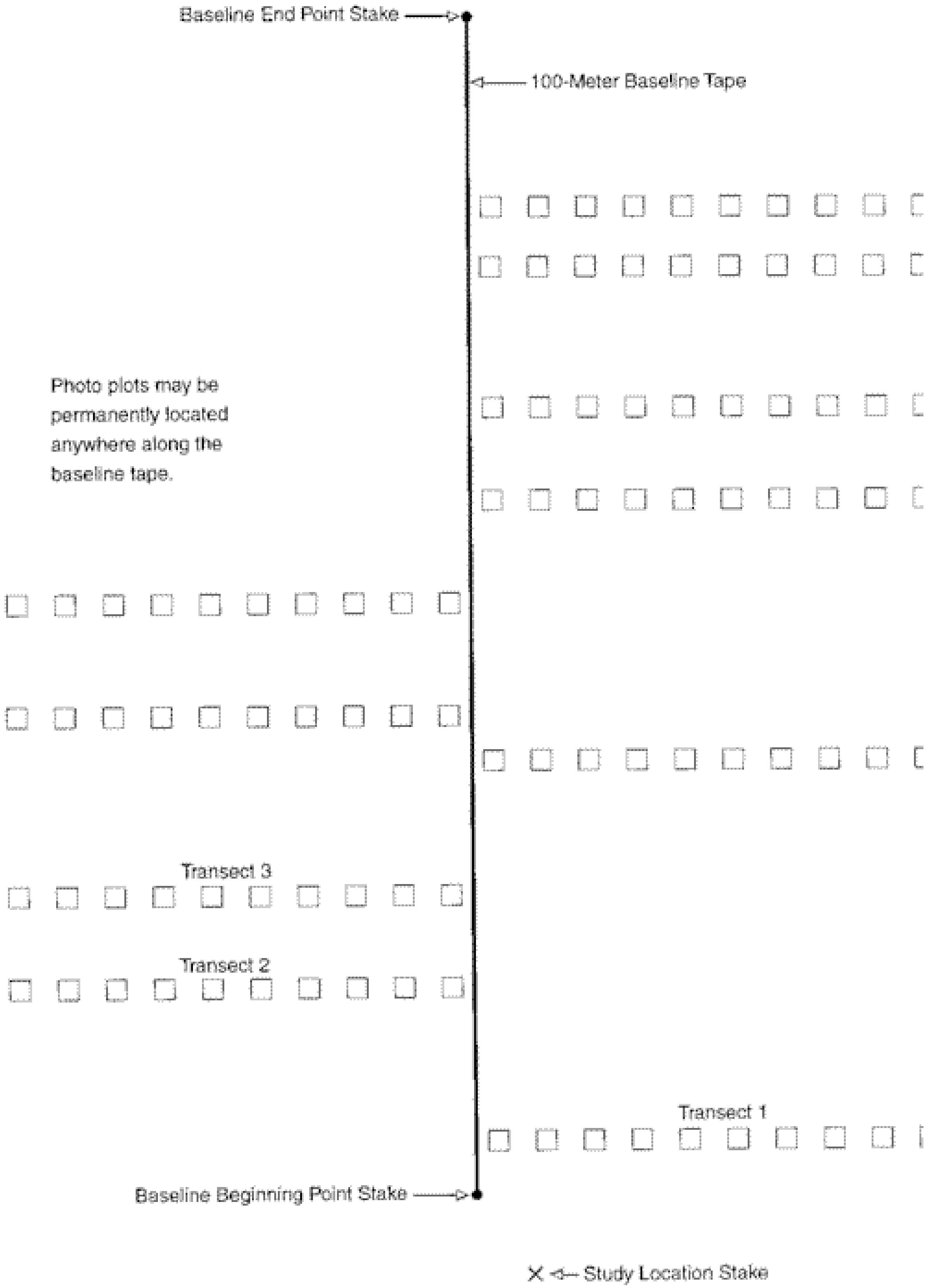
Statistical tests are used in step 7 to evaluate with a predetermined level of statistical confidence whether objectives were met. This level might not have to be as high (say, 95 or 99 percent) as would be expected for research, but the price for a lower level is an increased chance for a type I error (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.

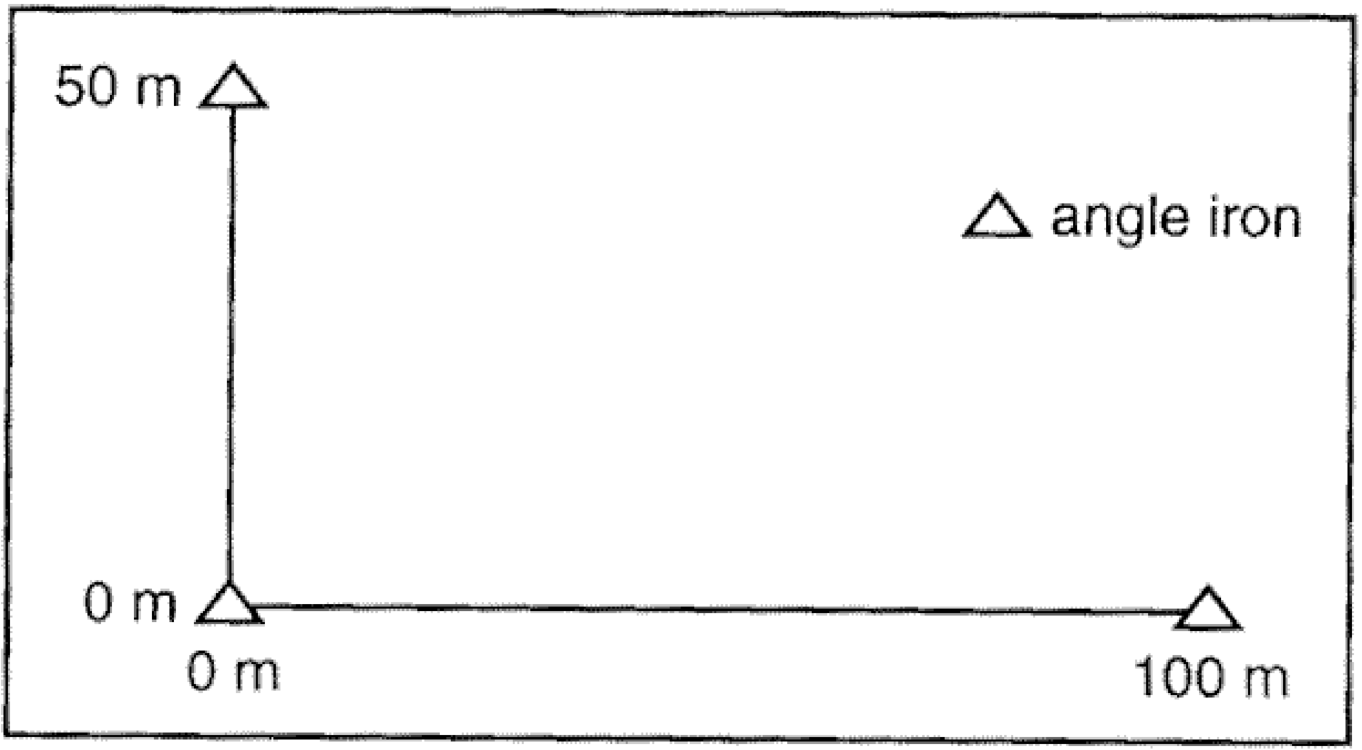
Common errors to avoid when using statistical tests include inaccurate data entry, errors in rounding numbers, use of incorrect degrees of freedom, and incorrectly reading statistical table (such as tables of t and F values).

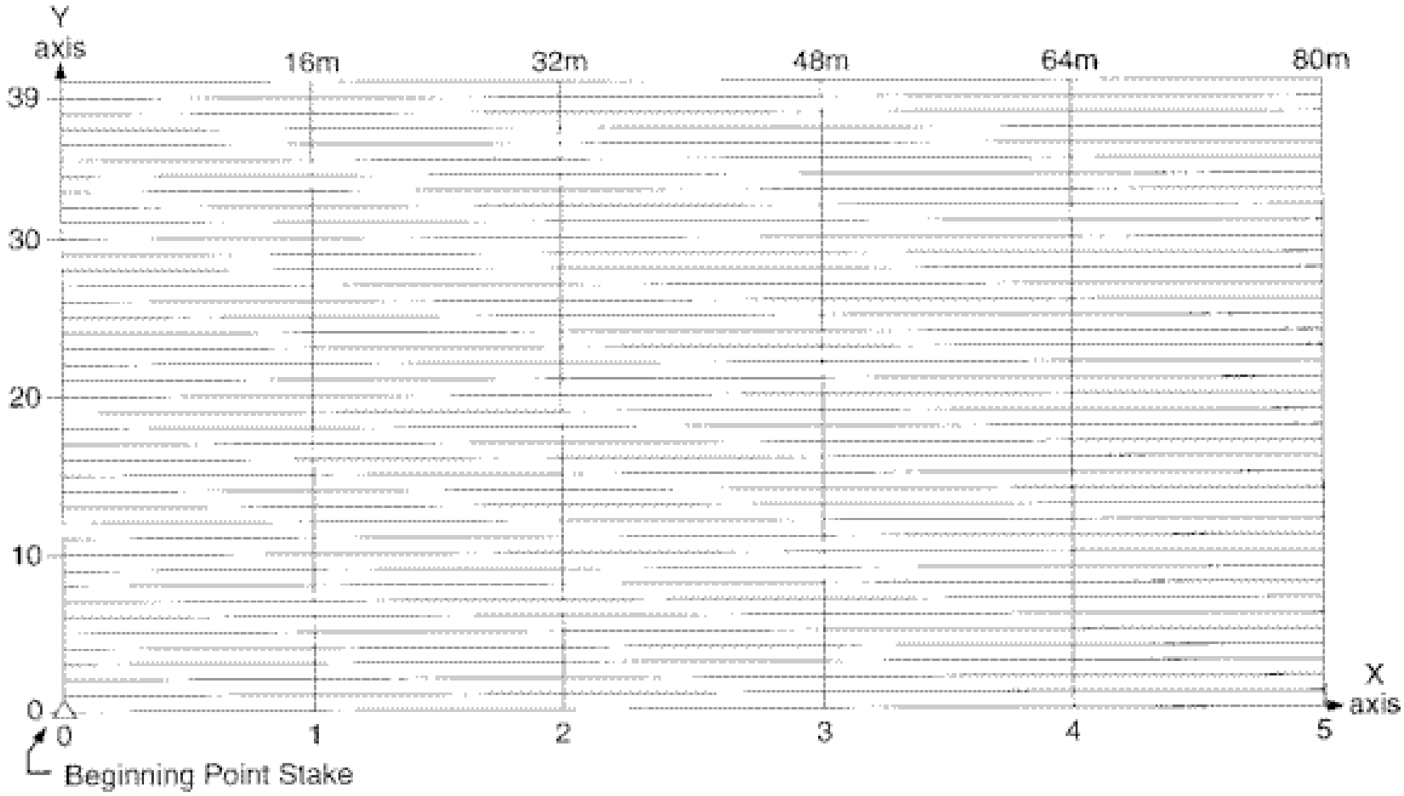
Based on results of hypothesis testing, it is possible to conclude with a stipulated level of statistical confidence whether objectives are met. If they are not met, there are two options: modify objectives and repeat the process until they are eventually met, or modify management and repeat the process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

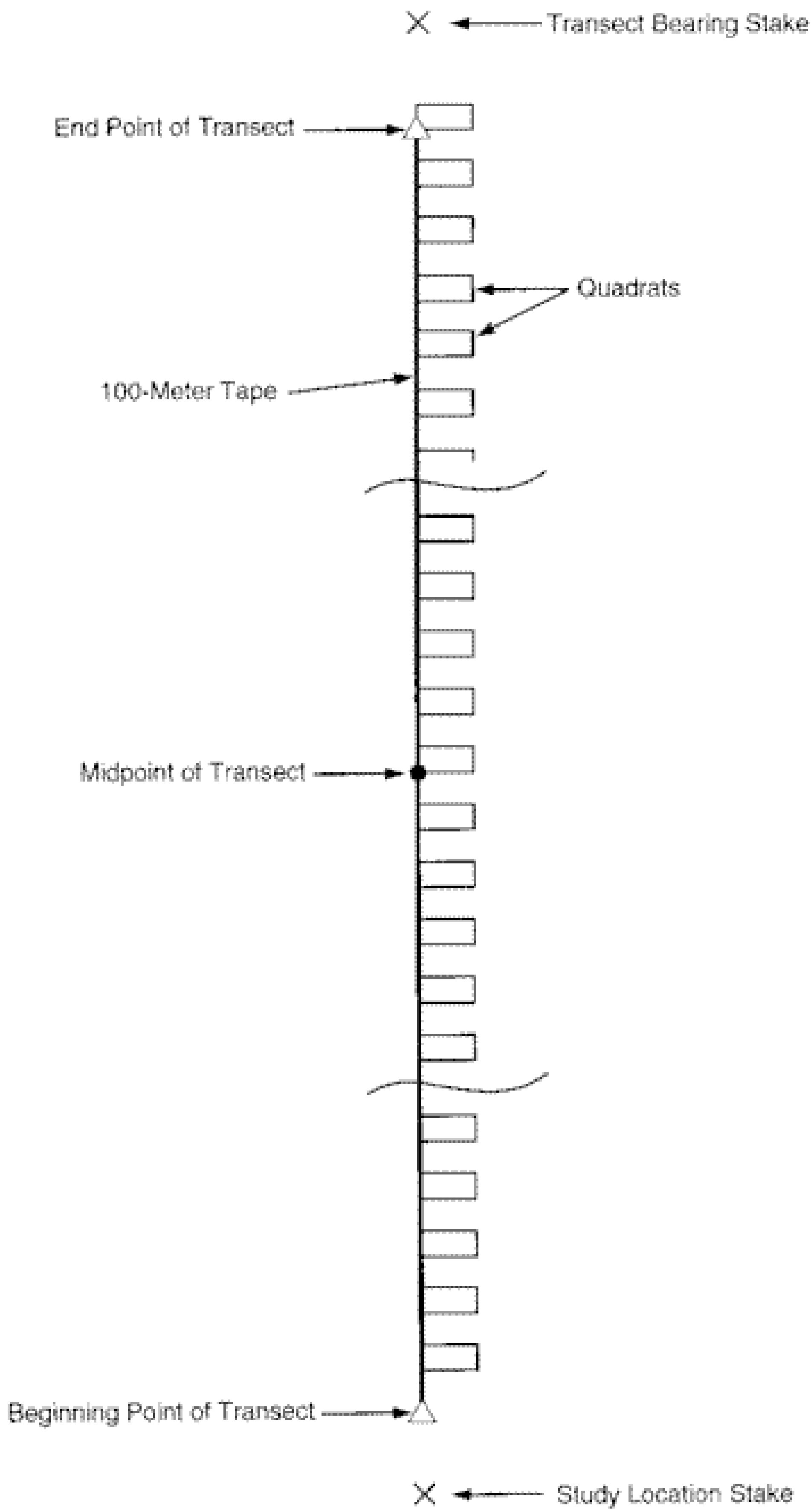
Study Layout




50 m
angle iron
0 m
0 m
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

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.

MANAGEMENT OBJECTIVES

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.

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:

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

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:

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

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:

$n' = n^* / (1+(n^*/N))$ 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 ± I0% 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:

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

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.

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

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 I0% 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:

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

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

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
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14	22	64	79	114	134	14	22	64	80	114	134	14	23	64	80	114	135	14	24	64	82	114	136
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16	24	66	82	116	136	16	25	66	82	116	136	16	25	66	83	116	137	16	26	66	84	116	139
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37	49	87	105	137	159	37	49	87	105	137	159	37	50	87	105	137	160	37	51	87	107	137	161

38	50	88	106	138	160	38	50	88	106	138	161	38	51	88	106	138	161	38	52	88	108	138	163
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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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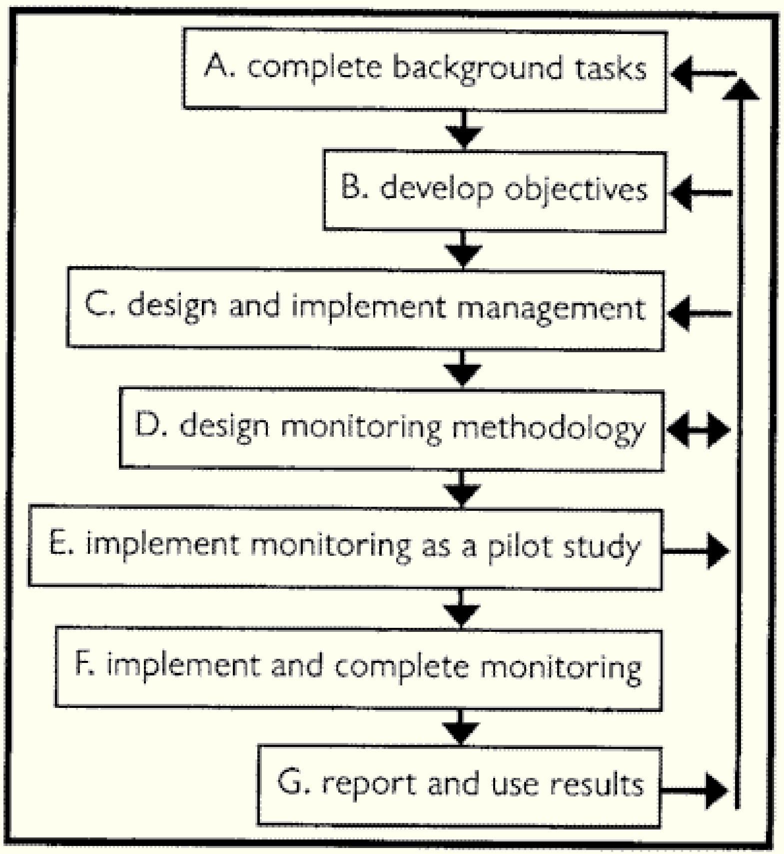
48	61	98	117	148	171	48	62	98	117	148	171	48	62	98	118	148	172	48	64	98	119	148	173
49	62	99	118	149	172	49	63	99	118	149	172	49	63	99	119	149	173	49	65	99	120	149	174
50	64	100	119	150	173	50	64	100	119	150	173	50	65	100	120	150	174	50	66	100	121	150	175

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.

- Complete Background Tasks
- Develop Objectives
- Design and Implement Management
- Design the Monitoring Methodology
- Implement Monitoring as a Pilot Study
- Implement Monitoring
- Report and Use Results



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.

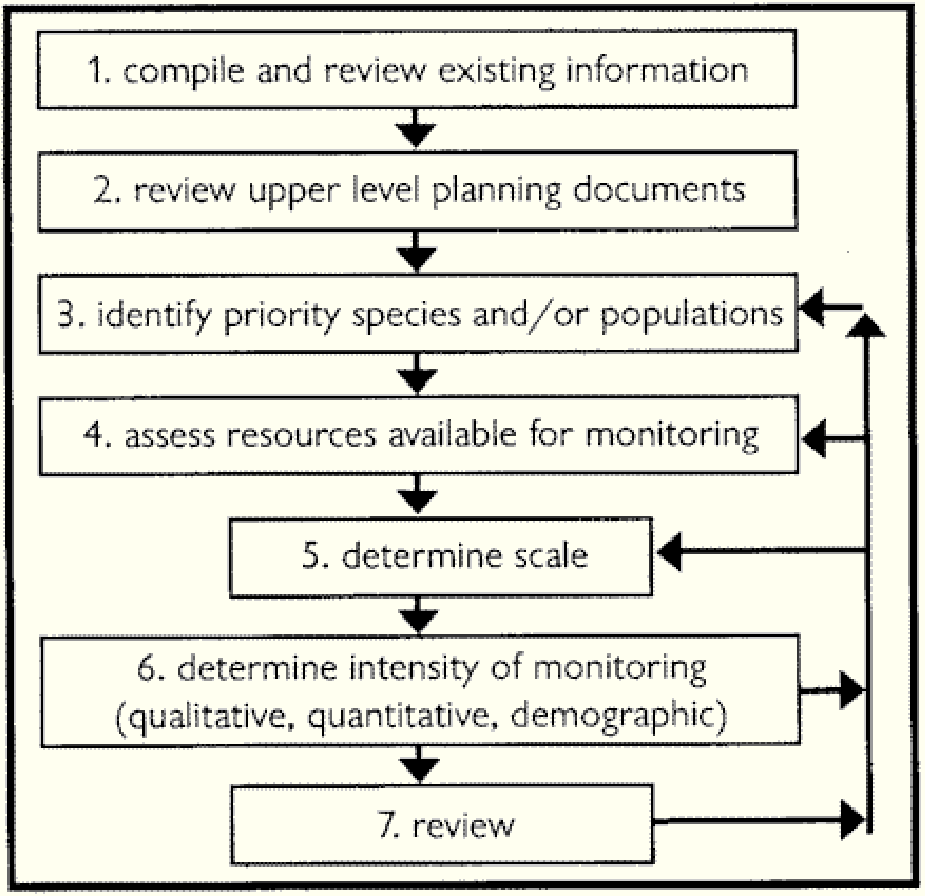
3. Identify priority resources Prioritize the resources for monitoring, and document your thought process. This documentation will be useful to you and your successor if managers and other parties question your priorities. For priority resources select priority targets. These priorities may periodically 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.

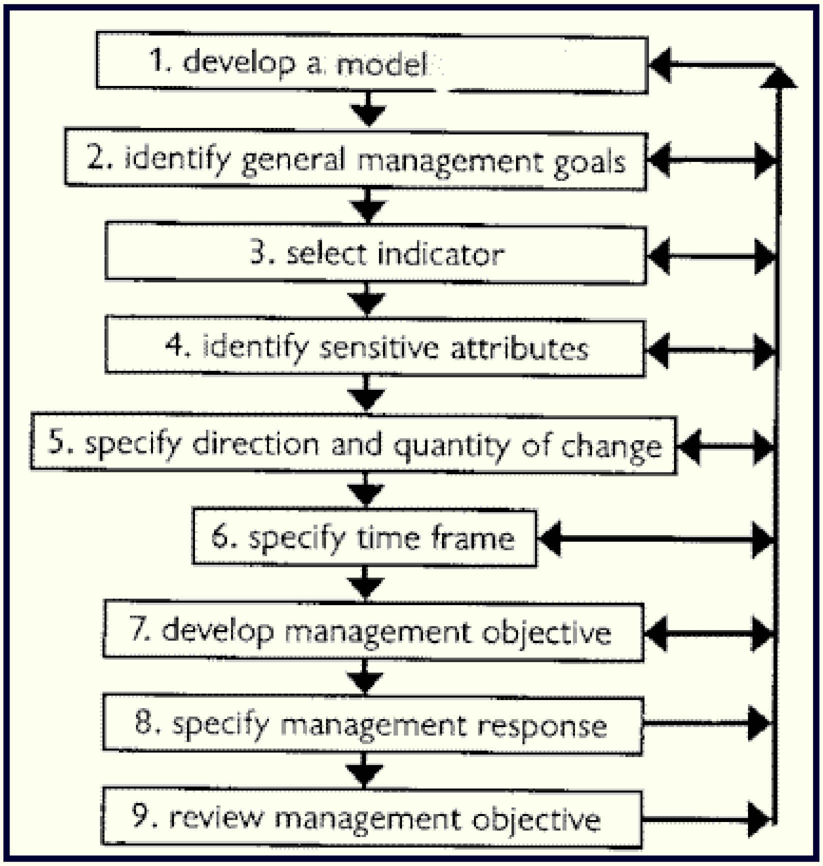
5. Specify direction and quantity of change Will you monitor for a percentage change or an absolute change, a target or threshold value? What increase do you want to see, or what decrease will you tolerate? Can you specify a target population size? The quantity has to be measurable (confidently measuring 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.

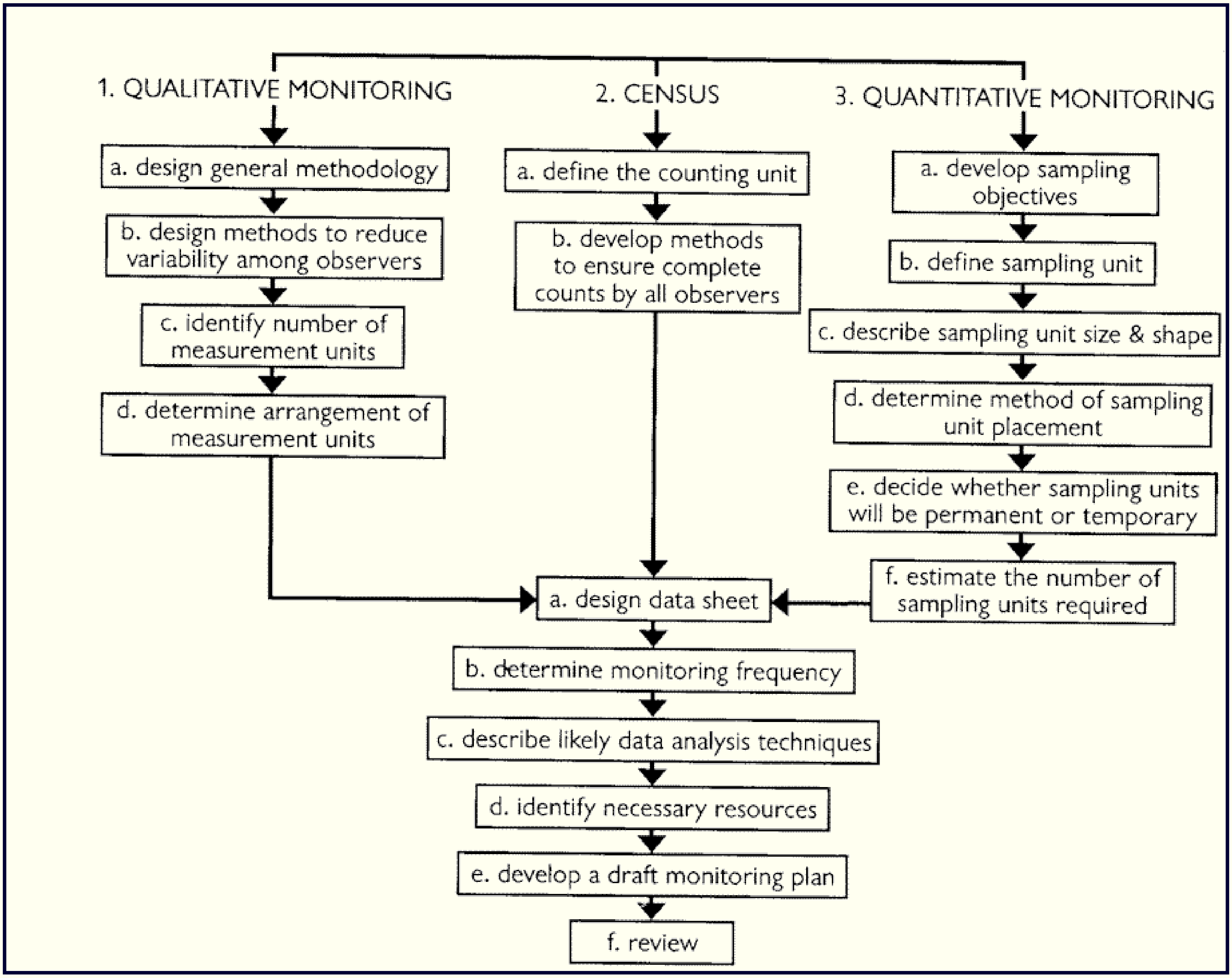
B. **Determine monitoring frequency** How often should the parameter be measured? Will you be monitoring annually? Every 3 years? The frequency varies with the the expected rate of change (long-lived plants may require infrequent measurement), the rarity and trend of the resource (the risk of loss for 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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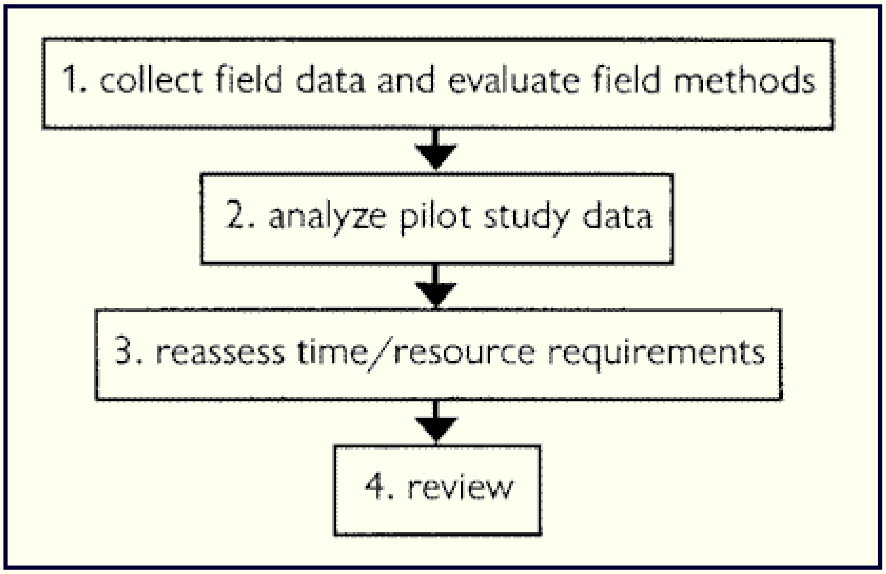
1. Collect field data and evaluate field methods The first trial of a monitoring method in the field often exposes problems with the methodology (e.g., plots cannot be positioned due to dense vegetation; the proposed counting unit cannot be applied consistently; lacy vegetation proves a problem for measuring 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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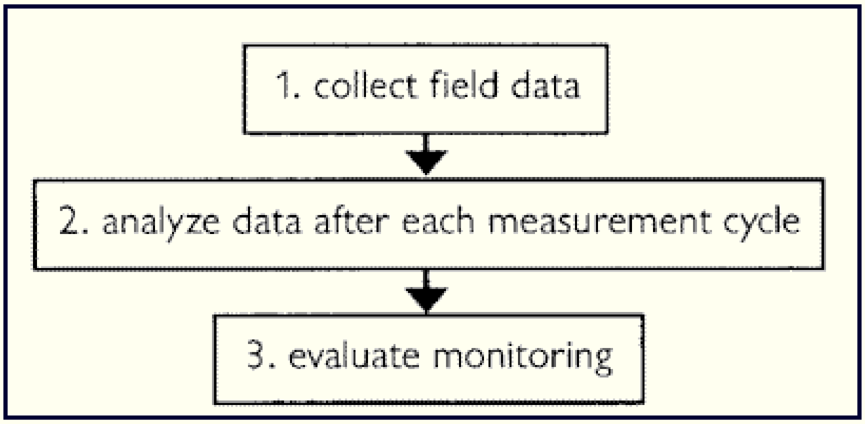
1. Collect field data Complete data collection at specified intervals. Ensure data sheets are completely filled out, duplicated, and stored in a safe place.

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.

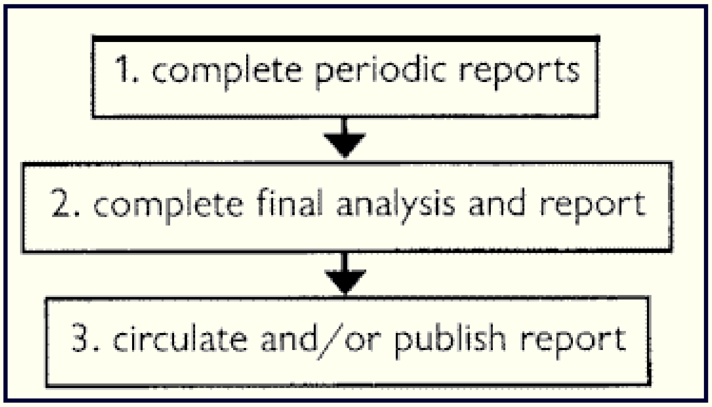


REPORT AND USE OF RESULTS

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.



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.

STANDING TREES
Weight-height Relationship

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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.

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

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

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.

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

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

HERBACEOUS VEGETATION AND LITTER
Relative Weight Estimate

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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 ($Êd^2$) [Ê = summation] for all pieces in the sampled area. Compute $Êd^2$ separately for sound and rotten categories. To obtain weights or volume for certain diameter ranges (3 to 9 inches, for example), compute $Êd^2$ 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 * Êd^2 * s * c) / Nl

where:
n = number of intersections
d^2 = squared diameters
Êd^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.

PLANT INJURY

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.

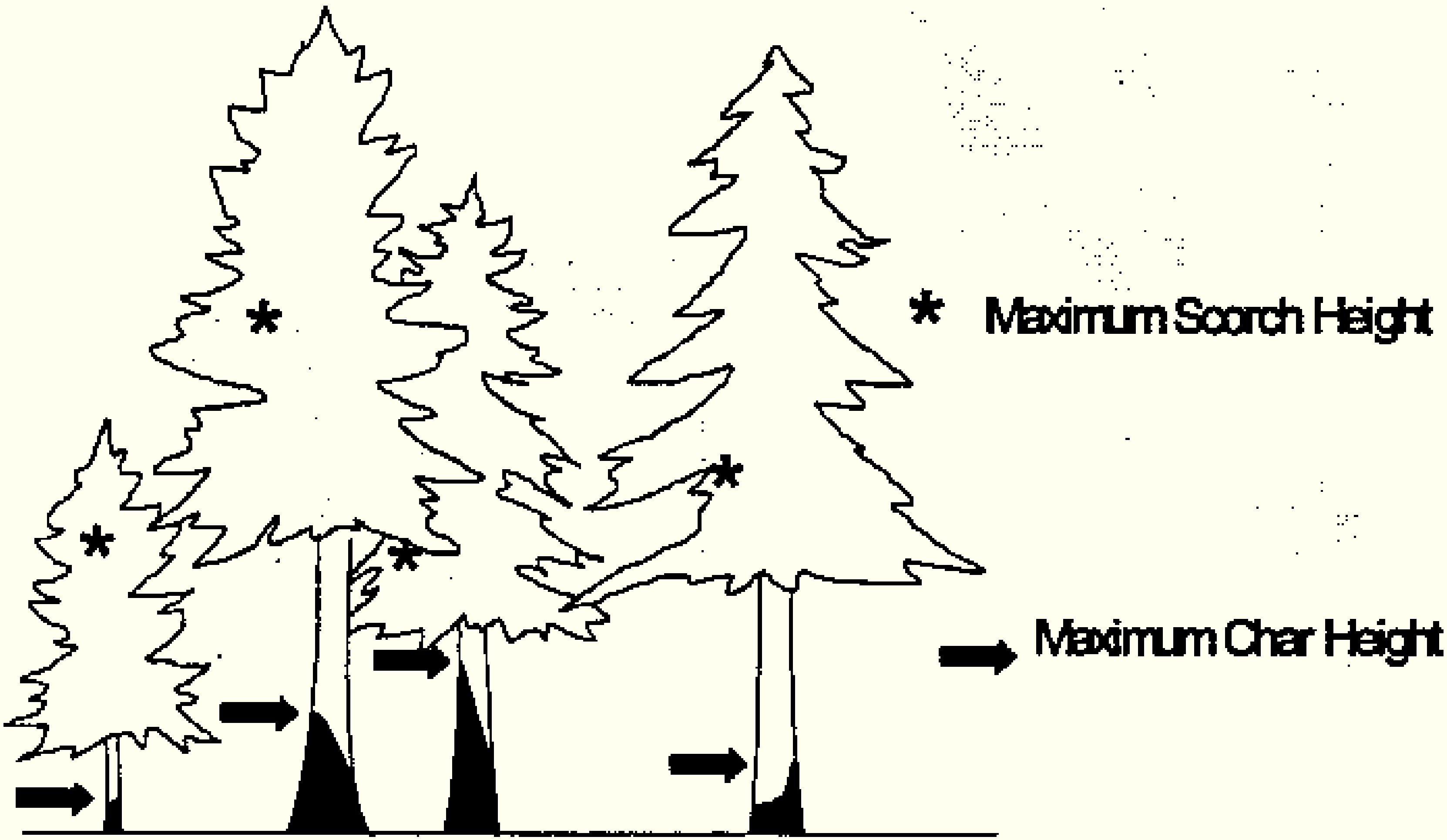
Maximum scorch height is measured from ground level to the highest point in the crown where foliar death is evident. Some trees will show no signs of scorch, but the surrounding fuels and vegetation will have obviously burned. In this case, you can estimate scorch height by examining adjacent vegetation. 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

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.

DRY WEIGHT RANK METHOD

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.

DAUBENMIRE METHOD

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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.

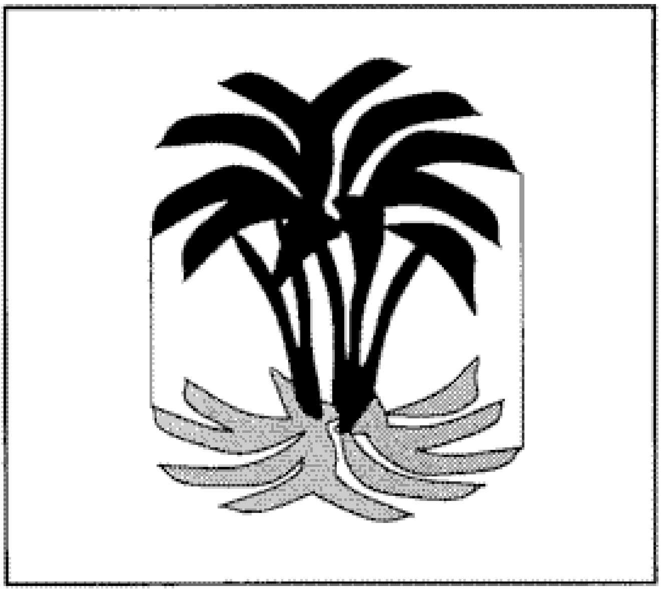
(5) Record the percent cover by species on the form.

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.

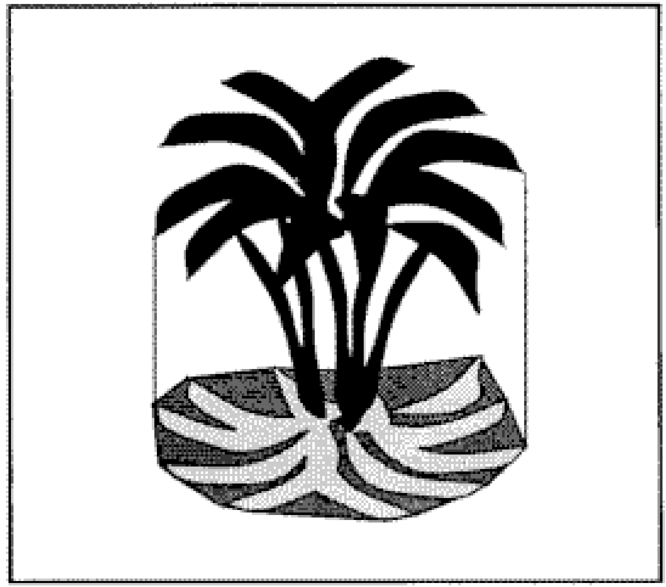
C. **Species Composition** With this method, species composition is based on canopy cover of the various species. It is determined by dividing the percent canopy cover of each plant species by the total canopy cover of all plant species. Record the percent composition on the form.

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.

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.

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.

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).

POINT INTERCEPT-SPHERICAL DENSIOMETER

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:

$$C_x = N_x/\hat{E}n\ (100)$$

where
C_x = cover of X (%)
N_x = number of dots intercepting X
$\hat{E}n$ = 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.

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.

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).

BITTERLICH METHOD

VARIABLE PLOT SAMPLING, PRISM CRUISING, OR THE SHRUB ANGLE GAUGE

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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.

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.

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.

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.

HARVEST METHOD

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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.

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.

VISUAL OBSTRUCTION METHOD
Robel Pole

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.

WATER TEMPERATURE

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: KCI, 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

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)

<u>Glassware or plastic ware</u>

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)

<u>Chemicals</u> (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.

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 18ºC 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 KCI 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 KCI 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.

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.

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.

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.

Fire Works!

HOME

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

[Water](#)

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[Fire Effects Predictors](#)

[CREDITS](#)

systematic methods of estimating the progress of drought has been 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

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. FIRES is a module of FireFamily Plus.

- FIRES: Fire Information Retrieval and Evaluation System - a program for fire danger rating analysis
- FireFamily Plus

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.

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.

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.

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

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.

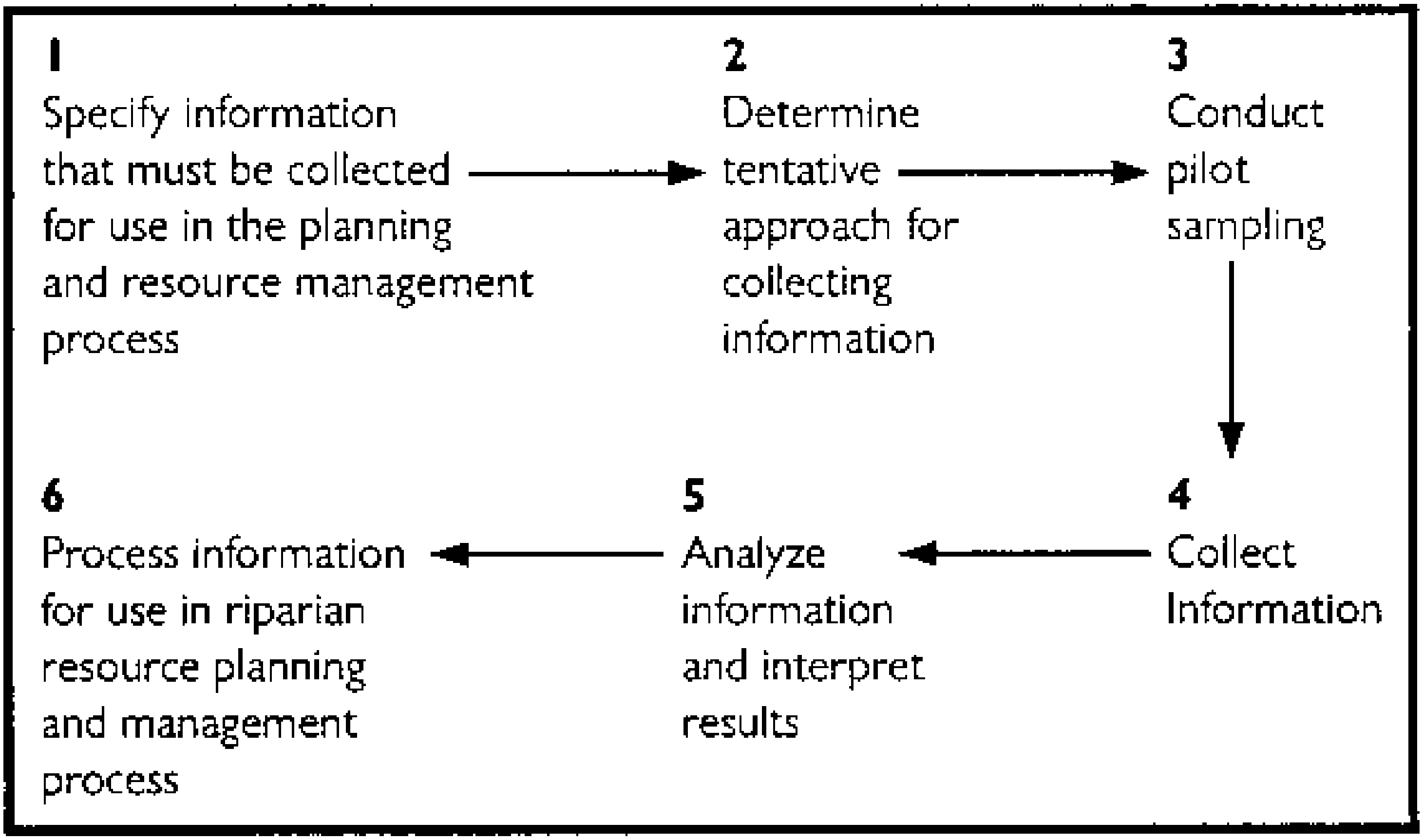
ACCURACY, BIAS, AND PRECISION

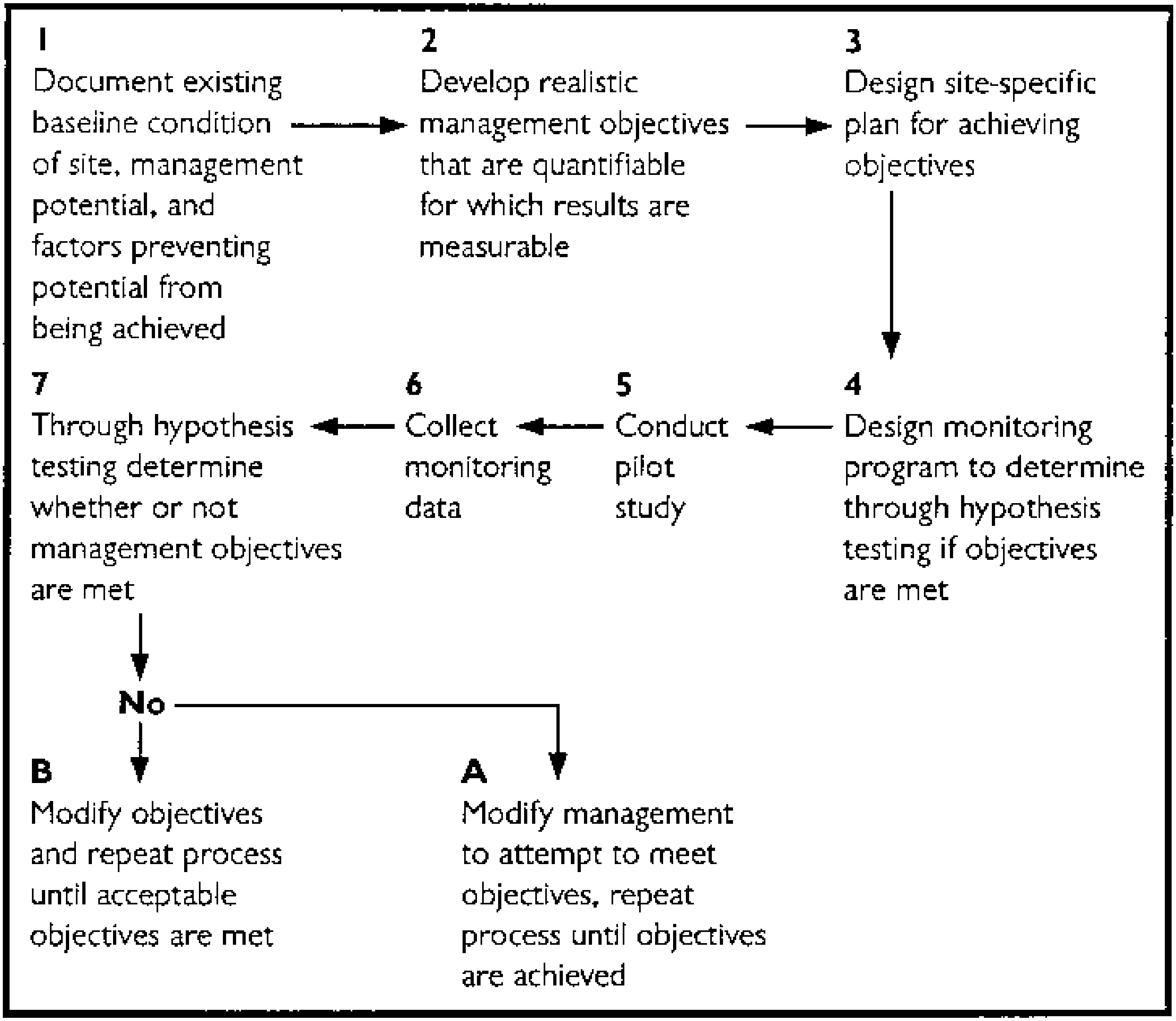
Criteria by which estimators are judged are accuracy, bias, and precision. Accuracy is defined as "exact conformity to truth," or "freedom from error." It is virtually impossible to determine accuracy because the true value being estimated with sampling and measurement methods is rarely known; thus,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

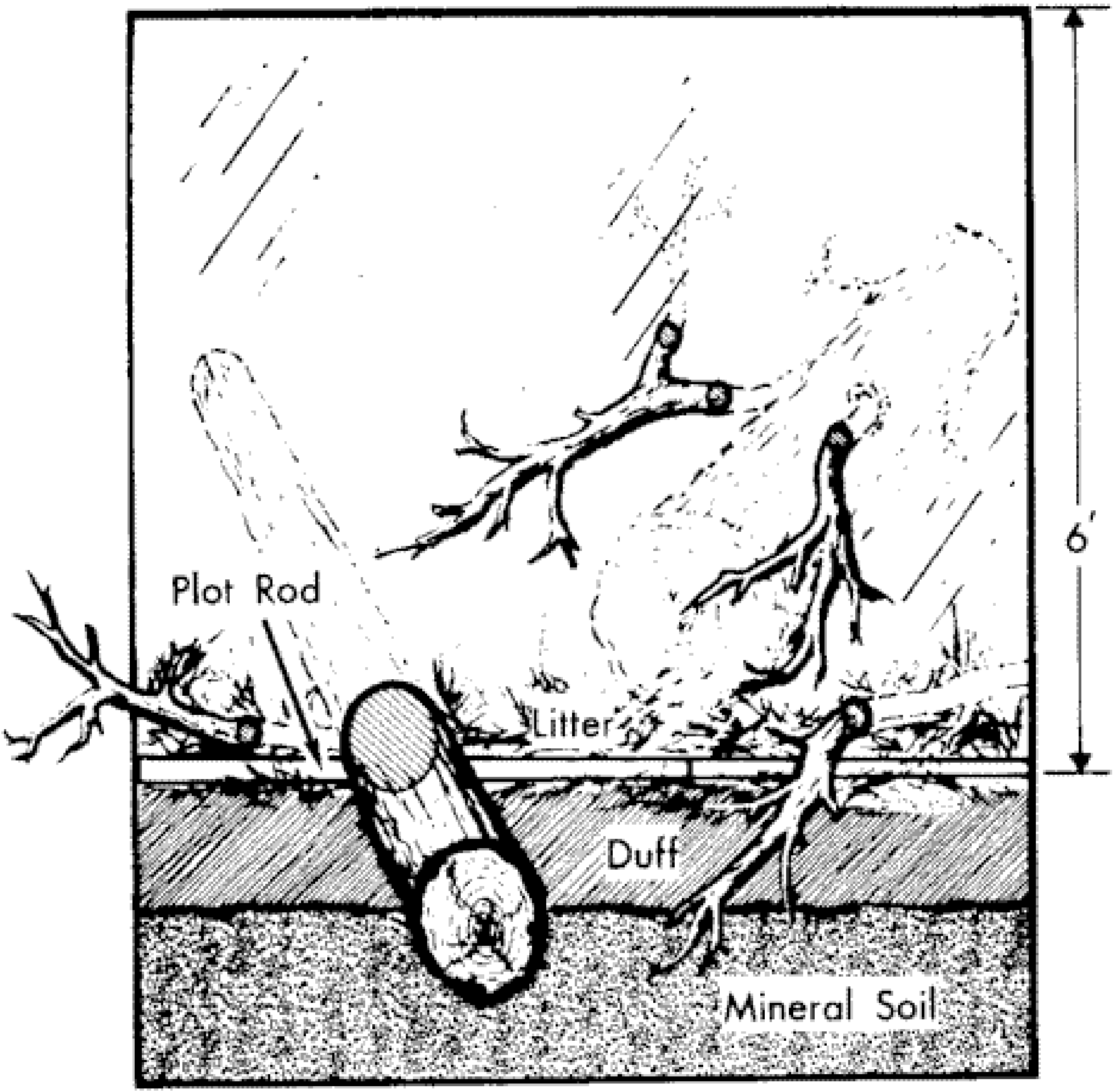
Bias is error introduced into sampling that causes estimates of parameters to be inaccurate. If a sampling experiment were repeated many times and each time an estimate computed, the average of these estimates will be near the value of the parameters if bias is small. Bias can be introduced into estimates 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.

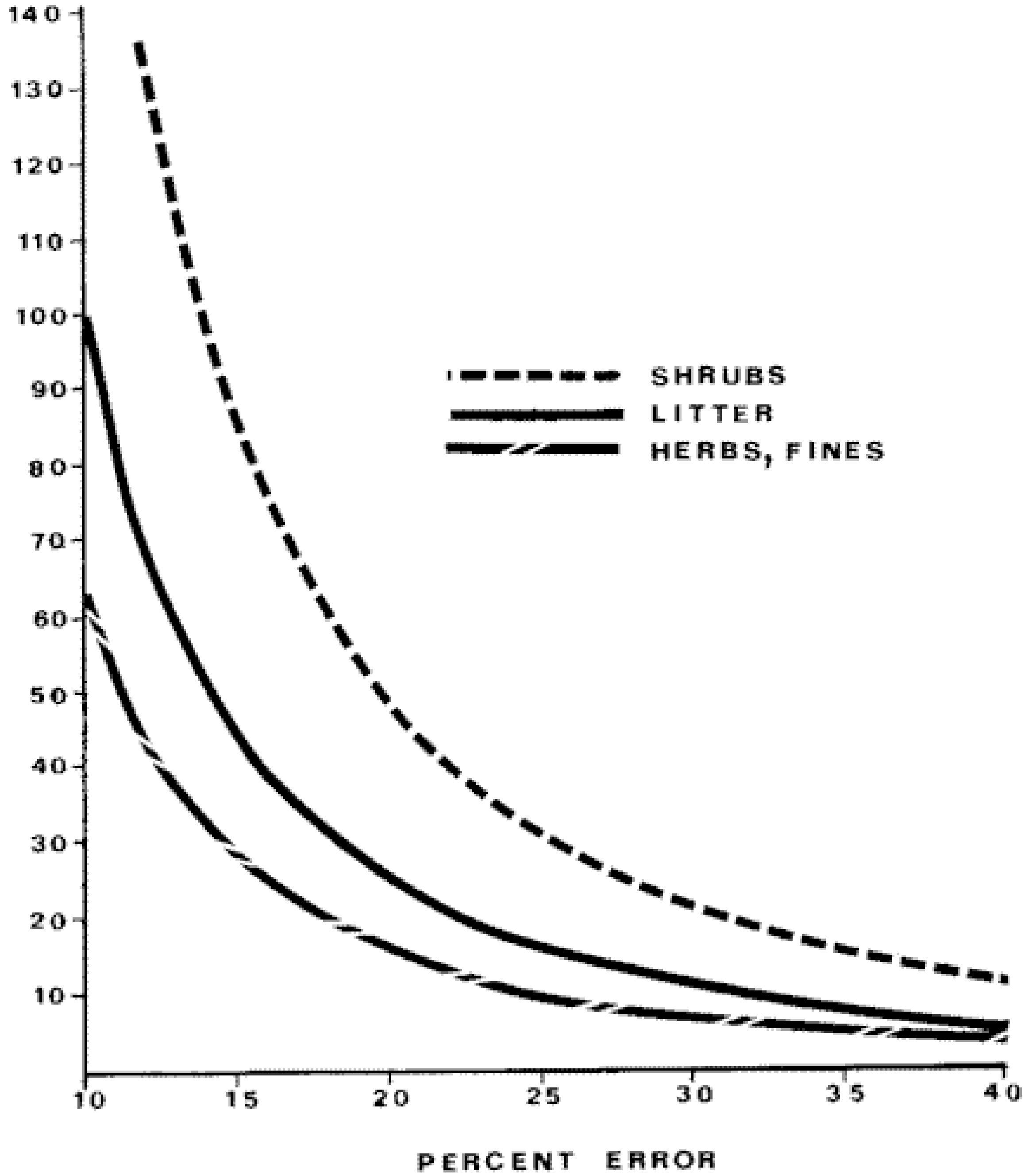
Target shooting is an analogy often used to illustrate the concepts of accuracy, bias, and precision. The bulls eye is the true population parameter the investigator is attempting to estimate with his sampling, which is shown by the shot pattern on the target. An unbiased, precise pattern is tightly 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.


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

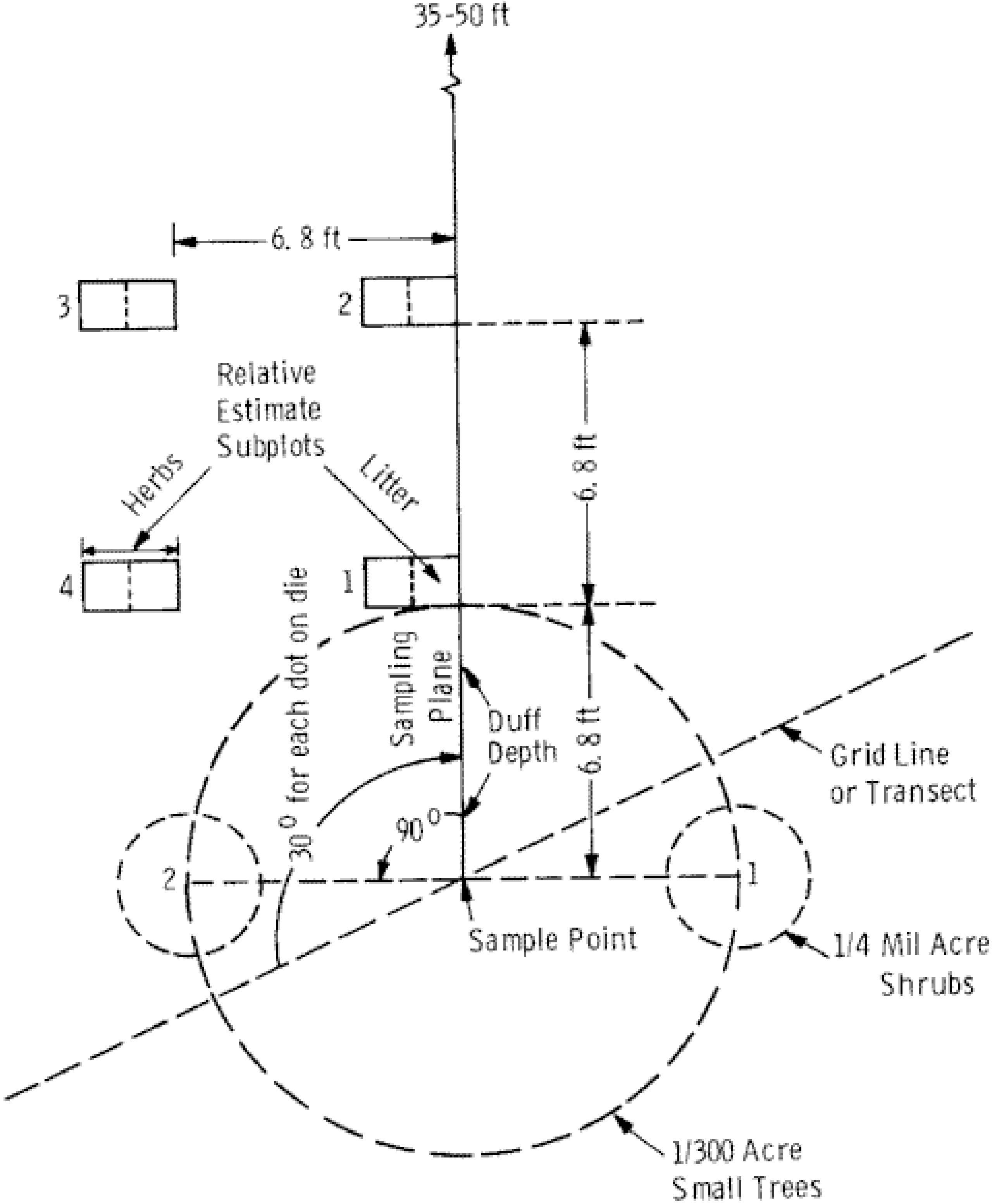

1
Document existing baseline condition of site, management potential, and factors preventing potential from being achieved
2
Develop realistic management objectives that are quantifiable for which results are measurable
3
Design site-specific plan for achieving objectives
4
Design monitoring program 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



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
4
1
6. 8 ft
30° for each dot on die
Sampling
Plane
Duff
Depth
6. 8 ft
90°
Grid Line
or Transect
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+

CARD 4

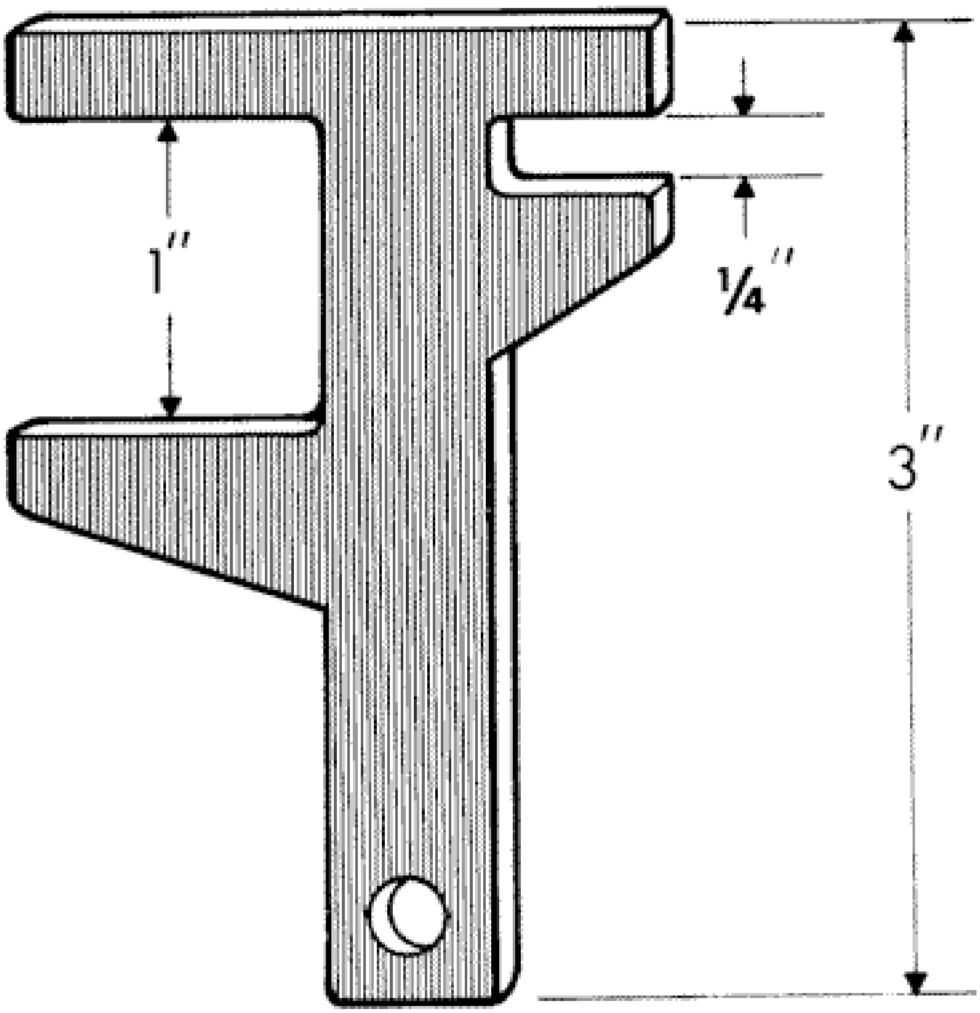
CARD 5

CARD 6

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

PERCENT CODES

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


1″
¼″
3″

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

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

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		
Location	Township	Range	Section	1/4 1/4 1/4	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.

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.

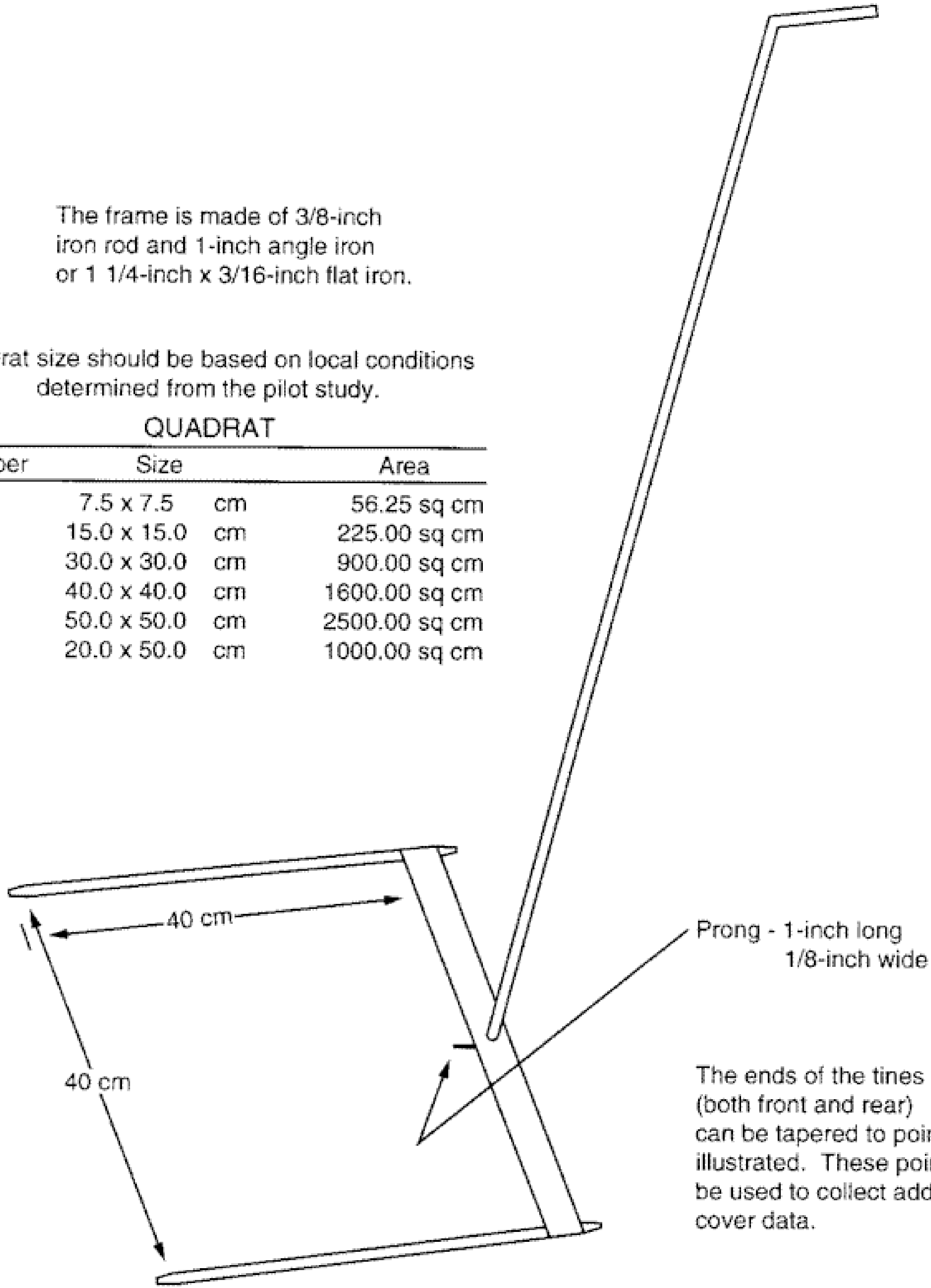
9. General Observations General observations concerning the sites on which photographs are taken can be important in interpreting the photos. Such factors as rodent use, insect infestation, animal concentration, fire, vandalism, and other site uses can have considerable impact on vegetation and soil 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.

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



The ends of the tines (both front and rear) can be tapered to points as illustrated. These points can be used to collect additional cover data.

Nested Plot Frame

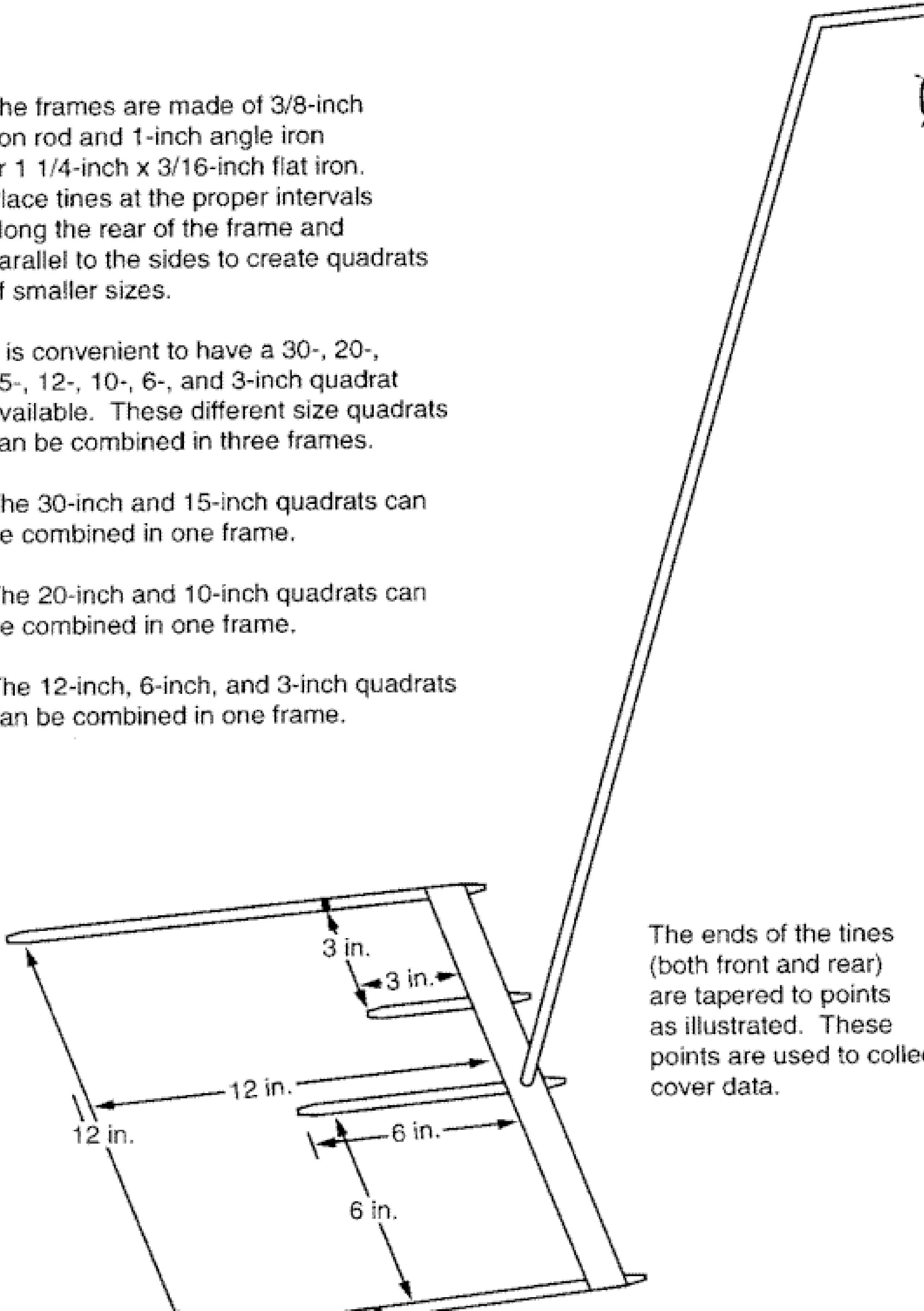
The frames are made of 3/8-inch iron rod and 1-inch angle iron or 1 1/4-inch x 3/16-inch flat iron. Place tines at the proper intervals along the rear of the frame and parallel to the sides to create quadrats of smaller sizes.

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.

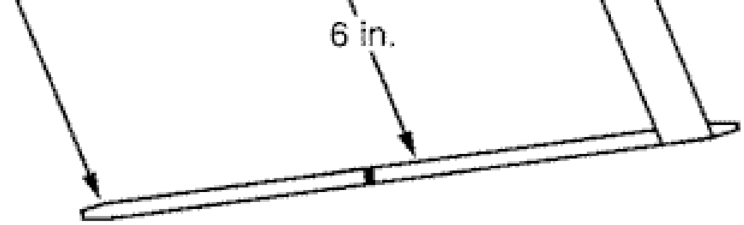
The 30-inch and 15-inch quadrats can be combined in one frame.

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.


6 in.

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	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	1		2		3		4	
																					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

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

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

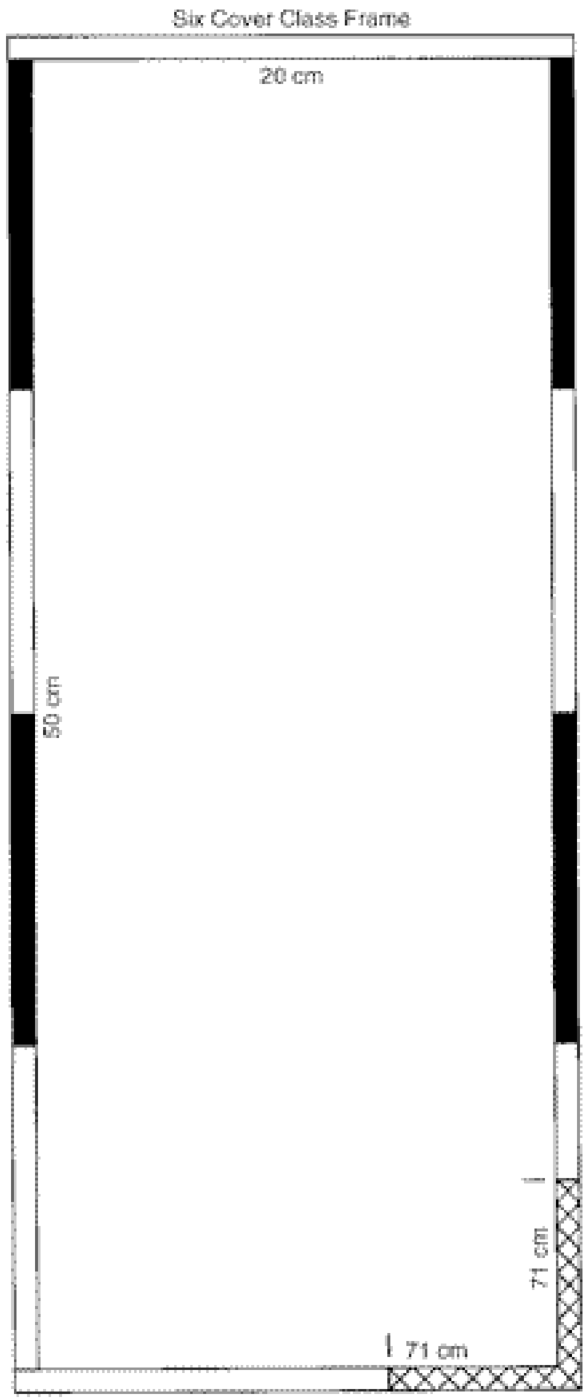
Daubenmire Summary

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

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

Cover Data

Study Number	Date	Examiner	Pasture
Allotment Name & Number	Study Location		Number of Points

Ground-Level Cover

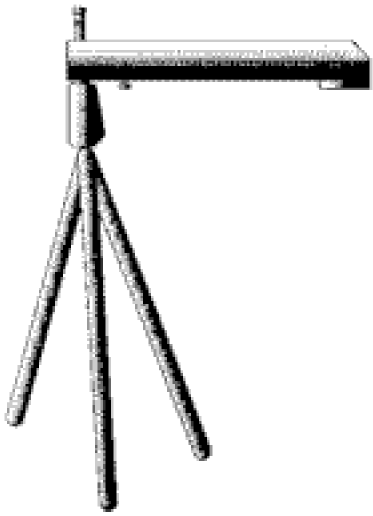
Category	B Bare Ground	L Litter	G Gravel (2mm-10")	S Stone (>10")	Vegetation	Total
Dot Count						
Total Hits						
% Cover						

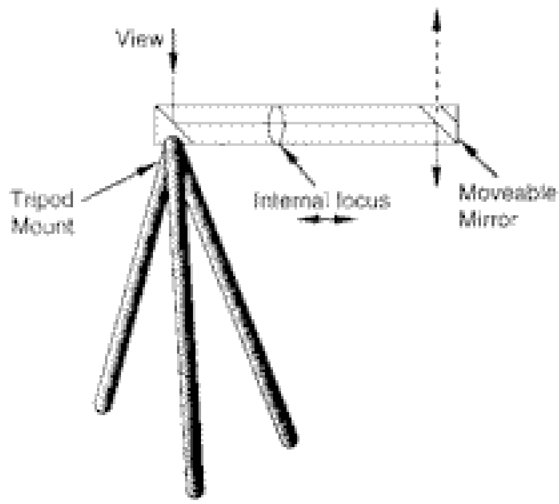
Basal and Canopy/Foliar Cover

Bsl or Grnd-Lev	Level 1	Level 2	Level 3	Dot Count	Total Hits
				Total	

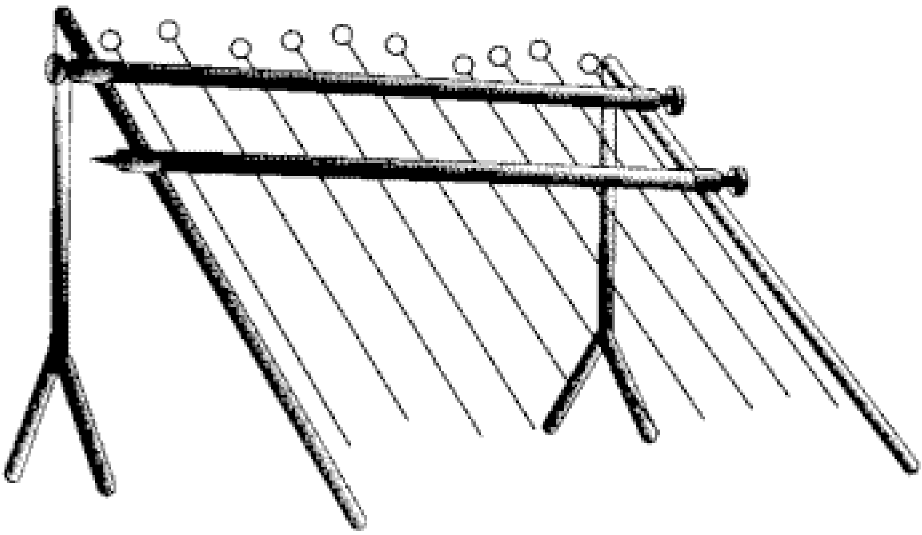
Notes (use other side or another page)

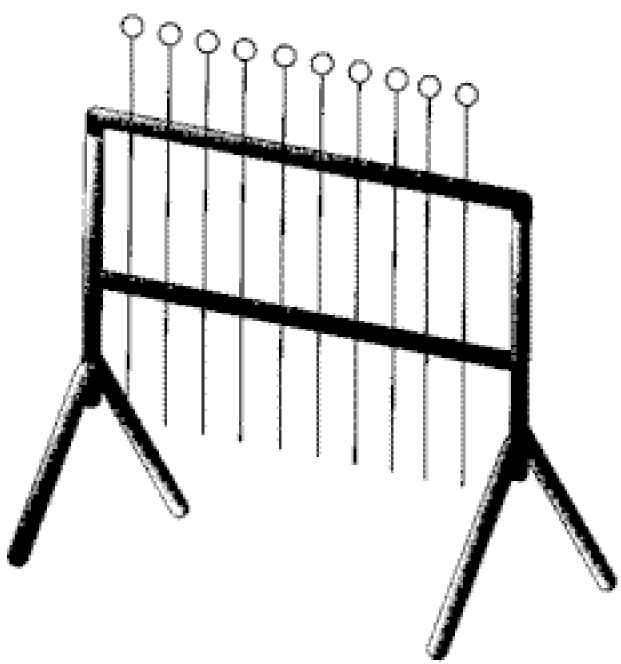
Examples of Sighting Devices



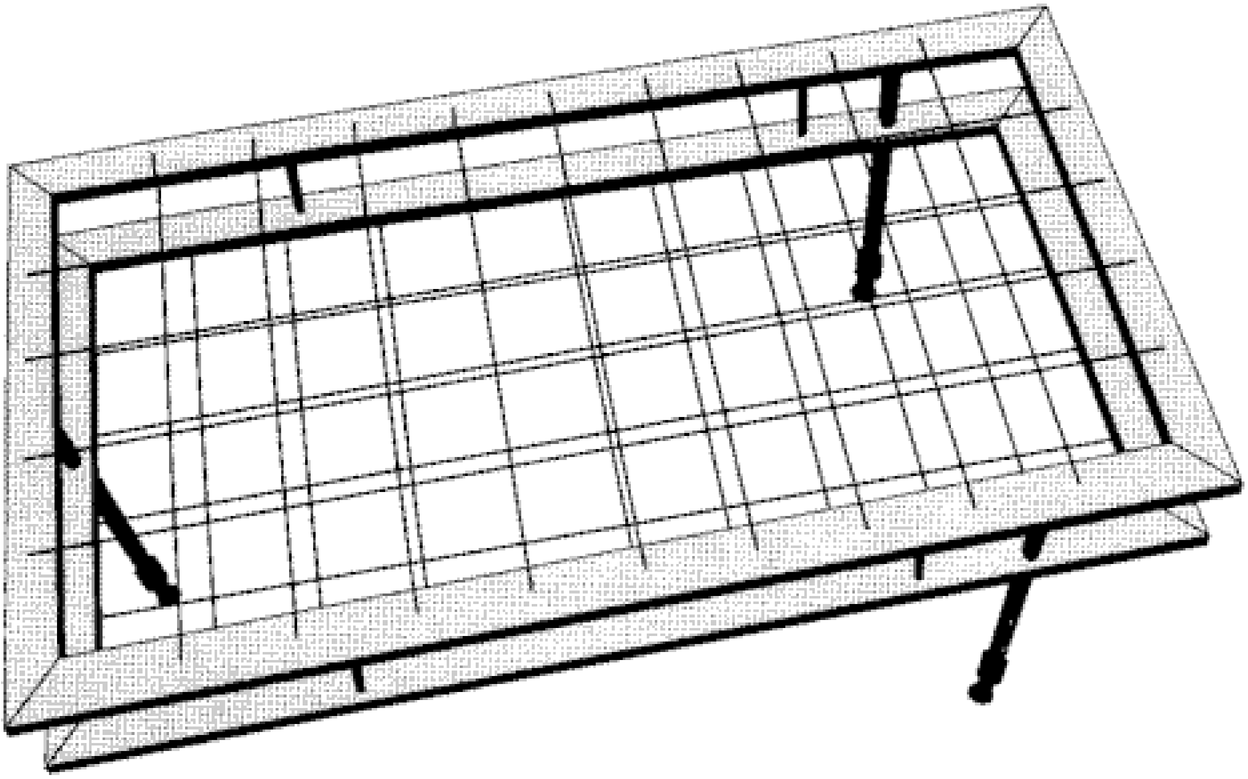


Examples of Pin Frames

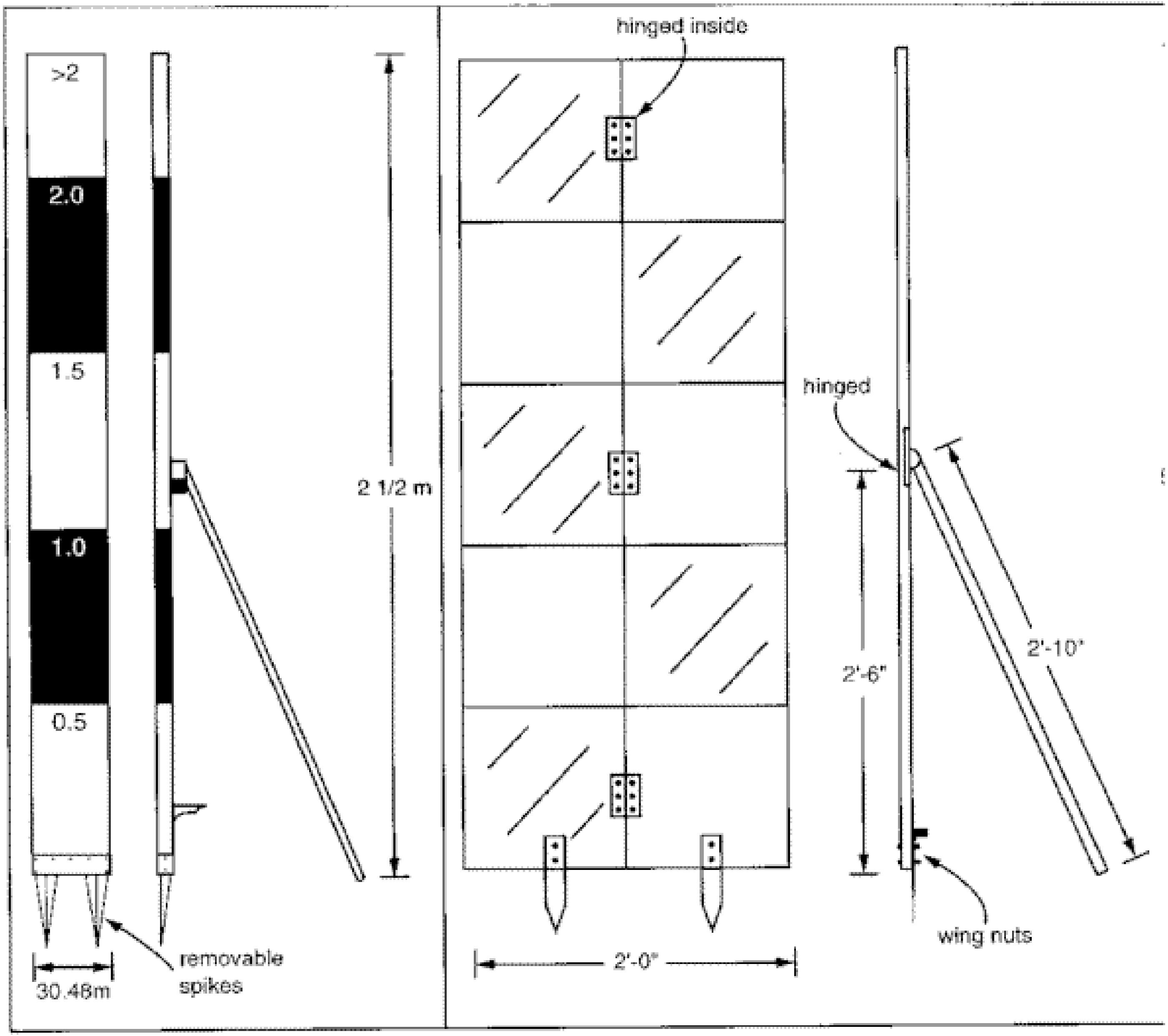




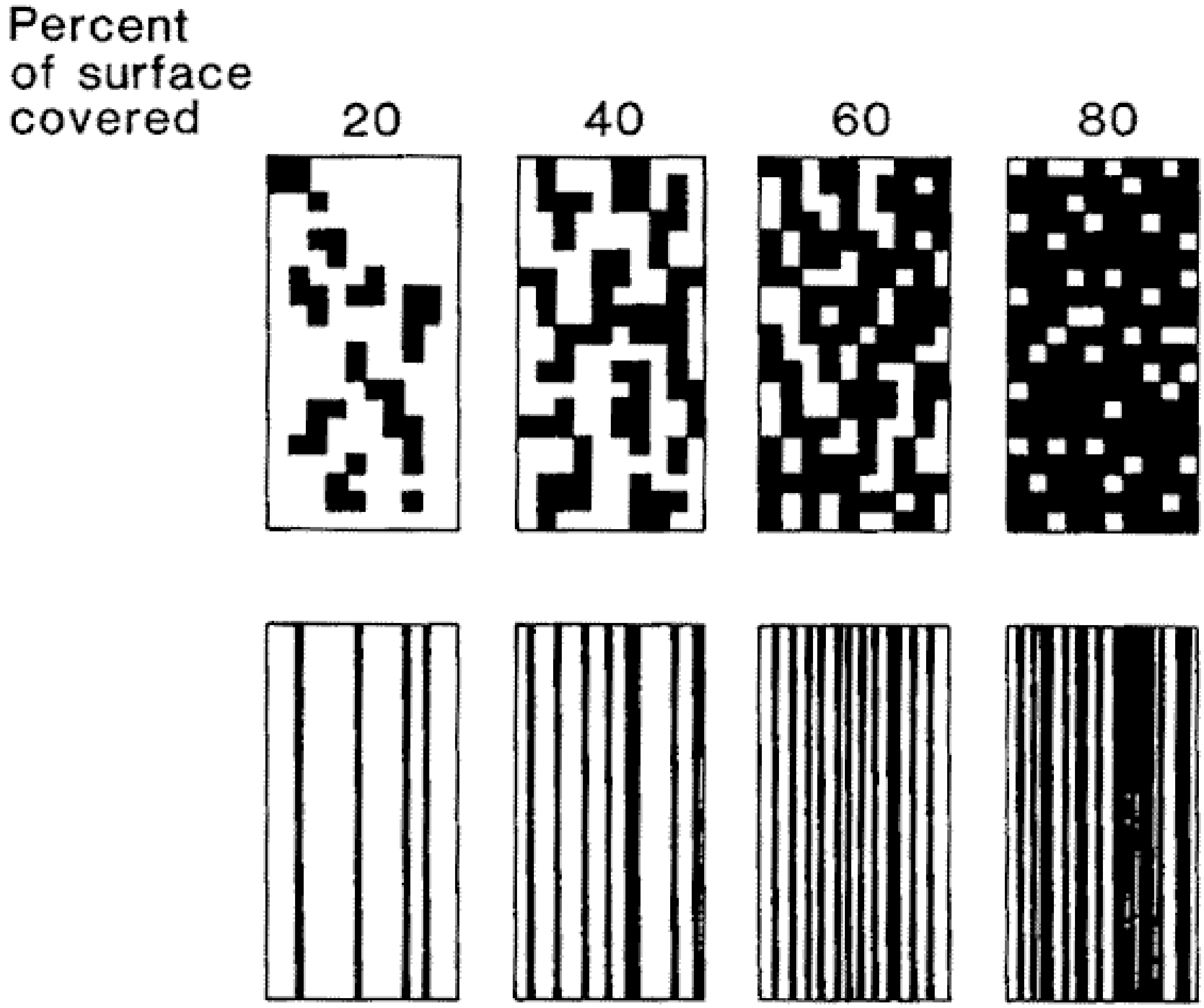
Example of a Point Frame



Examples of Cover Boards



Profile Board **Density Board**


Percent
of surface
covered
20
40
60
80

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

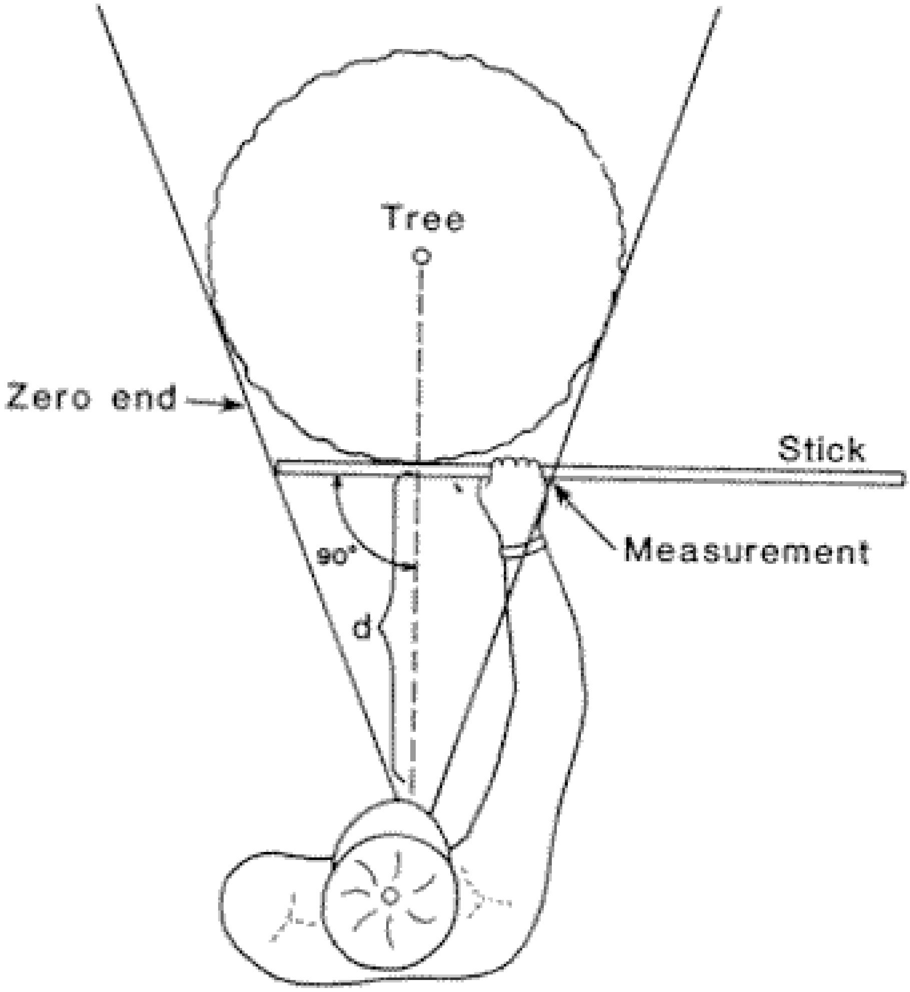
Study Number	Date	Examiner	Allotment Name & Number	Pasture

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:

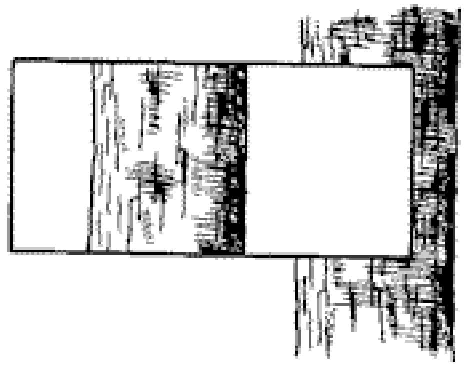
[1] Daubenmire Classes: 0=0; 1=1-5; 2=5-25; 3=25-50; 4=50-75; 5=75-95; 6=95-100



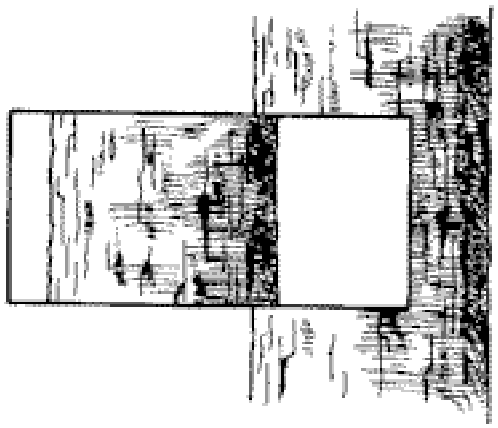
d = Specified distance between eye and tree trunk for the Biltmore stick being used

Figure 7. Use of the Biltmore Stick to estimate the diameter of a tree.

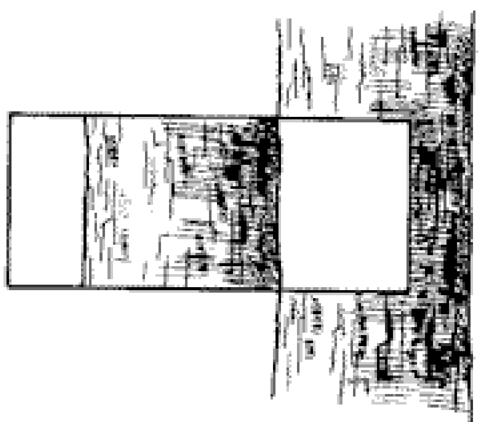
Do not count this tree.



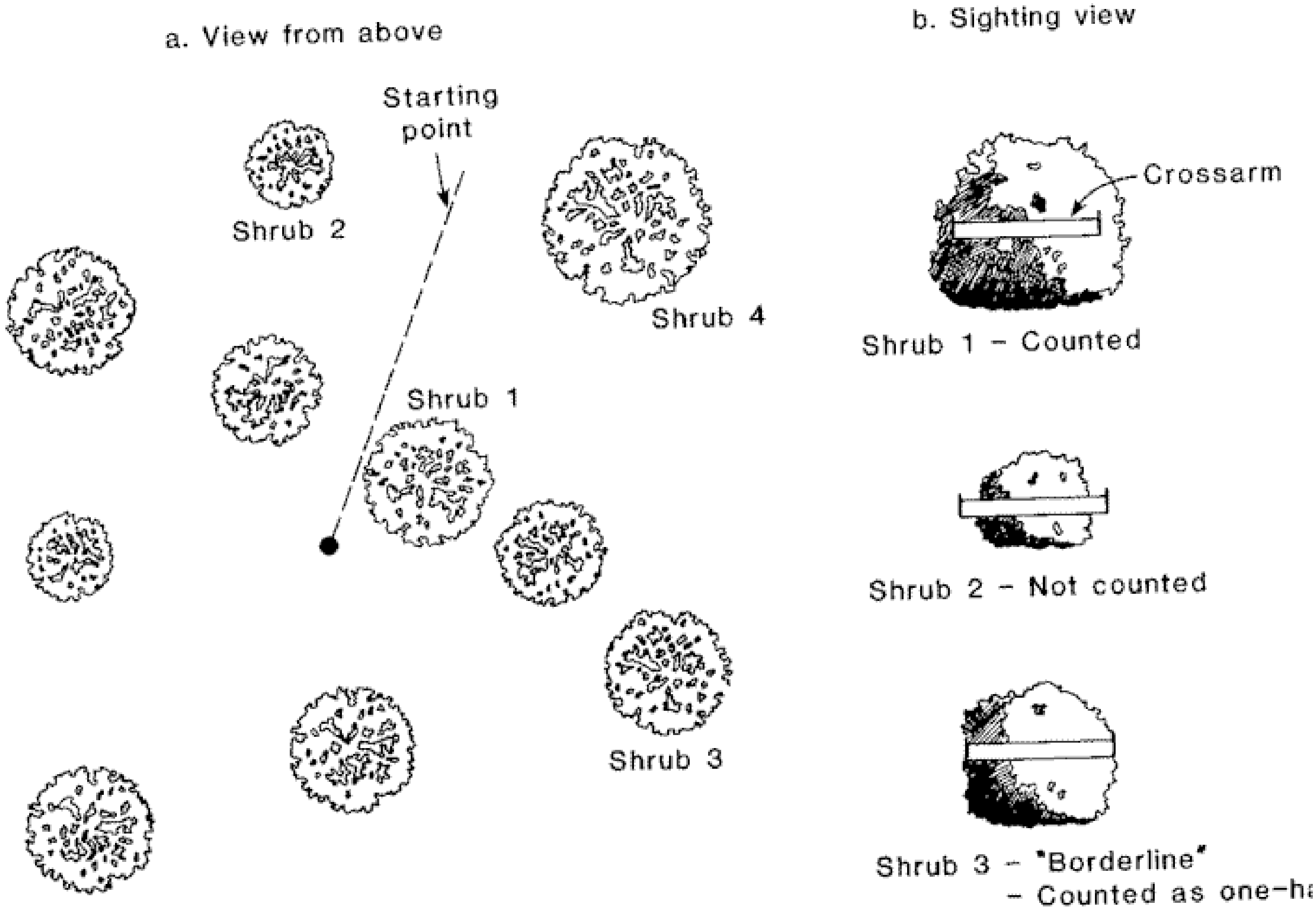
Count this tree.

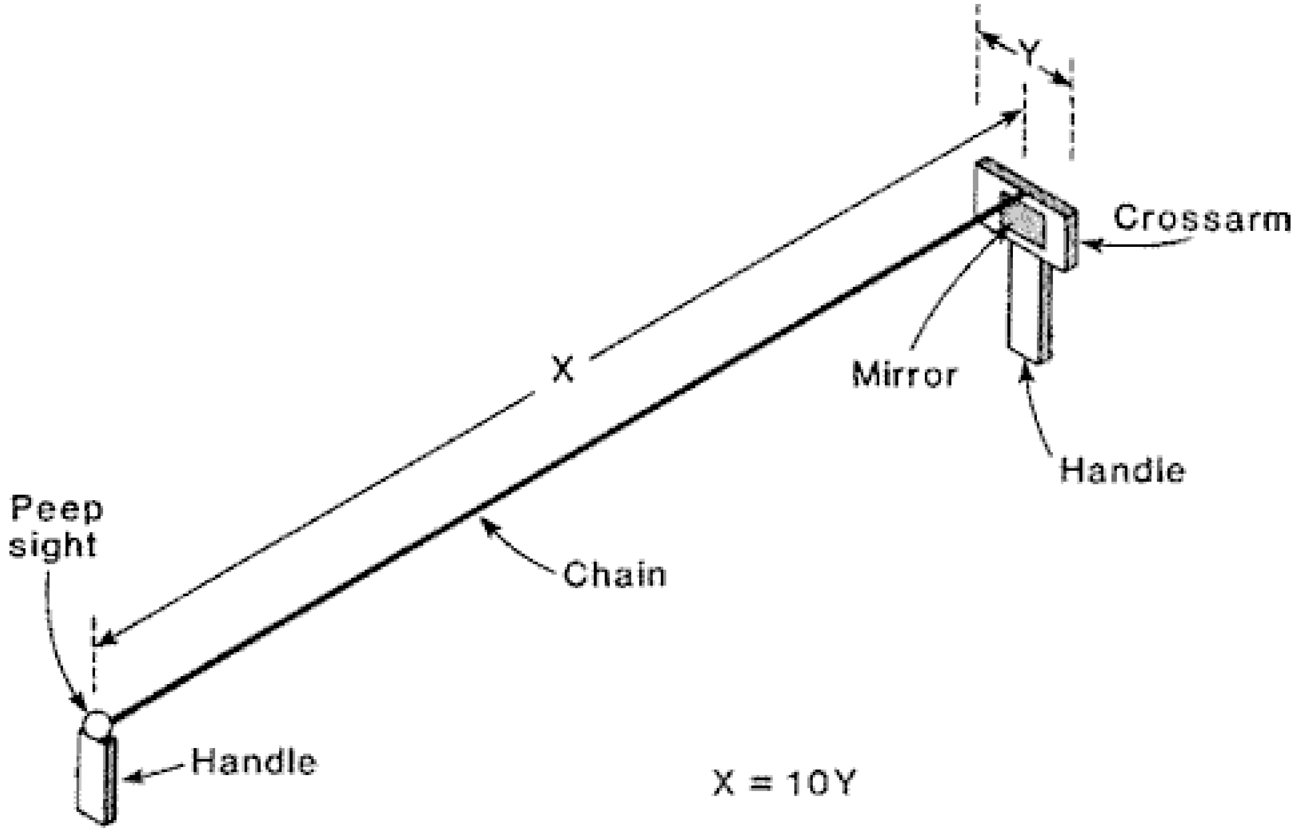


Borderline tree. Count as one-half, or measure the diameter and distance.



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.

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

Page ____ of ____

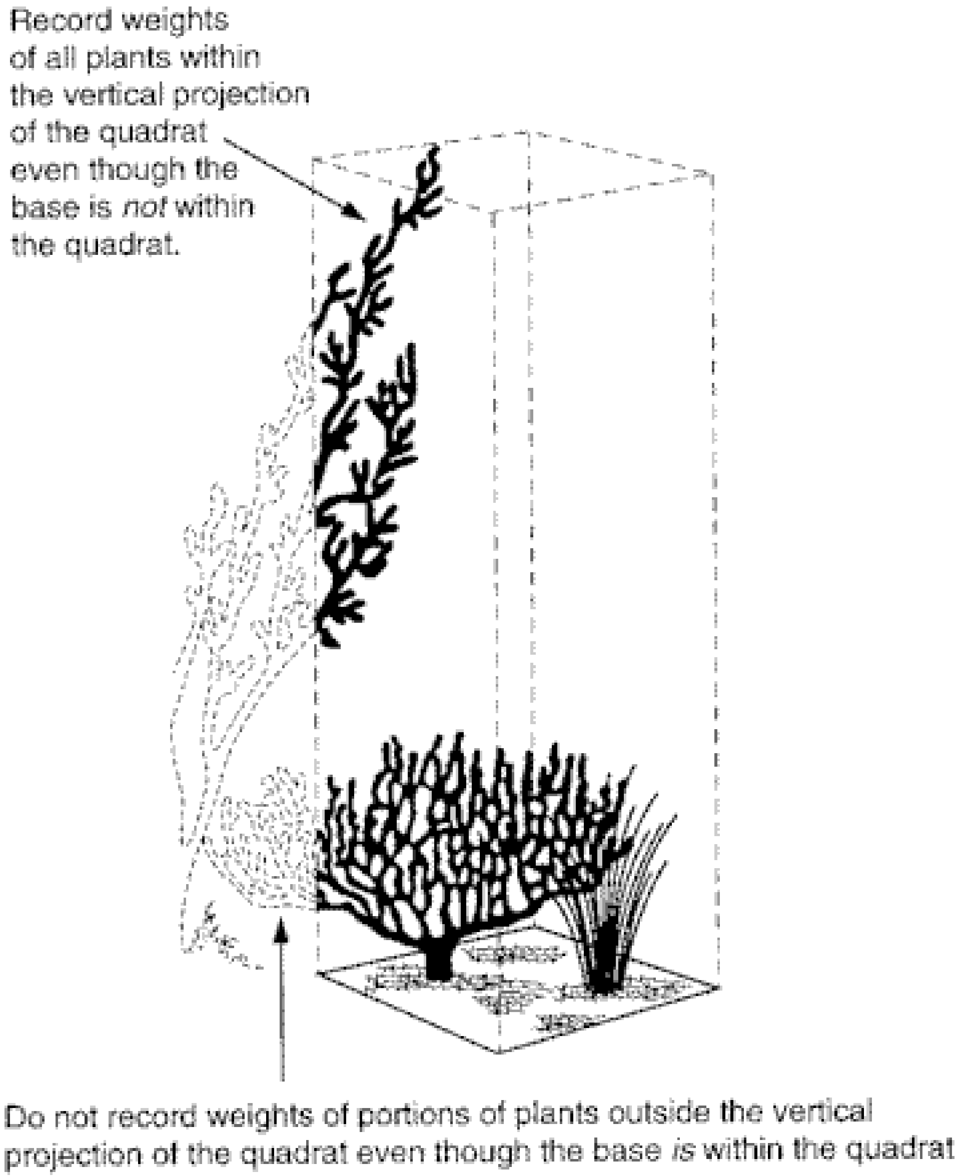
Production

Study Number	Date	Examiner	Allotment Name & Number	Pasture
Transect Location			Quadrat Size	Transect Bearing

	Plant	Estimated or Clipped Weight Per Species										Wt Clipped Plots			QCF	%Dry	Wt All	Avg	Pct
Plant Name	Symbol	(Circle Plots that are Clipped) (3)										Est	Clip	Dry		Wt	Plots	Yield	Comp
(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



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				

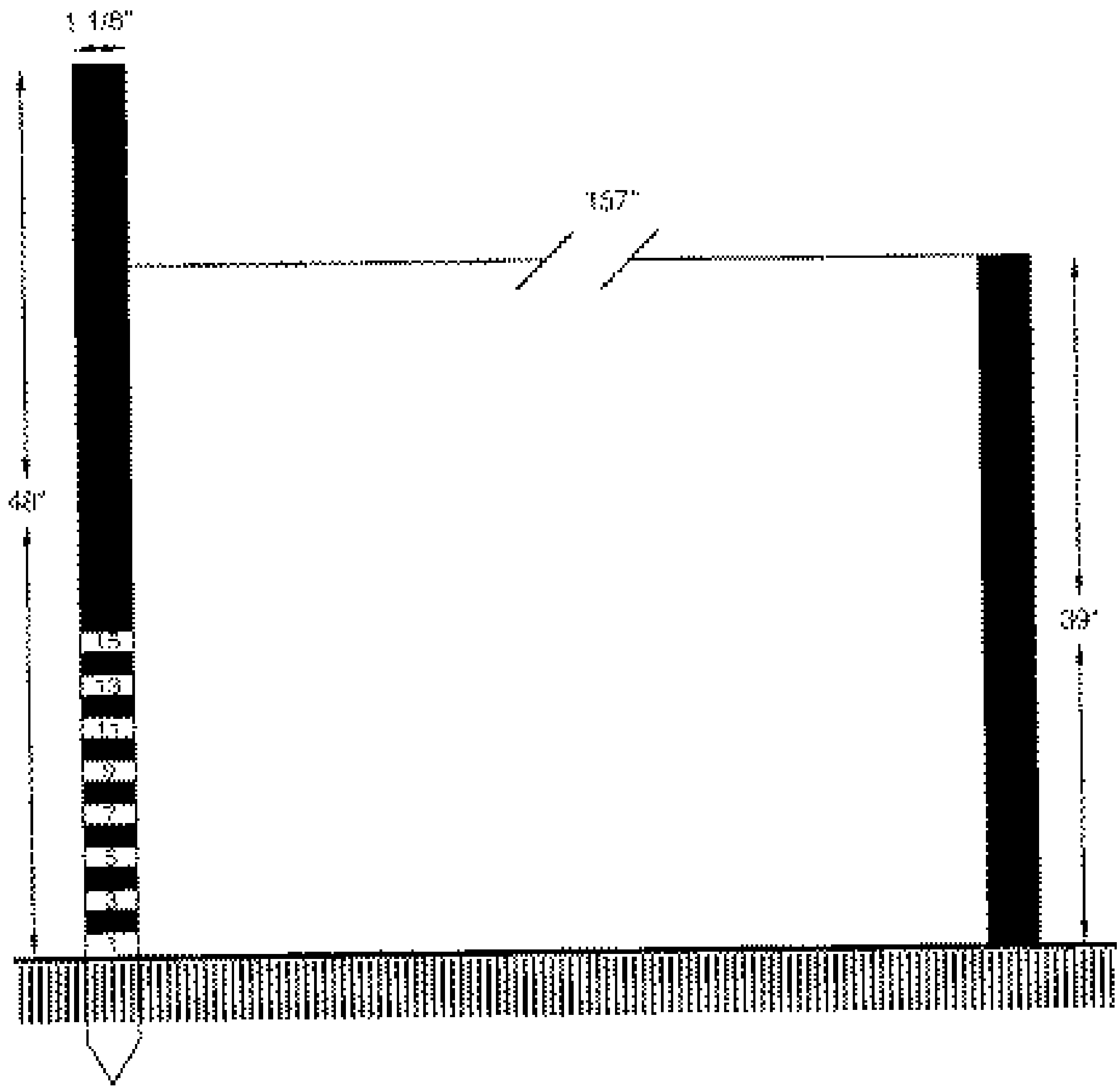
Notes

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.

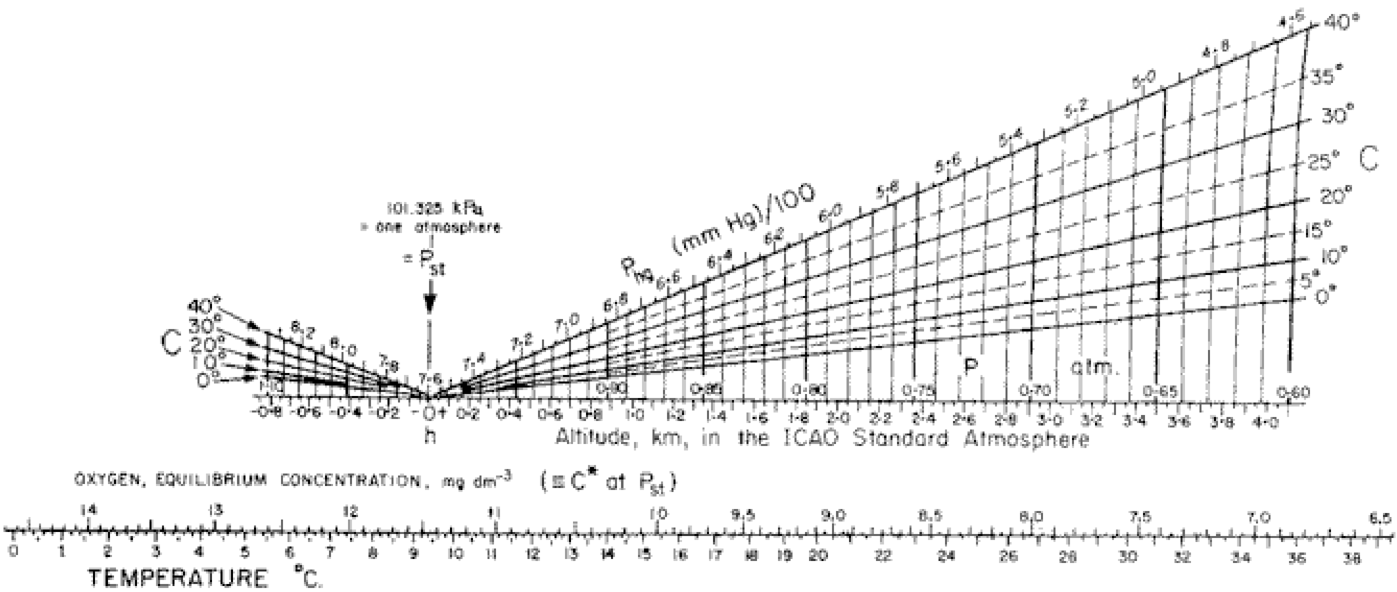
2. Pole is painted with alternating 1-inch bands of flat white and gray colors, starting with white on the bottom. Alternating 1-inch bands can be extended to the top of the pole if needed.

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.



101.325 kPa
= one atmosphere
= P_{st}
P_{Hg} (mm Hg)/100
C
40°
35°
30°
25°
20°
15°
10°
5°
0°
P atm.
h
Altitude, km, in the ICAO Standard Atmosphere
OXYGEN, EQUILIBRIUM CONCENTRATION, mg dm^{-3} ($\equiv C^*$ at P_{st})
TEMPERATURE °C.

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 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 ____________________________________

____

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.

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

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

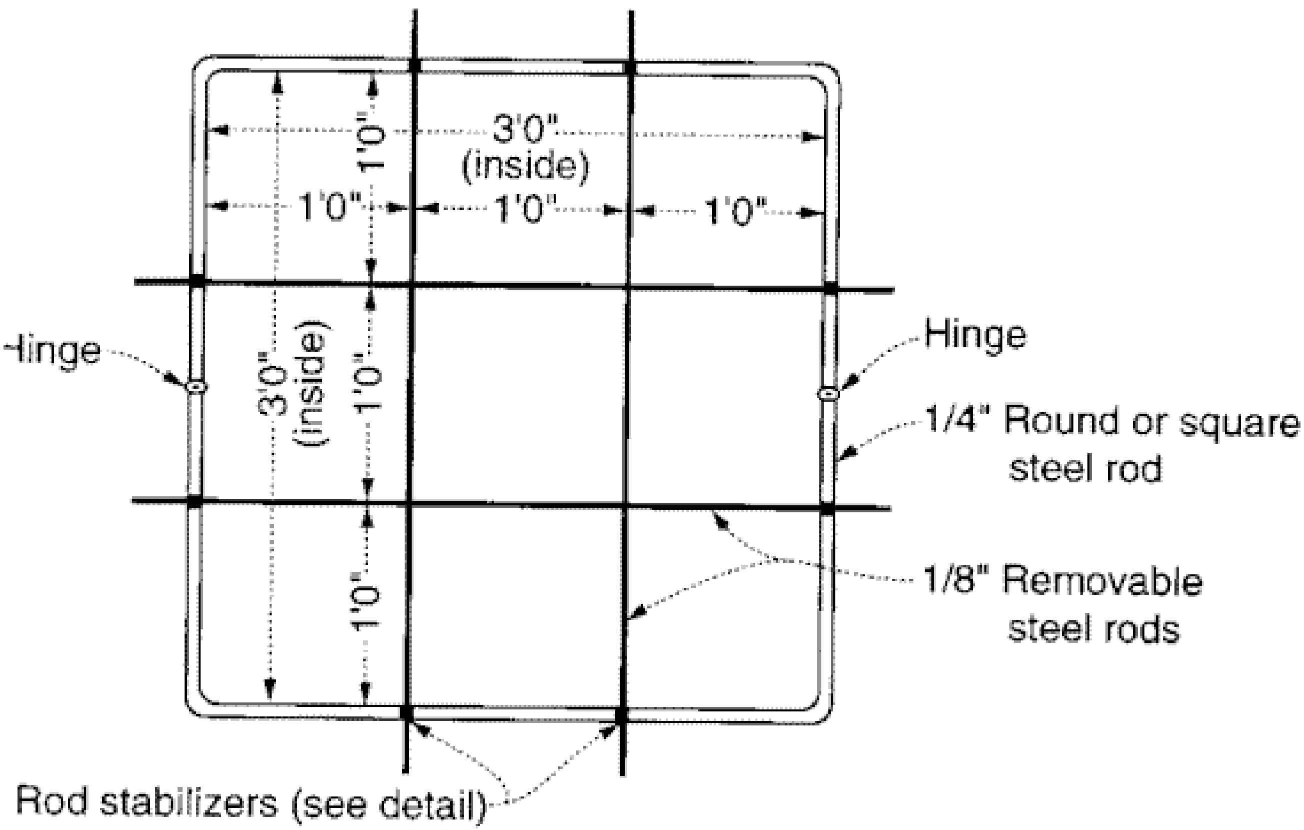
Temp oF	Drought Index Yesterday (or as reduced by precipitation) 40-59 inches annual precipitation															
	0-49	50-99	100-149	150-99	200-249	250-299	300-349	350-399	400-449	450-499	500-549	550-639	640-699	700-759	760-799	800
107+	62	58	54	50	46	42	38	34	30	26	22	16	10	6	2	0
104-106	53	50	46	43	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

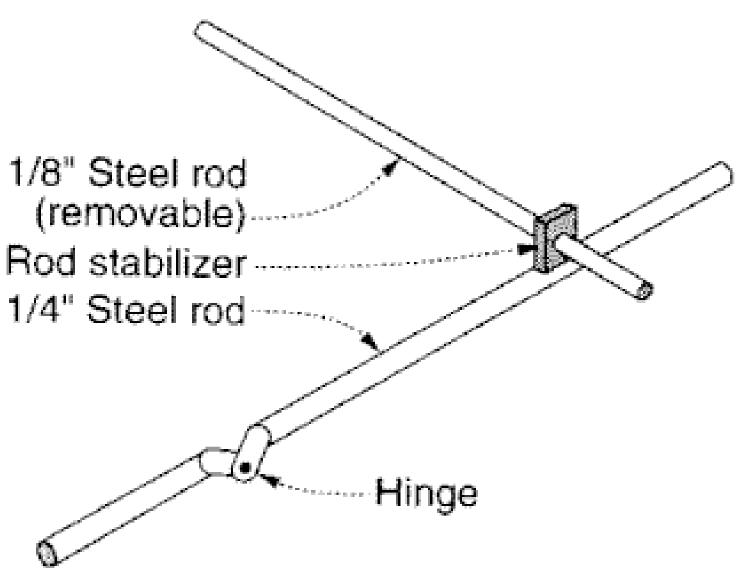
77-79	12	11	11	10	9	8	8	7	6	5	4	3	2	1	1	0
74-76	10	10	9	8	8	7	6	6	5	4	4	3	2	1	1	0
71-73	8	8	7	7	6	6	5	5	4	4	3	2	1	1	0	0
68-70	7	6	6	6	5	5	4	4	3	3	2	2	1	1	0	0
65-67	6	5	5	4	4	4	3	3	3	2	2	2	1	1	0	0
62-64	4	4	4	4	3	3	3	2	2	2	2	1	1	1	0	0
59-61	3	3	3	3	3	2	2	2	2	1	1	1	1	1	0	0
56-58	3	2	2	2	2	2	2	1	1	1	1	1	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 °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

Photo Plot Frame - 3- x 3-foot

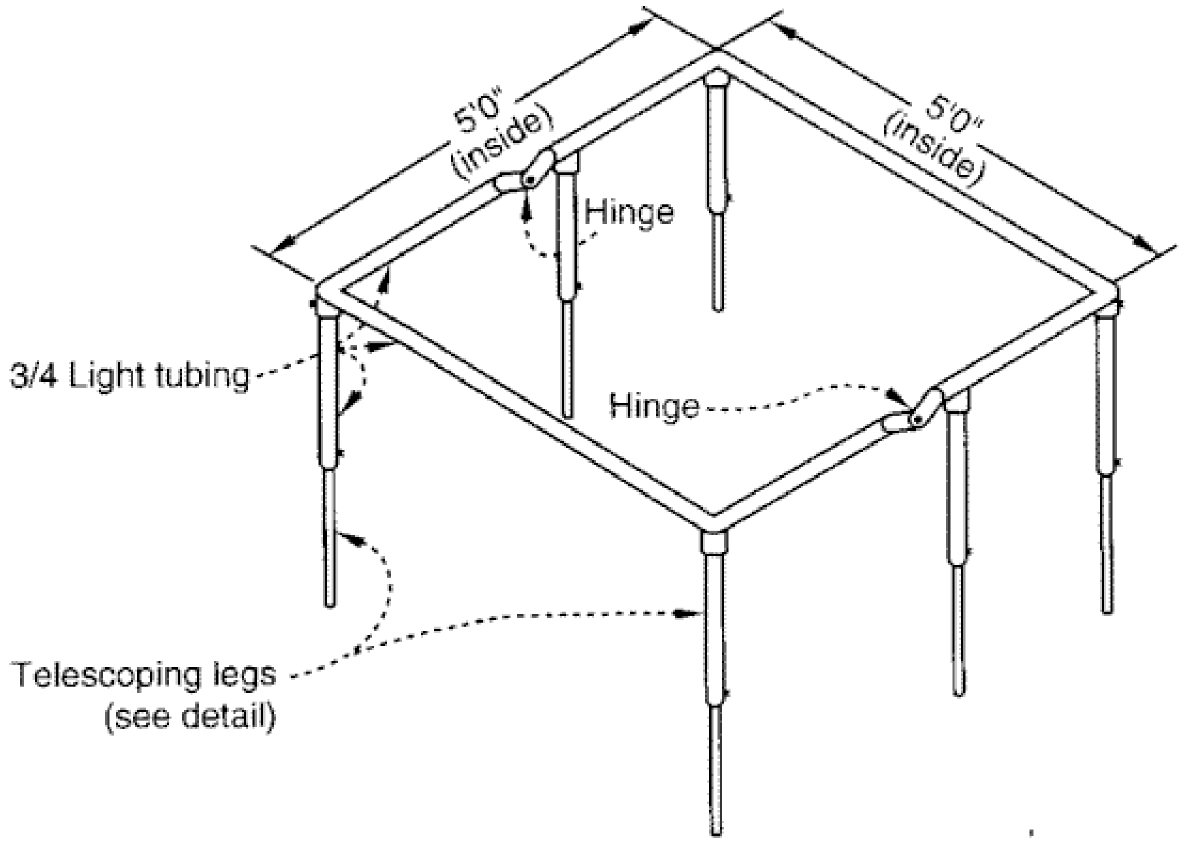


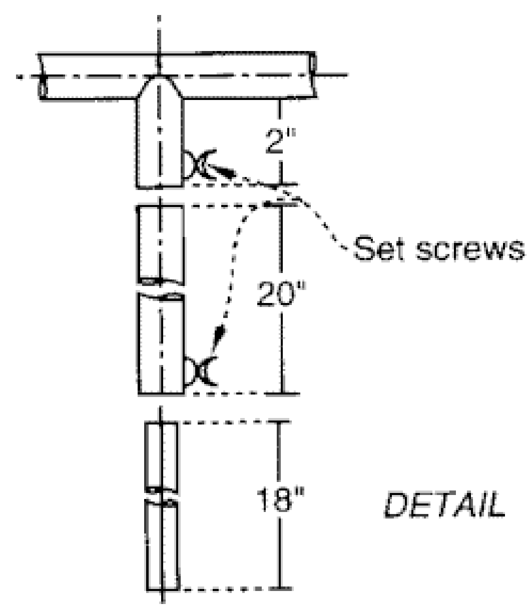


DETAIL

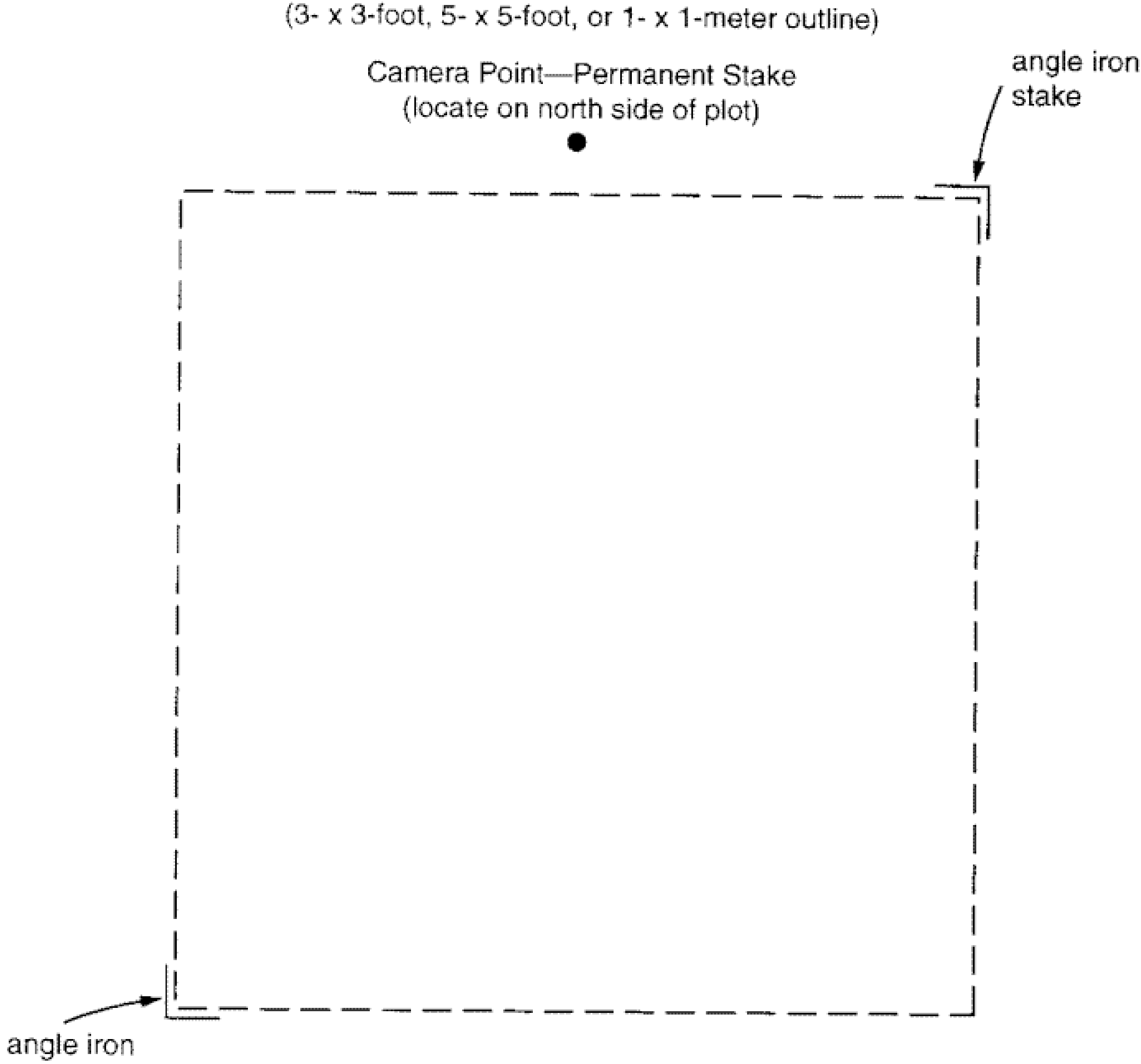
DETAIL

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.

Live Fuel Moisture Samples

Page ___ of ____

Agency	Forest/State	District/Unit	Site Name or Number

Collection Record			Moisture Determination Record		
Observer	Date	Time	Observer	Date in	Time in
	/ /9			/ /9	

Can, Bag or Bottle Number	Species	Condition			A	B	C	D	E	F
	//////////////	New	Old	Mix	Gross Weight WET	Gross Weight DRY	Tare Weight	Water Weight	Dry Weight	% Moist.

Phenological Observations

Leaf/Stem stages:		Flowers/Fruits:	
Dormant	[ ]	Buds / flowers present	[ ]
Stem / leaf growth	[ ]	Seeds/fruits developing	[ ]
Growth complete	[ ]	Seeds/fruits ripe	[ ]
New stems lignified	[ ]	Seeds/fruits falling	[ ]
Leaves curing falling	[ ]	None	[ ]
Frosted or frozen	[ ]		

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.

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							

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.

References and Suggested Readings

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FIRE EFFECTS GUIDE

Sponsored by:

National Wildlife Coordinating Group

Fire Use Working Team

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Great Basin Area Cache
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PREFACE

by Dr. Bob Clark and Melanie Miller

A. Purpose

The Federal government manages a variety of ecosystems across the United States, including deserts, grasslands, tundra, shrublands, forestlands, estuaries, and riparian zones. These ecosystems range from arid to humid, warm to cold, and sea level to over 10,000 feet elevation. Fires naturally occur in almost all of these ecosystems, with fire characteristics determined by climate, vegetation, and terrain.

The purposes of this Guide are to summarize available information on fire effects principles and processes, provide references for additional information, and provide guidelines for the collection, analysis, and evaluation of wild and prescribed fire effects data. Basic mechanisms of fire effects are described so that the reader will be able to understand and interpret fire effects literature, and evaluate observed results that conflict with those presented in published reports. The goal is to improve fire management by improving our ability to manage fire effects.

The Guide was written as an aid for resource managers and fire managers. It can be used for managing and evaluating wildfires; developing and implementing emergency fire rehabilitation plans; planning, monitoring, and evaluating prescribed fires; developing activity plans such as timber management plans, allotment management plans, and threatened and endangered species recovery plans; and providing fire management input for land use plans.

B. Assumptions

Ecosystems have evolved with, and adapted to, specific fire regimes. In a particular ecosystem, natural fires occurred with fairly specific, albeit irregular, frequency and typical season of occurrence; with characteristic fireline intensity and severity; and characteristically did or did not involve the crowns of trees or shrubs. Gross differences occurred among ecosystems. For example, frequent, low intensity, surface fires were common in ponderosa pine ecosystems, whereas fires in big sagebrush were probably less frequent, of higher intensity, and killed much of the sagebrush overstory. High intensity, stand replacement fires at long intervals were characteristic of some forest types, while annual fires may have been common on some Great Plains grasslands. Despite this variability in fire regimes, universal principles and processes govern response of ecosystem components to fire. Recognition and understanding of the principles and processes can help our understanding of the variability in postfire effects that is often reported in the literature, and differences between reported results and local observations on burned areas. This knowledge will enable resource and fire managers to predict and evaluate fire effects, regardless of ecosystem or fire regime.

Fire effects are the result of an interaction between the heat regime created by the fire and the properties of ecosystem components present on the site. For example, plant species in vegetation types that have evolved with frequent fire tend to be much more resistant to fire than species from plant communities that rarely burned. The effects of a fire burning under the same conditions may be very different on soils of different textures or chemical properties. Variation in fire effects may also occur within ecosystems because of differences in site characteristics, fuel conditions, and weather prior to, during, and after the fire. A fire may have different effects upon the same site if it occurs in different seasons or within the same season but with different fuel, duff, and soil moisture. For these reasons, it is important to document conditions under which the fire occurred, and the characteristics of the fire, as part of any effort to monitor postfire effects.

The words fire intensity, severity, fireline intensity, and burn severity are often used interchangeably in the literature. The following terminology is used throughout this Handbook to describe the properties of fire. All definitions that describe the behavior of a flaming fire are those used in the Fire Behavior Prediction System (Rothermel 1983), including fireline intensity, the rate of heat release per linear foot of the flaming front. Burn severity is a qualitative assessment of the heat pulse toward the ground, and relates to subsurface heating, large fuel and duff consumption, and consumption of litter and organic layers beneath isolated trees and shrubs. The terms fire intensity and intensity are used by some authors to describe the overall heat regime of a fire. They are generic terms that are often confused with fireline intensity, and are not used as a synonym for fireline intensity in this Handbook.

The Guide recognizes that a natural fire regime cannot be perpetuated in unnatural communities. Timber harvest practices, grazing patterns and degree of use, the accidental or deliberate introduction of exotic plants and animals, other cultural activities that alter fuel continuity and loading, and the modification of historic fire patterns through active suppression have changed many plant communities. Interruption of fuel continuity by livestock grazing, road construction, and other developments has resulted in fires that are less frequent, smaller, and of lower fireline intensity, in some ecosystems. The introduction of exotic plants such as cheatgrass, coupled with anthropogenic ignition sources, has greatly increased fire size and frequency in other ecosystems.

Active suppression has resulted in large areas, especially in shrublands and forests, that are extremely susceptible to fire. The exclusion of fire has resulted in a larger proportion of vegetation in older age classes, except in regulated forests, which are more susceptible to insect and disease infestations. The amount of dead plant material has increased, either accumulated on the ground or retained on plants. In plant communities with historically short fire cycles, the absence of fire has allowed the development of fuel ladders between the surface and the overstory. Fires which do occur are often carried into the tree crowns by large accumulations of down dead woody fuels or understory trees, causing a stand replacement fire in forest types where historically, overstory trees were rarely killed. In vegetation communities with long natural fire cycles, younger, intermixed, less flammable age classes of vegetation are not as prevalent as they would have been under a natural fire regime. Coupled with the increased incidence of insect and disease, the continuity of highly flammable stands has increased, resulting in greater potential for extremely large fires. Plans for the

C. Handbook Organization

The chapters of this Guide discuss different elements that relate to our management of fire effects and specific responses of different ecosystem components to fire. This Handbook recognizes that separate discussions of fire effects on fuels, soils, watershed, plants, and wildlife are artificial, because fire effects are an integration of the responses of all of these components to fire. Despite the fact that fire effects occur holistically, ecosystem components are discussed individually as a means of organizing the information. Chapters describe basic principles and processes that regulate fire effects, including fire behavior and characteristics, fuels, air quality, soils and watershed, plants, wildlife, and cultural values. Considerations for management of fire effects on these resources, and a discussion of appropriate techniques for monitoring fire effects, are contained in each of these chapters. Monitoring is included in this Handbook because techniques that accurately describe long-term trends in plant community condition, for example, are not adequate to detect significant and sudden changes caused by burning. Because an understanding of prefire and postfire grazing management, data analysis, and documentation and evaluation procedures is critical to sound management and monitoring of fire effects, chapters on each of these topics are also included. Resource management is goal oriented. The first chapter in this Guide is a discussion of goals and objectives and how they fit into planning for the use and management of fire.

National Wildfire Coordinating Group

Fire Effects Guide

CHAPTER I - DEVELOPMENT OF OBJECTIVES

By Dr. Tom Zimmerman

A. Introduction

Management is the process of anticipating the future, setting objectives, implementing an action, achieving an output, and performing an evaluation comparing the output to the objective. Management is not possible without setting objectives. Clear and easily communicated objectives facilitate the management process.

In land management programs, the desired outcome of management actions is expressed as management objectives. Objectives represent an important component of all land management programs and are the single most important factor driving all management actions.

B. Definitions and Qualities of Good Objectives

1. Goals and Objectives - Definition. In land management, both goals and objectives are important. Goals are primary and basic products of the long range management plans. These goals are commonly referred to as land use decisions. Goals are relatively short statements that discuss what the public lands are to be used for and where the uses will occur. Each statement addresses a land use, but is not limited to the principal or major use.

Objectives are a necessary component of the planning process; they provide a bridge between goals and the implementation phase. Objectives describe what procedures will be used and when actions will be completed.

During the planning of fire management projects, objectives are formulated and used as the basis for development of an action plan. Interdisciplinary (I.D.) teams coordinate various concerns and develop objectives for a project. The I.D. teams are composed of resource specialists from different disciplines who address concerns of the affected resources and resolve conflicts among resource disciplines that arise from specific management actions.

2. Qualities of Good Objectives. Fire management objectives must be made up of certain attributes or they will not convey the necessary guidance. Good objectives must be informative and **SMART**. Objectives that are **SMART** are:

S - Specific - what will be accomplished, using limiting factors, and identifying the range of acceptable change from the present to the proposed condition.

M - Measurable - the present and proposed condition must be quantifiable and measurable.

A - Achievable - can be achieved within a designated time period.

R - Related/Relevant - related in all instances to the land use plan goals and relevant to current fire management practices.

T - Trackable - objectives must be trackable over time and must include a definite timeframe for achievement, monitoring, and evaluation.

3. Kinds of Objectives.

a. Land use decisions (goals). These are broad statements, usually specified in land management plans, that deal with large areas over long time periods (e.g., 10 years). Land use decisions establish resource condition objectives; the allowable, limited, or excluded uses for an area (land use allocations) and the terms and conditions for such use; and management actions that will be taken to accomplish multiple use goals.

b. Resource management objectives. Resource management objectives identify the changes in water, soil, air, or vegetation from the present to proposed conditions. Resource objectives can also describe an existing resource condition that should be maintained.

c. Treatment objectives. These are very well-defined statements that describe what a treatment must accomplish in order to meet a stated resource management objective. This type of objective is site-specific and must utilize the **SMART** concept.

Any statement that is an objective **must** identify the change from present conditions to the proposed conditions (the changes that are planned) and the limiting factors.

C. How Objectives Relate to Project Inventory, Development, Implementation, Monitoring, and Evaluation

Objectives are an important part of management actions and are prerequisite to sound land and resource management. Objectives not only drive the planning system, they also drive the full spectrum of project implementation, monitoring, and evaluation.

During the fire planning process, for example, the planner uses resource management objectives (standards) as guidance to determine what fire management responses and activities are necessary. These standards then provide guidance in determining what and how much information should be collected prior to and during project implementation. At this point, knowledge of fire effects becomes a necessary part of the planning process. Fire effects information helps to determine what will be done, how many resources are needed, how much funding the fire program will need, and what should be evaluated to ensure efficient accomplishment of the workload.

D. Relationships of Different Tiers (Levels) of Planning to Objectives

Generally, objectives start as issues when the land use planning process is initiated. (Issues are usually conflicts between two or more resource uses or demands that must be resolved in the plan.) Issues are generally defined in terms of the desired state of achievement for environmental values and socioeconomic conditions affected by management activities and resource decisions. The next step is development of alternatives that include a range of ways to resolve the issues. After the preferred alternative is selected, local guidance for resource functions is developed that contains resource management objectives.

Land use planning systems used by most federal agencies are divided into five distinct tiers: national, geographically defined management areas, individual resource functions, and strategic and tactical site specific implementation (Table I-1). National policy is established in public laws, federal regulations, Executive Orders, and other Presidential, Secretarial, and Director approved documents. Policy guidance for planning is developed, as needed, through interpretation of national policy, public participation activities, and from coordination and consultation with other federal agencies.

Table I-1: Relationship of Planning Tiers to Fire Management Objectives, Products and Fire Effects Applications

Planning Tier	Type of Objectives	Product	Fire Effects Applications
National		Policy and Regulations	National policies and guidance regarding fire presence and exclusion in wildland ecosystems
Geographically defined management area	Land use decisions	Resource Management Plan (BLM, NPS) Comprehensive Conservation Plan (FWS) Integrated Resource Management Plan (BIA) Forest Land Management Plan (FS)	Integration of fire and resource management within a geographically defined management area

Local guidance for individual resource components	Resource management objectives	Habitat Management Plan Compartment Plan Allotment Plan	The role of fire in resource management within a specific administrative unit.
Strategic site specific implementation	Strategic program objectives	Fire Management Activity Plans Fire Management Plan Fire Management Action Plan Wilderness Fire Management Plan	Identification of appropriate allocation of fire suppression, fire use and fuels management activities necessary to achieve resource management objectives
Tactical site specific implementation	Treatment objectives	Prevention Plan Presuppression Plan Escaped Fire Situation Analysis Postfire Rehabilitation Plan Prescribed Fire Plan Other	Interpretation and analysis of site specific fire effects to guide development and implementation of a program of action to accomplish treatment objectives

Resource management plans developed for geographically defined management areas establish the combinations of land and resource uses; related levels of investment, production, and/or protection to be maintained; and general management practices and constraints for various public land resources. These are set forth as the terms, conditions, and decisions that apply to management activities and operations and are presented in the form of multiple-use prescriptions and plan elements.

The third planning tier, developed at a local level, provide guidance for individual resource functions. At this level the role of fire is discussed, and how fire can be used or is detrimental in achieving the individual resource objectives.

Site specific stratigic and tactical implementation plans are the final step in the fire planning process. The primary role of these plans is to identify operational guidance to accomplish site specific treatment objectives. To continue with the example of the fire management component, Fire Management Activity Plans delineate areas to receive different levels of fire suppression, fire use, and fuels treatment. Resource management objectives developed at this level are derived directly from land use decisions. Prescribed fire plans refer to resource management objectives developed in activity plans and identify treatment objectives. Resource management objectives referenced in prescribed fire plans describe second order fire effects, the indirect effects of fire treatment that occur over the longer term, such as increased plant productivity, changes in species composition, or increased off-site water yield. Fire treatment objectives are developed from the resource management objectives and state exactly what immediate effects the fire must create in order to achieve the resource objectives. Fire treatment objectives describe first order fire effects such as plant mortality, fuel reduction, or duff consumption. An example of a fire treatment objective is: to remove 90 percent of existing sagebrush crown cover, using fireline intensities that consume sagebrush crowns, leaving residual stems that are six inches or less in height.

E. Summary

Land management programs are objective driven. Objectives must be based on an amount of information sufficient to determine if a change from the present condition to the proposed condition can be achieved. Establishing objectives is a task of major importance and deserves an allotment of sufficient attention and time. Both objectives and fire effects information become more precise as site specificity increases.

CHAPTER II - FIRE BEHAVIOR AND CHARACTERISTICS

by Melanie Miller

A. Introduction

Frequently a fire is described as hot or cool, high or low intensity, or flaming or smoldering. Too often fire behavior and characteristics are not described at all. Standard terminology exists for describing the behavior, characteristics, and heat regime of wildland fires. Monitoring and documentation of fire behavior and characteristics according to these standard terms can increase understanding of the relationship between the effects created by a specific fire and that fire's heat regime, and make comparisons among different fires possible.

The behavior of the flaming front of a surface fire can be predicted with fire behavior technology. Other characteristics of the surface fire, such as duration of all phases of combustion and penetration of heat into duff and soil layers cannot be predicted with existing models. The rate of heat release and growth of crown fires can be estimated. It is important to understand some of the different properties a wildland fire can have, how they can be described, which can be predicted, and how the various aspects of a fire's heat regime can be related to the fire treatment.

This chapter contains a brief overview of principles of fire behavior and characteristics. More detailed information can be obtained from formal courses in fire behavior and in courses that are prerequisites for certain prescribed fire positions. The chemistry and phases of the combustion process are described in the Air Quality chapter of this Guide, Chapter IV.B.1. The effect of fuel moisture on fire behavior is described in this chapter, but factors affecting fuel moisture content and fuel consumption are discussed in Chapter III.B, this Guide.

B. Principles and Processes

1. The Fire Environment. Wildland fire is influenced by three interacting classes of variables: fuels, topography, and air mass (Countryman 1972).

a. Fuels. Wildland fuels provide the energy source for fire. Fuels consist of both living and dead vegetation, the latter in various stages of decay. Fuels occur in three fairly distinct strata: ground, surface, and aerial. A fire can burn in one, two, or all three strata at once, or change the layer in which it is burning as fuels and environmental conditions change throughout an area. Fuels are discussed in greater detail in Chapter III. B.1., this Guide.

(1) Ground fuels. Ground fuels are all combustible materials below the surface litter layer. These fuels may be partially decomposed, such as forest soil organic layers (duff), dead moss and lichen layers, punky wood, and deep organic layers (peat), or may be living plant material, such as tree and shrub roots.

(2) Surface fuels. Surface fuels are those on the surface of the ground, consisting of leaf and needle litter, dead branch material, downed logs, bark, tree cones, and low stature living plants.

(3) Aerial fuels. Aerial fuels are the strata that is above the surface fuels and include all parts of tree and tall shrub crowns. The aerial fuel layer consists of needles, leaves, twigs, branches, stems, and bark, and living and dead plants that occur in the crowns such as vines, moss, and lichens.

(4) Ladder fuels. Ladder fuels bridge the gap between surface and aerial fuels. Fuels such as tall conifer reproduction can carry a fire from the surface fuel layer into tree crowns.

b. Topography. Topography includes slope, aspect, elevation, and how these elements are configured. Topography can change suddenly, particularly in mountainous terrain, and its influence on fire behavior can rapidly change as well.

(1) Direct effect.

(a) Slope is an extremely important factor in fire behavior because the flames of a fire burning upslope are positioned closer to the fuels ahead of the fire. This dries and preheats the fuels at a greater rate than if they were on flat terrain.

(b) Topography channels wind and can create turbulence and eddies that affect fire behavior. Topography also affects diurnal air movement, influencing the velocity of day time upslope and night time downslope winds.

(2) Indirect effect.

(a) The combined effects of aspect and elevation create different microclimates that affect vegetation distribution and hence fuel type.

(b) Fuel moisture can vary with aspect, elevation, and vegetation type. This is discussed further in Chapter III.B.4, this Handbook.

c. Air mass. Weather components such as temperature, relative humidity, windspeed and direction, cloud cover, precipitation amount and duration, and atmospheric stability are all elements of the air mass. These values can change quickly over time, and significantly with differences in aspect and elevation. The air mass affects fire both by regulating the moisture content of fuel (discussed in

Chapter III.B.4.), and by its direct effect on the rate of combustion. The following is a brief discussion of the effect of air mass factors on fire behavior and characteristics.

(1) Temperature. Atmospheric temperature affects fuel temperature. The ease of ignition, the amount of heating required to raise fuel to ignition temperature (320 C.; 608 F.) (Burgan and Rothermel 1984), depends on initial fuel temperature. The most important effect of temperature, however, is its effect on relative humidity and hence on dead fuel moisture content. (See Chapter III.B.4.).

(2) Windspeed. Wind has a significant effect on fire spread. It provides oxygen to the fuel and, combined with slope, determines which way the fire moves. Wind tips the flame forward and causes direct flame contact with fuel ahead of the fire (Burgan and Rothermel 1984). These fuels are preheated and dried by this increased transfer of radiant and convective heat. Windspeed has the most influence on fire behavior in fuel types with a lot of fine fuels, such as grasslands.

2. Combustion Process.

a. Two stage process. Within a wildland fire, the processes of pyrolysis and combustion occur simultaneously (Ryan and McMahon 1976 in Sandberg et al. 1978).

(1) Pyrolysis. When first heated, fuels produce water vapor and mostly noncombustible gases (Countryman 1976). Further heating initiates pyrolysis, the process by which heat causes chemical decomposition of fuel materials, yielding organic vapors and charcoal (ibid.). At about 400F. (204 C)., significant amounts of combustible gases are generated. Also at this temperature, chemical reactions start to produce heat, causing pyrolysis to be self-sustaining if heat loss from the fuel is small. Peak production of combustible products occurs at when the fuels are about 600 F. (316 C.) (ibid.).

(2) Combustion. Combustion is the process during which combustible gases and charcoal combine with oxygen and release energy that was stored in the fuel (Countryman 1976) as heat and light.

b. Phases of combustion. The following summary is derived from Ryan and McMahon (1976 in Sandberg et al. 1978), except where noted. For a more complete discussion of the phases of combustion, see Sandberg et al. (1978).

(1) Pre-ignition phase. In this phase, heat from an ignition source or the flaming front heats adjacent fuel elements. Water evaporates from fuels and the process of pyrolysis occurs, the heat-induced decomposition of organic compounds in fuels.

(2) Flaming phase. Combustible gases and vapors resulting from pyrolysis rise above the fuels and mix with oxygen. Flaming occurs if they are heated to the ignition point of 800 to 900F. (427 to 482 C.), or if they come into contact with something hot enough to ignite them, such as flames from the fire front (Countryman 1976). The heat from the flaming reaction accelerates the rate of pyrolysis. This causes the release of greater quantities of combustible gases, which also oxidize, causing increased amounts of flaming (Ryan and McMahon 1976 in Sandberg et al. 1978).

(3) Glowing phase. When a fire reaches the glowing phase, most of the volatile gases have been driven off. Oxygen comes into direct contact with the surface of the charred fuel. As the fuel oxidizes, it burns with a characteristic glow. This process continues until the temperature drops so low that combustion can no longer occur, or until all combustible materials are gone.

(4) Smoldering phase. Smoldering is a very smoky process occurring after the active flaming front has passed. Combustible gases are still being released by the process of pyrolysis, but the rate of release and the temperatures maintained are not high enough to maintain flaming combustion. Smoldering generally occurs in fuel beds with fine packed fuels and limited oxygen flow such as duff and punky wood. An ash layer on these fuel beds and on woody fuels can promote smoldering by separating the reaction zone from atmospheric oxygen (Hartford 1993).

3. Fire Behavior Prediction. The Fire Behavior Prediction System is a collection of mathematical models that were primarily developed to predict the behavior of wildland fires (Rothermel 1983). The models include those used to forecast behavior, area and perimeter growth of a surface fire; models that estimate spot fire potential, crowning potential, and crown fire behavior; and fire effects models that predict tree crown scorch height and tree mortality.

Solutions for most of these models can be obtained from nomograms (Albini 1976) and the BEHAVE system. BEHAVE is a set of programs for use on personal computers (Andrews 1986; Andrews and Chase 1989; Burgan and Rothermel 1984). More information about the BEHAVE system is contained in Chapter XII.C.1, this Guide.

4. Fire Spread Model. A fire spread model was developed by Rothermel in 1972 that allows managers trained in the use of the model to make quantitative estimates of fire behavior. The model is a mathematical representation of fire behavior in uniform wildland fuels. The fire spread model describes the processes that control the combustion rate: moisture evaporation, heat transfer into the fuel, and combustible gas evolution (Rothermel 1972).

a. Assumptions. Basic assumptions of the fire spread model are (Rothermel 1983):

(1) The fire is burning in a steady state in homogeneous surface fuels, not in crown or ground fuels.

(2) The percent slope and aspect are uniform.

(3) The wind is constant in both velocity and direction.

(4) The model describes fire behavior within the flaming front. The model does not describe behavior after the fire front has passed, such as during fuel burnout.

(5) The behavior of the fire is no longer influenced by the source of ignition or by suppression activities.

These assumptions are often violated when prescribed burning because ignition is often used to manipulate the fire. A common objective for burning is to consume fine fuels before the fire reaches a steady state. The predicted values do provide an estimate of fire behavior if a prescribed fire escapes.

b. Inputs to the Fire Spread Model. Required inputs to the fire spread model include fuel model, fuel moisture content, slope, and wind.

(1) Fuel model. A fuel model is a mathematical representation of the amount and kind of fuels present. The Fire Behavior Prediction System provides 13 standard fuel models that describe the characteristics of the portions of the fuel complex carrying the fire. Custom fuel models more closely describing a specific fuel situation also can be developed using the BEHAVE program (Burgan and Rothermel 1984). (See XII. C.1.a., this Guide.)

(a) Categories. In most situations, the flaming front of a fire advances through fine fuels such as grass, shrub foliage, litter, and small diameter down dead woody fuels. Wildland fuels can be grouped into four categories, according to the nature of the carrier fuels.

i. Grass or grass dominated: the primary carrier of the fire is grass.

ii. Shrub dominated: the primary carrier of the fire is either shrubs or litter beneath shrubs.

iii. Timber litter dominated: the primary carrier of the fire is litter beneath a timber (tree) stand.

iv. Logging slash: the primary carrier of the fire is residual material left from logging operations.

(b) Fuel properties. Fuel particles within a fuel complex have physical properties that influence the way they burn. The 13 standard fire behavior fuel models have specified physical properties (Anderson 1982). Properties can be changed to create a custom fuel model that may better describe a particular fuel complex.

(See XII.C.1.a., this Guide.) Fuel properties that are the most important for determining the way a fire will behave include the following.

i. Fuel loading. The amount of live and dead fuel is expressed in weight per unit area. Loadings are grouped by particle size class and are usually expressed in tons per acre (kilograms per square meter). Total fuel is all plant material both living and dead present on a site. Available fuel is the amount of fuel that will burn under a specific set of fire conditions.

ii. Fuel size class. Dead fuels are divided into size classes based on diameter: less than 1/4-inch, 1/4 to 1-inch, 1 to 3 inches, and greater than 3 inches. (Metric equivalents of these size classes are: less than 0.6 centimeters, 0.6 to 2.5 centimeters, 2.5 to 7.6 centimeters, and greater than 7.6 centimeters.) Fuel size class is related to the rate at which particles wet and dry. This is discussed further in Chapter III.B.4., this Guide.

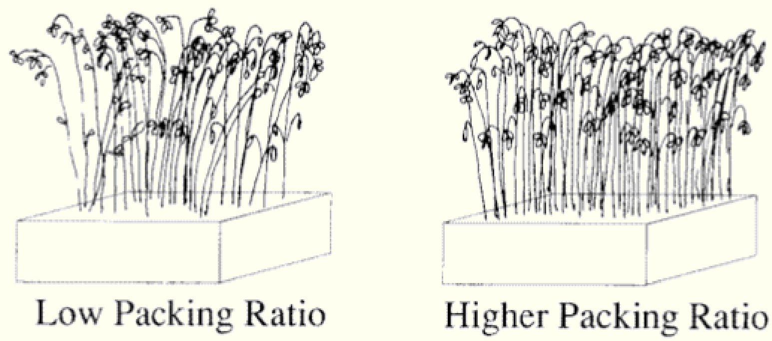
iii. Size class distribution. Fires usually start and spread in fine fuels, that is, those less than 1/4 inch in diameter. These fuels ignite increasingly larger size classes of fuels. If fine fuels or an intermediate size class are missing, a fire may not ignite or may not spread.

iv. Surface area to volume ratio. The surface area to volume ratio is a function of the particle size: the more finely divided the fuel material, the larger the ratio. Because small fuel particles have a large surface area compared to their volume, they dry out and ignite more rapidly than larger particles. Therefore, fine fuels usually have the most influence on fire behavior.

v. Fuel bed depth. Fuel bed depth is the depth of the surface fuel layer, i.e., the average height of surface fuels contained in the combustion zone of a spreading fire front.

vi. Packing ratio. The packing ratio is a measure of the compactness of the fuel bed. Expressed as a percentage, the packing ratio is the percentage of the fuel bed that is composed of fuel, the remainder being air space between the individual fuel particles (Burgan and Rothermel 1984). A fuel bed with no fuel has a packing ratio of zero, while a solid block of wood has a packing ratio of one (ibid.). A very open or porous fuel bed burns slowly because individual fuel particles are located so far apart that little heat is transferred among particles. A very compact fuel bed also burns slowly because airflow among the fuel particles is impeded, and there are large numbers of fuel particles that must be heated to ignition temperature. For every size of fuel particle, there is an optimum packing ratio at which heat transfer and oxygen produce the most efficient combustion (Burgan and Rothermel 1984). Compactness also influences the drying rate of fuel.

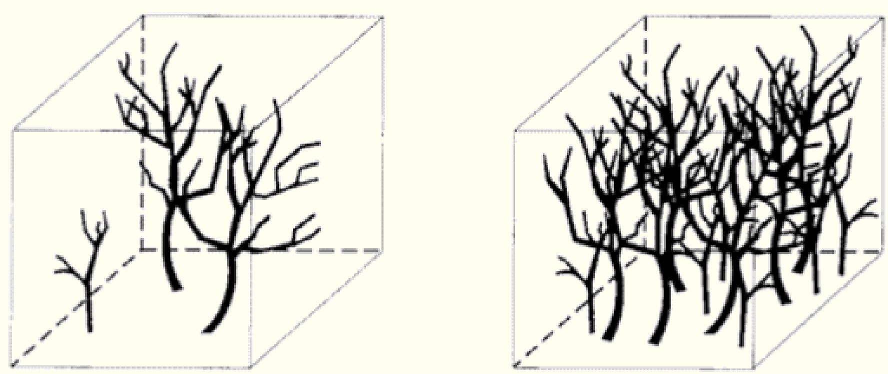
Packing ratio - percentage of the fuel bed volume that is composed of fuel.



Expressed as: ratio between 0 and 1.0.

vii. Bulk density. Bulk density is the actual fuel weight per unit. It is calculated by dividing the weight per unit area by the fuel bed depth. It is a measure of the oven dry weight of fuel per cubic foot of the fuel bed, usually expressed as pounds per cubic foot. The higher the bulk density of the fuel, the slower the spread rate, because more fuel must be preheated to ignition temperature in order for the fire to spread.

The actual weight of the fuel within a volume of a fuel bed.



Expressed as: pounds per cubic foot (lbs./ft^3), or grams per cubic centimeter (g/cm^3).

viii. Fuel continuity. Fuel continuity is a description of the distribution of fuels. Fire spread is most likely in continuously distributed fuels. The greater the fuel discontinuity, the higher the fireline intensity required for fire spread. Fuel continuity is described in terms of both horizontal and vertical continuity. Horizontal continuity relates to the horizontal distances between fuel particles and relates to percent cover. The proximity of tree or shrub crowns affects the ease with which fire can spread in a live fuel strata. Vertical continuity describes the proximity of surface fuels to aerial fuels and affects the likelihood that a fire can move into the vegetative canopy.

ix. Heat content. The most important aspect of fuel chemistry influencing fire behavior is heat content. This value expresses the net amount of heat that would be given off if the material burns completely (or at 100 percent efficiency), rated as Btu per pound of fuel. The heat content for all species of dead woody fuel is essentially the same (Albini 1976). The presence of pitch in wood, and of volatile compounds such as oils and waxes in some live fuels, increases heat content, and thus flammability.

x. Live fuels. Some fuel types contain a significant component of live fuels in the surface fuel layer, including shrubs, grasses, and forbs. The importance of live fuels to fire behavior can change throughout the year. Their volume can increase significantly during greenup and the early part of the growing season. They can lose their foliage at the end of the growing season or during a drought. Seasonal fluctuations in moisture content occur that significantly affect flammability. The moisture cycles within live fuels are discussed in more detail in Chapter III.B.5., this Guide.

While technically live fuels, mosses and lichens do not have physiologically controlled seasonal moisture cycles. Their moisture content is very sensitive to changes in temperature and relative humidity and can become as low as that of surface litter layers. A dry surface layer of mosses and lichens can readily carry a fire in black spruce forests in Alaska (Dyrness and Norum 1983).

The volatile compounds in some species of live fuels allow them to burn at a higher moisture content than if there are few or no volatiles (Norum 1992). Sagebrush (*Artemisia* spp.) is considered to be a moderately volatile fuel, while chaparral shrubs, conifers, and dead juniper are highly volatile fuels (Wright and Bailey 1982).

Fire behavior in stands of shrubs containing volatile compounds can be extreme. This is attributed not only to their chemical content, but also to the high percentage of dead material that some of these stands of shrubs contain, and the ideal mixture of fuel to air within the shrub canopy (Burgan 1993).

(2) Fuel moisture. Fuel moisture content describes how wet or dry the fuels are. Moisture content is the single most important factor that determines how much of the total fuel is available for burning, and ultimately, how much is consumed. Fuel moisture determines if certain fuels will burn, how quickly and completely they will burn, and what phases of combustion the fuels will support. Fuels with a higher moisture content reduce the rate of energy release of a fire because moisture absorbs heat released during combustion, making less heat available to preheat fuel particles to ignition temperature (Burgan and Rothermel 1984). Ignition will not occur if the heat required to evaporate the moisture in the fuels is more than the amount available in the firebrand (Simard 1968). Environmental factors regulating dead fuel moisture content, and the relationship between fuel moisture content and fuel consumption, are discussed in III.B.4., this Guide.

(a) Fuel moisture formula. Fuel moisture content is the percent of the fuel weight represented by water, based on the dry weight of the fuel. In a word equation, it is:

Percent Moisture Content = Weight of Water / Oven-dry Weight of Fuel x 100

Moisture content can be greater than 100 percent because the water in a fuel particle may weigh considerably more than the dry fuel itself. For example, a green leaf may contain three times as much water as there is dry material, leading to a moisture content of 300 percent. Moisture content of duff and organic soil can be over 100 percent. Methods to measure and calculate fuel moisture content are described in Chapter III.D., this Guide.

(b) Moisture of extinction. The extinction moisture content is the level of fuel moisture at which a fire will not spread. It is a function of the fuel type and fuel bed geometry (Byram et al. 1966 in Albini 1976). The moisture of extinction is much lower for light, airy fuels such as fine grass, about 12 to 15 percent (Sneeuwjagt 1974 in Albini 1976), than it is for dense fuel beds such as pine needles, in which it has been measured at 25 to 30 percent (Rothermel and Anderson 1966 in Albini 1976). Under favorable burning conditions, the moisture of extinction has little effect on fire behavior, but when "conditions for burning are poor, it can cause significant changes in predicted fire behavior" (Rothermel 1983).

(3) Slope. The steepness of slope is measured as the rise of the ground in feet for every horizontal foot traversed, commonly referred to as "rise over run."

Percent Slope = Rise / Run x 100

Percent slope can be measured directly with instruments or calculated from topographic maps.

(4) Wind. Both windspeed and direction are used as inputs to the Fire Behavior Prediction System.

(a) Midflame windspeed. The speed of the wind is measured at the midpoint of the height of the flames because this best represents the wind that blows directly on the fire. Most weather forecasts, and most weather measurement stations, give the windspeed at 20 feet (6 meters) above the ground or above local obstructions. For fire behavior calculations, the 20-foot windspeed is reduced to the speed occurring at the midflame height. This compensates for the friction effect of vegetation and land surface that slows the speed of the wind. The adjustment factor varies with vegetation type, amount of canopy closure, and position on slope.

20 Foot Windspeed x Wind Adjustment Factor = Midflame Windspeed

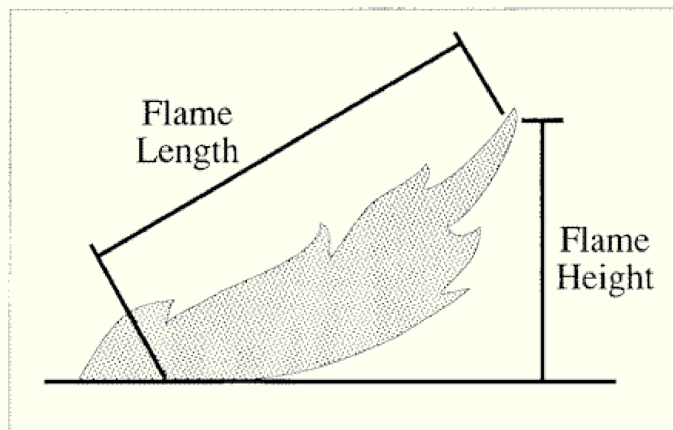
(b) Effective windspeed. As an intermediate step in obtaining solutions to the fire spread model, effective windspeed is determined. This value integrates the additive effects of slope steepness with a wind that is moving across or up a slope.

c. Outputs of the Fire Spread Model. The accuracy of predictions depends on how representative the fuel model chosen is of the fuels on the site, how accurately inputs are measured or estimated, and to what degree the situation meets the spread model assumptions. For predictions to be within a factor of two of actual fire behavior (from one-half to two times) is considered to be an acceptably accurate estimate (Norum 1993). The model is flexible enough that an experienced practitioner can make fairly good projections of fire behavior by carefully estimating or measuring the input values and tempering the results with judgment. Personal experience in a particular fuel type is necessary for refining output from this model.

(1) Forward rate of spread. One of the most important measures of fire behavior is the speed at which the fire moves across the landscape. The spread model calculates the rate of spread at the head of fire when the fire reaches its full, steady state speed. It predicts the speed of a fire burning in surface fuels, spreading on a single, unified front, that is not influenced by other ignitions. Rate of spread is generally stated in chains per hour, feet per minute, or meters per minute.

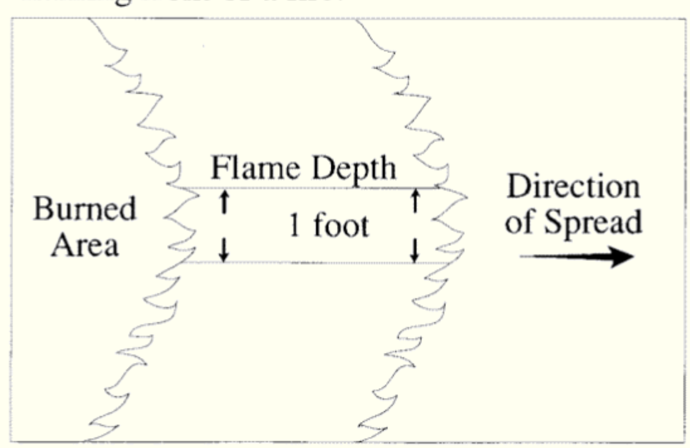
(2) Flame length. A second spread model output is the length of the flames when the fire has reached its full, forward rate of spread. Flame length is the distance along the slant of the flame from the midpoint of its base to its tip Flame height is the perpendicular distance from the ground to the flame tip and is not predicted by the fire spread model.

The average length of flame, measured along the slant of the flame from the midpoint of its base to its tip.



(3) Fireline intensity. Fireline intensity describes the nature of a fire in terms of its rate of energy release. Fireline intensity is the amount of heat given off by a fire along each foot of the leading edge of the fire each second, usually expressed as Btu per lineal foot of fireline per second.

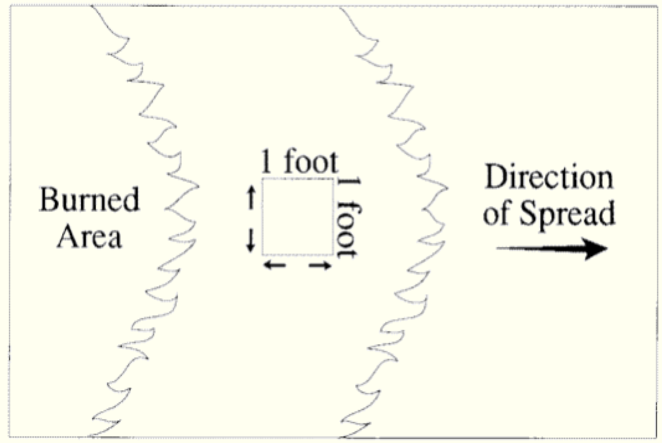
Rate of heat release in each **lineal foot** of the flaming front of a fire.



Btu's/lineal foot of fireline/second

(4) Heat per unit area. Another measure of the energy released from a fire is heat per unit area. It is the total amount of heat released in each square foot of the flaming fire front, usually expressed as Btu per square foot. All of the heat given off in the flaming front is included in this value, regardless of the length of time that the flaming front persists. For a given area with a specific amount and distribution of fuel, heat per unit area is inversely related to fuel moisture content. Heat released in flaming combustion that occurs as fuels burn out after the flaming front has passed is not included in the heat per unit area value.

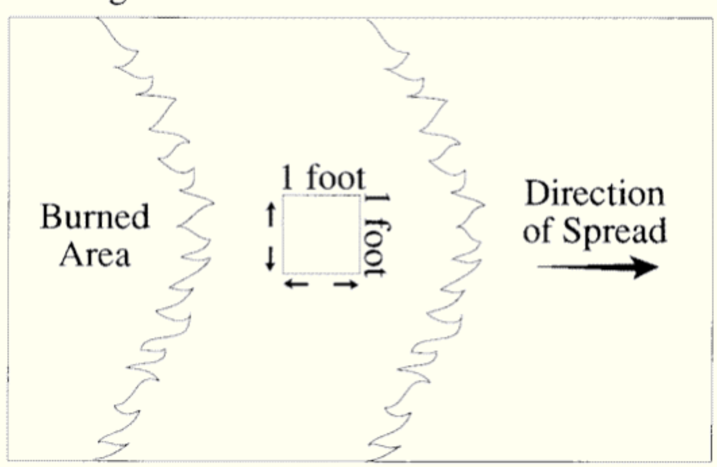
Rate of heat release in each **square foot** of the flaming front of a fire.



Btu's/square foot/minute

(5) Reaction intensity. Reaction intensity is a rate of heat release per unit area of flaming fuels, usually expressed in Btu per square foot per minute. This is the amount of energy released each minute by a square foot of flaming front, compared to heat per unit area which measures the total amount of energy given off per square foot. For a given fuel complex, reaction intensity can vary significantly with differences in moisture content.

Rate of heat release in each **square foot** of the flaming front of a fire.



Btu's/square foot/minute

d. Other predictable aspects of fire behavior.

(1) Probability of ignition. The probability of ignition, expressed as a percentage, is an estimate of the probability that a spark or firebrand landing on representative fuels will start a fire (Rothermel 1983). It is based on the amount of heat required to bring fine fuel to ignition temperature. Model inputs are fine fuel moisture, ambient air temperature, and the amount of shade.

(2) Maximum spotting distance. For many fuels situations, it is possible to make reasonably accurate estimates of the maximum distance to which fire may spot ahead by airborne embers (Rothermel 1983). The inputs required include the source of the embers, i.e. whether it is burning piles or trees; the species of tree, and their size and shape; the topography at and downwind from the fire; and the 20 foot windspeed. The model calculates the farthest distance a live ember is likely to be carried. It does not estimate how many burning embers will be lofted, or if the ember will ignite a spot fire. However, a combination of maximum spotting distance with the probability of ignition provides a workable idea of how far a fire may spot and the probability that it will cause a new fire.

(3) Crown fires.

(a) Classes. Van Wagner (1977) grouped crown fires into three classes based upon their dependence on the behavior of the surface fire.

i. Passive crown fires are those in which trees torch as individuals, ignited by the surface fire. These fires spread at essentially the same rate as surface fires. Trees torch within a few seconds with the entire crown enveloped in flames from its base to the top.

ii. Active crown fires are those in which a solid flame develops in the crowns. The surface and crown fires advance as a single unit dependent upon each other.

iii. Independent crown fires advance in the crowns alone, independently of the behavior of the surface fire.

(b) Crowning potential. The conditions necessary to cause the ignition of the crowns of trees or tall shrubs can be estimated. A probability of crown fires can be calculated, given the foliar moisture content and the height of the lowest part of the crowns. From these, an estimate can be derived of the fireline intensity needed to ignite the crowns (Rothermel 1983).

(c) Wind-driven vs. plume-dominated crown fires. The following discussion is taken from Rothermel (1991).

i. Wind-driven crown fire. A running crown fire can develop when winds blow flames from torching trees into adjacent tree crowns, or slope effectively accomplishes the same thing. Strong winds are the major force pushing the fire, and its spread rate can be greatly accelerated by slope. A strong convection column rapidly develops that is tipped over by the wind.

ii. Plume-dominated crown fire. A plume-dominated crown fire behaves quite differently from one driven by wind. Plume-dominated crown fires occur when windspeeds are fairly low. A strong convection column develops that rises above the fire, rather than leaning over before the wind. Air movement within the convection column generates the winds that cause significant rates of crown fire spread.

(d) Predicting size and intensity of crown fires. Rothermel (1991) presents methods for estimating and displaying the important elements of the behavior of a wind-driven crown fire. The model is applicable to coniferous forests of the northern Rocky Mountains, or forests with similar structure and fuels. Using these methods, an experienced fire behavior analyst can predict the rate of spread of a wind-driven crown fire, the length of flames, the time period when a particular crown fire will run, the probable area and perimeter of the crown fire, and the maximum rate of crown fire spread.

A method for calculating and comparing the power of a fire with the power of the wind is provided. The power of the fire is the heat energy released by combustion that drives the convection column, expressed as foot pounds per second per square foot. If the power generated by the fire is close to or exceeds that of the wind, a plume-dominated crown fire may develop. The onset of a plume-dominated fire may cause a sudden acceleration of the fire and faster spread rates than predicted. The model can thus predict the potential for onset of a plume-dominated fire, but not its behavior.

5. Relationships between Fire Behavior and Fire Effects. Few fire effects are known to be directly related to the behavior of the surface fire, that is to its spread rate, flame length, or rate of heat release. The following effects can be estimated from outputs of the Fire Behavior Prediction System.

a. Crown scorch height. There is a direct relationship between crown scorch height and flame length, ambient air temperature, and wind. All of these variables are used to measure the height above the surface of the ground that lethal temperatures occur. The height of tree crown scorch can be predicted from these values, using a model (SCORCH) in the Fire Behavior Prediction System. (See XII.D.1.a, this Guide.)

b. Tree mortality. A model (MORTALITY) estimates the percentage of tree mortality from scorch height, tree height, tree diameter, and crown ratio for eight species of conifers that occur in the northern Rocky Mountains. (See XII.D.1.b, this Guide.)

c. Total heat pulse to the site. Heat per unit area is a good estimate of the total heat pulse to the site when all of the fuel that is burned is consumed by the passing flame front. However, because this value does not account for long-term burnout of heavy fuels or organic soil layers, heat per unit area is not a very good estimate of the heat regime of the fire when much of the fuel, litter, or duff consumption occurs after the flaming front has passed.

6. Aspects of a Fire's Heat Regime that Cannot Presently Be Predicted. Many aspects of the heat regime of a fire cannot presently be predicted with any known model. Many of the most important and influential effects of fire on a site and its biological components are related to aspects of the heat regime of a fire that are not described by the Fire Behavior Prediction System.

Fireline intensity, as described in II.B.3.b.(3), is a rate of heat release that is related to flame length. However, the release of energy in flames has little relationship to the amount of subsurface heating (Hungerford 1989). Peak subsurface temperatures and the amount and duration of soil heating are not related to any value predicted by the Fire Behavior Prediction System. The effects of fire on fuels, soils, watershed, understory vegetation, and wildlife habitat cannot be estimated from measures of fireline intensity or flame length alone.

a. Fuel burnout time. This is the length of time that fuels continue to burn after the flaming front has passed, including all phases of combustion. The length of the fuel burnout period is related to fuel properties and fuel moisture but cannot be estimated by any known method.

b. Duration of smoldering and glowing combustion. Smoldering and glowing combustion are related to the amount of fuel, its size class distribution, thickness of duff and organic layers, and the moisture content of heavier fuels and duff. We cannot presently predict the duration of time during which these combustion phases will occur.

c. Total heat pulse to the site. Total heat pulse considers not only the heat released in flames but also that released by smoldering and glowing combustion. Heat per unit area only includes the amount of heat that is released in the flaming front. Extensive studies in physics modelling is currently underway at the Intermountain Fire Sciences Lab which may provide means to calculate the total heat pulse to the site.

d. Soil heating. Most heat produced by the flaming front moves upward. Downward movement of heat from flames cannot presently be predicted, but it is not believed to be a significant source of subsurface heat. Most soil heating results from long term fuel, duff, and organic layer burnout. Neither this heat, nor its penetration into soil layers, has been modelled.

e. 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 (Ryan and Noste 1985). 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. Factors regulating fuel and duff consumption, and thus burn severity, are discussed in Chapter III.B.2. and 3. The relationship between burn severity and its effects on plants is described in Chapter VI.B.1.c. and VI.B.2.c.

(1) Descriptive classes. An example of a set of burn severity classes is given below. Agency specific guidelines for assessing burn severity are described in USDI-NPS (1992).

(a) Unburned.

(b) Scorched. Foliage is yellow; litter and surface vegetation are barely burned or singed.

(c) Low severity. Small diameter woody debris is consumed; some small twigs may remain. Leaf litter may be charred or consumed, and the surface of the duff may be charred. Original forms of surface materials, such as needle litter or lichens may be visible; essentially no soil heating occurs.

(d) Moderate severity. Foliage, twigs, and the litter layer are consumed. The duff layer, rotten wood, and larger diameter woody debris is partially consumed; logs may be deeply charred; shallow ash layer and burned roots and rhizomes are present. Some heating of mineral soil may occur if the soil organic layer was thin.

(e) High severity. Deep ash layer is present; all or most organic matter is removed; essentially all plant parts in the duff layer are consumed. Soil heating may be significant where large diameter fuels or duff layers were consumed. The top layer of mineral soil may be changed in color; the layer below may be blackened from charring of organic matter in the soil.

(2) Relationship between fireline intensity and burn severity. There can be many combinations of fireline intensity and burn severity on any site, depending on fuel loading and distribution, and site weather and moisture conditions at the time of the fire. For example, given a site with good, continuous surface fuels, and a deep litter/organic layer, any of the following combinations of fireline intensity and burn severity can occur (as well as a lot of intermediate combinations).

(a) High fireline intensity/high burn severity. Both the carrier fuels and organic layer are dry. The result is a fire with high fireline intensity that exhibits vigorous fire behavior, that is also a deep burning, high severity fire. Flames are long, large fuels are removed, soil organic layers are consumed, and the long duration fire causes a significant amount of subsurface heating.

(b) High fireline intensity/low burn severity. The carrier fuels are dry, but the litter/duff layer is wet. The result is a fire with high fireline intensity, that exhibits vigorous fire behavior, but which is a very low severity fire because the organic layer is too wet to burn. Flames are long but little subsurface heating occurs.

(c) Low fireline intensity/high burn severity. The carrier fuels and surface litter are moist, and litter/duff layers are dry. The result is a fire of low fireline intensity that may barely cover the area, but of high burn severity wherever the litter/duff layer ignites because it is dry enough to burn. Even though the surface fire was of little apparent consequence, a significant amount of soil heating can occur, caused by the consumption of dry duff layers, peat, and/or large diameter downed woody fuels.

(d) Low fireline intensity/low burn severity. The carrier fuels are moist and the litter/duff layer is wet. The result is a fire with low fireline intensity that also has low severity.

(3) Application to shrub dominated communities. Burn severity concepts can also apply to litter and duff layers beneath isolated trees and shrubs.

(1) Low severity fire may just scorch the litter beneath the shrub or tree crown.

(2) A moderate severity fire may consume some basal litter and organic matter, but residual material remains. Some heating of deeper organic layers and soil may occur.

(3) A high severity fire removes all litter and duff, leaving only an ash layer. Significant amounts of soil heating can only occur where there is a high degree of consumption of thick, basal organic layers. Isolated patches of severely burned ground may occur where shrubs used to be, surrounded by extensive areas where little soil heating occurred.

f. Burn pattern. The pattern of a fire is the mosaic of burned and unburned vegetation and fuels. It can be further defined in terms of the degree of heating and consumption of fuels and vegetation, such as scorched compared to severely burned areas. A pattern can occur in the tree canopy, shrub canopy, in surface fuels, or in litter, duff, and organic layers. The size of the mosaic can vary from acres of scorched, consumed, and unburned patches in the canopy, to mosaic patterns of burned and unburned fuels and litter layers of only a few feet, or even inches. The effects of fire are closely related to the pattern of the fire, both on a large and small scale. Fire effects vary considerably with burn pattern because it reflects the variation in the fire's heat regime, above, at, and below the surface.

Significant variations in burn pattern are the result of differences in fuel continuity, fuel loading, fuel moisture, aspect, wind, and ignition methods and techniques. Whether a fire will become a surface or crown fire, and its effects on fuel consumption and soil heating, can be estimated by a person skilled in fire behavior or prescribed fire. However, there are presently no computational tools with which to predict the exact burn pattern that will occur.

C. Resource Management Considerations

1. Levels of Fireline Intensity. Different levels of fireline intensity, along with corresponding flame lengths, have special meaning both for the design of prescriptions for prescribed fire, and in wildfire management activities. From widely held and commonly agreed upon experience, the following are reliable rules (Rothermel 1983).

a. When fireline intensity is below 100 Btu per foot of fireline per second, flame lengths are less than 4 feet (1.2 meters).

(1) Fires can generally be attacked at the head or flanks of the fire by persons using hand tools.

(2) Handlines should be adequate to hold the fire.

b. Fireline intensity 100 to 500 Btu per foot of fireline per second; flame lengths are between 4 and 8 feet (1.2 to 2.4 meters).

(1) Fires are too intense for direct attack at the head of the fire by persons using hand tools.

(2) Handline cannot be relied upon to hold the fire.

(3) Equipment such as bulldozers, pumpers, and retardant aircraft may still be effective.

(4) Fires are potentially dangerous to personnel and equipment.

c. Fireline intensity 500 to 1,000 Btu per foot of fireline per second; flame lengths are between 8 and 11 feet (2.4 to 3.4 meters).

(1) Fires may present serious control problems, such as torching out, crowning, and spotting ahead.

(2) Control efforts at the head of the fire probably will be ineffective. Indirect attack is probably the only means of suppression.

(3) Fires are definitely dangerous to personnel and equipment.

d. Fireline intensity above 1,000 Btu per foot of fireline per second; flame lengths are greater than 11 feet (3.4 meters).

(1) Crowning, spotting, and major fire runs are probable.

(2) Control efforts at the head of the fire are ineffective by any known means of suppression. Indirect attack and tactical counterfiring may be the only means to slow the spread of the fire in certain directions.

(3) Fires are extremely dangerous to personnel and equipment in the immediate vicinity of the fire.

These values have obvious implications for holding actions on prescribed fires and suppression actions on wildfires. If only hand crews are available to hold a prescribed fire, and handlines are the only lines of control, then prescription variables (inputs to the spread model) should be set so that surface fires do not exceed 100 Btu per second per foot, nor flame lengths exceed 4 feet (1.2 meters).

2. Relationship between Moisture Content of Big Sagebrush and Fire Behavior. In vegetation types dominated by shrubs, moisture content of foliage can be a dominant factor in the behavior of wildland fires. Within a given geographical area, it is possible to determine threshold levels of foliar moisture content that relate to degrees of fire behavior activity and difficulty of control. In order to obtain such a database, foliar moisture content levels must be documented in areas where fires are occurring and fire behavior observations must be recorded. Sampling at established intervals over a period of several years and relating moisture levels to easily identifiable growth stages of the plants would provide the most useful information.

Threshold levels of moisture that relate to fire behavior in sagebrush have been determined for Nevada and eastern Oregon.

a. Nevada. When Greg Zschaechner worked for the Bureau of Land Management in Nevada on the Great Basin Live Fuel Moisture Project, he established guidelines that relate the moisture content of big sagebrush *(Artemisia tridentata)* to fire behavior and effective suppression tactics. Suppression tactics are included in the following descriptions because they provide additional description of the behavior of the fire. These levels are most accurate within Nevada but may serve as general guidelines elsewhere.

(1) 181 percent and above. Fires will exhibit VERY LOW FIRE BEHAVIOR with difficulty in continued burning. Residual fine fuels from the previous year may carry the fire. Foliage will remain on the stems following a burn. Fires can generally be attacked at head or flanks by persons using handtools. Handlines should hold the fire without any problems. Fires will normally go out when the wind dies down.

(2) 151 percent to 180 percent. Fires will exhibit LOW FIRE BEHAVIOR with fire beginning to be carried in the live fuels. Both foliage and stem material up to 1/4 inch (0.6 centimeters) in diameter will be consumed by the fire. Burns will be generally patchy with many unburned islands. Engines may be necessary to catch fires at the head. Handline will be more difficult to construct but should hold at the head and flanks of the fire.

(3) 126 percent to 150 percent. Fires will exhibit MODERATE FIRE BEHAVIOR with a fast continuous rate of spread that will consume stem material up to 2 inches (5.1 centimeters) in diameter. These fires may be attacked at the head with engines but may require support of dozers and retardant aircraft. Handline will become ineffective at the fire head but should still hold the flanks. Under high winds and low humidities, indirect line should be given consideration.

(4) 101 percent to 125 percent. Fires will exhibit HIGH FIRE BEHAVIOR leaving no material unburned. Head attack with engines and dozers will be nearly impossible on large fires, but may still be possible on smaller, developing fires. Flanking attack by engines and indirect attack ahead of the fire must be used. Spotting should be anticipated. Fires will begin to burn through the night, calming down several hours before sunrise.

(5) 75 percent to 100 percent. Fires will exhibit EXTREME FIRE BEHAVIOR. Extreme spread rates and moderate to long range spotting will occur. Engines and dozers may be best used to back up firing operations and to protect structures. Indirect attack must be used to control these fires. Fires will burn actively through the night.

(6) 74 percent and below. Fires will have ADVANCED FIRE BEHAVIOR with high potential to control their environment. Large acreage will be consumed in very short time periods. Backfiring from indirect line such as roads must be considered. Aircraft will need to be cautious of hazardous turbulence around the fire.

b. Eastern Oregon. Fire behavior and its relationship to moisture content in sagebrush has been monitored on Oregon rangelands east of the Cascades (Clark 1989). The following moisture levels indicate how readily a fire can propagate, given that adequate fine fuels are present between sagebrush plants to carry the fire, or that sagebrush density is high enough for flames to reach between plants where herbaceous fuels are sparse.

(1) Above 90 percent. Fire behavior is docile. The fire may or may not spread and is easy to control.

(2) 60 to 90 percent. Fire is much more difficult to control. Fire is likely to burn actively throughout the night, especially if wind is present.

(3) Less than 60 percent. The fire displays extreme fire behavior and rates of spread, and is essentially uncontrollable by normal suppression methods.

3. Effect of Fuel Type Changes on Fire Behavior. The dominating factor regulating fire behavior is wind in some fuel types and moisture content in others. The behavior of fires in fuel types with a large component of fine materials, such as the grass models, is most influenced by wind. Fuel moisture is much more important than wind in regulating the activity of fires in fuel types with a lot of larger diameter, dead woody fuels. Wind, while influential, is not so dramatically important in heavy fuels as it is in grass or shrub type fuels.

Fire behavior can drastically change when a fire moves into a different fuel type. If a fire moves from an area of logging residue to one dominated by cured grassy fuels, flame length and fireline intensity will probably decrease, but the rate of spread is likely to increase significantly. An optimal prescription for burning the logged unit to reduce hazard fuels would include low moisture content in smaller size classes of fuels and low windspeeds. Under these conditions, the desired amount of consumption in the harvested area would be achieved, and any escape into the grass fuels outside of the unit could easily be caught.

4. Effect of Long-Term Drying on Heat Release. Long periods of limited precipitation result in deep drying of the surface organic layers. Deeper drying of the entire fuel complex leads to an increase in fire behavior because of greater involvement of larger fuels and surface organic fuels in the fire front. Because more fuels burn in the initial stages of flaming combustion, fireline intensities and flame lengths can be greater. More heat can also be generated during smoldering and glowing phases of combustion, as deeper organic layers may burn. Fire effects may be much more notable than if the site had burned under less droughty conditions.

5. Burn Pattern. When igniting a prescribed fire, the pattern of burn that is being obtained should be noted throughout the ignition period. If the desired mosaic is not being obtained, alteration of ignition pattern may change the percent of the prescribed fire area that is actually being covered by fire.

6. Firewhirls. Firewhirls are tight, spinning vortices filled with flame and hot gas that have the appearance of a small tornado of fire. They can cause severe difficulty in controlling a wildfire or prescribed fire by spreading pieces of flaming material great distances beyond the project area.

When igniting a prescribed fire using strip headfires, it is important to let one strip of fire burn down in intensity before igniting the next strip. This avoids concentrated mutual convection, competition for incoming air, and a high probability of initiating firewhirls at the ends of the strips. Also, by skillfully designing the ignition pattern and sequence, the risk of firewhirls developing on lee slopes, and where two fires merge, can be minimized.

D. Methods to Monitor Fire Behavior and Characteristics

Fire prescriptions contain elements that define ranges of acceptable weather and moisture conditions that produce the desired fire behavior and characteristics. Monitoring for a prescribed fire can include monitoring of weather and fuel moisture before the fire to determine the daily weather patterns in a particular area and to determine how close moisture conditions are to the prescribed range. Some factors vary diurnally, such as temperature, relative humidity, and the associated moisture content of small diameter fuels. Other prescription elements, such as moisture content of soil organic layers or live fuel moisture content, decrease slowly, and weekly monitoring is often adequate to detect change.

It is important to monitor all elements of the prescription during a fire to determine that the fire remains within prescription, that the fire behavior predictions were adequate, and to correlate with the subsequent effects of the fire treatment. Whenever possible, information on fuel moisture, fire behavior, and fire characteristics should be obtained in the same location(s) as fire effects data collection occurs. In order to most effectively monitor rates of fire spread, flame length, and burn severity, some equipment may need to be installed before a fire.

If site characteristics vary on the burned area, specific site attributes should be documented as observations about fire behavior are made. Fuel type, vegetation type, slope, and aspect should be recorded, as well as a notation about the location where the observation is made. Whether the fire is a heading, backing, or flanking fire should be noted at the same time as observations are made.

1. Burning Conditions.

a. Fuel moisture. Fuel moisture is a critical determinant of fire behavior and characteristics. Techniques to monitor fuel moisture are described in Chapter III. D.4, this Guide.

b. Weather. An important part of monitoring fire behavior and characteristics is to have a good record of weather that occurred during the time that a fire occurs. A standard set of weather observations should be taken at regular intervals during the fire: temperature, relative humidity, windspeed and direction, clouds or other indicators of instability, and the presence of thunderstorms. Standard procedures for monitoring weather are detailed in Finklin and Fischer (1990). Agency specific guidance on weather data collection is available in USDI-NPS (1992).

2. Fire Behavior and Characteristics. Agency specific guidelines for monitoring fire behavior and characteristics are described for forests and for grassland and brush types in USDI-NPS (1992). The following description provides additional methods.

a. Rate of spread. Observations of rate of fire spread should only be taken after the fire has reached a steady state, because this is what the fire behavior system predicts. Rate of spread measurements are difficult to document on prescribed fires with center or perimeter firing patterns, or narrow strip headfires. In these situations the fire often has not reached a steady state, or its behavior is influenced by the ignitions that have occurred in adjacent areas. Whether the fire is heading, backing, or flanking at the point of observation should be noted. The following discussion is taken largely from Zimmerman (1988).

(1) Visual observation. Visual observation and pacing of distances can be used to take rate of spread measurements, particularly on a slowly moving fire. A stopwatch is used to determine how long it takes a fire to cover a specific distance. Rate of spread is calculated from the time/distance relationship.

(2) Metal tags. Numbered metal tags can be thrown at or near the flaming front.

A stopwatch is started when the front crosses a tag and a second tag is thrown ahead of the fire. When the flaming front crosses the second tag, the stopwatch records the elapsed time. The distance between the two tags is measured by pacing or steel tape, and the spread rate calculated.

(3) Grid marking system. When high spread rates are expected, and/or when it is not safe to be immediately adjacent to the fire, fire behavior can be measured using a grid system installed before the fire. Spacing of markers should be related to the expected rate of forward spread of the fire. Reference point markers can consist of materials such as flagging tape tied to branches or poles painted with bright paint. Times are recorded with a stopwatch or wrist watch as the fire burns past each marker, and rate of spread is determined.

(4) Sketch map. Sketch maps of the fire perimeter can be made at different times during the period of fire growth, a useful technique if reference points are plentiful or the fire will cover a large area. This method requires a good vantage point or the use of an aircraft. Rate of spread can later be calculated by dividing the distances between different landmarks by the time periods it took to cover these distances.

(5) Photography. Pictures of the fire can be taken at specific intervals and time noted when each photo is taken. A 35 mm camera with split lens can be used (Britton et al. 1977), in which one side of the image is focused on a watch, and the other on the flame. Cameras are now commercially available that record date and time on each image. The use of black and white infrared film greatly increases the value of this technique because it increases the quality of an image recorded through visually obscuring smoke.

(6) Video camera. Video cameras can be very successfully used when monitoring fire behavior. Time and other observations can be recorded on an audio track while recording the visual image. The advantages of video cameras include the potential for making a complete record of fire as it burns in specific areas, the fact that image quality can be immediately assessed, and that cameras are relatively inexpensive and very portable.

A computerized image analysis system has been used to study video tapes. A grid representing a known size or distance is set on the first frame, and subsequent measurements can be made from the screen image (McMahon et al. 1987).

b. Flaming residence time. Residence time is the amount of time that it takes the flaming front of the fire to pass a particular point. Residence time can be difficult to measure because of the indefinite trailing edge of the fire as concentrations of fuel continue to flame. It can be estimated from observations, still photography, or a video camera. The video position analyzer system (ibid.) also can be used to obtain more accurate residence time estimates. Use of infrared sensors or film are extremely useful when smoke obscures flames.

c. Fuel burnout time. Residence time discussed above is only a measure for flaming combustion. For monitoring that will later be related to fire effects, an estimate of the total duration of smoldering combustion of large diameter fuels and duff layers is important. Observation, repeated photography of the same points particularly with black and white infrared film, repeated video camera images, or a Probe-eye® can record fuel burnout time. Infrared images can sense higher temperatures caused by continued smoldering or glowing combustion when no visible signs of combustion are present. While it is not important to document the duration of long-term combustion to the exact minute, it is important to note whether smoldering combustion lasts for only a few minutes, or a few hours, or several days.

d. Flame length. Flame length is measured along the slant of the flame. The accuracy of estimation of flame length can be increased by installing reference points that provide scale. Steel posts with 1-foot sections alternately painted red and white or metal flags attached every 3 feet (the choice depends on the expected scale of the flames) set in the burn area work very well (Rothermel and Deeming 1980). These markers can be the same as those used to measure rate of fire spread.

(1) Observations. Flame length data are usually obtained from visual observations of average flame length at set intervals. Flame length is usually recorded at the same time as rate of spread observations are made.

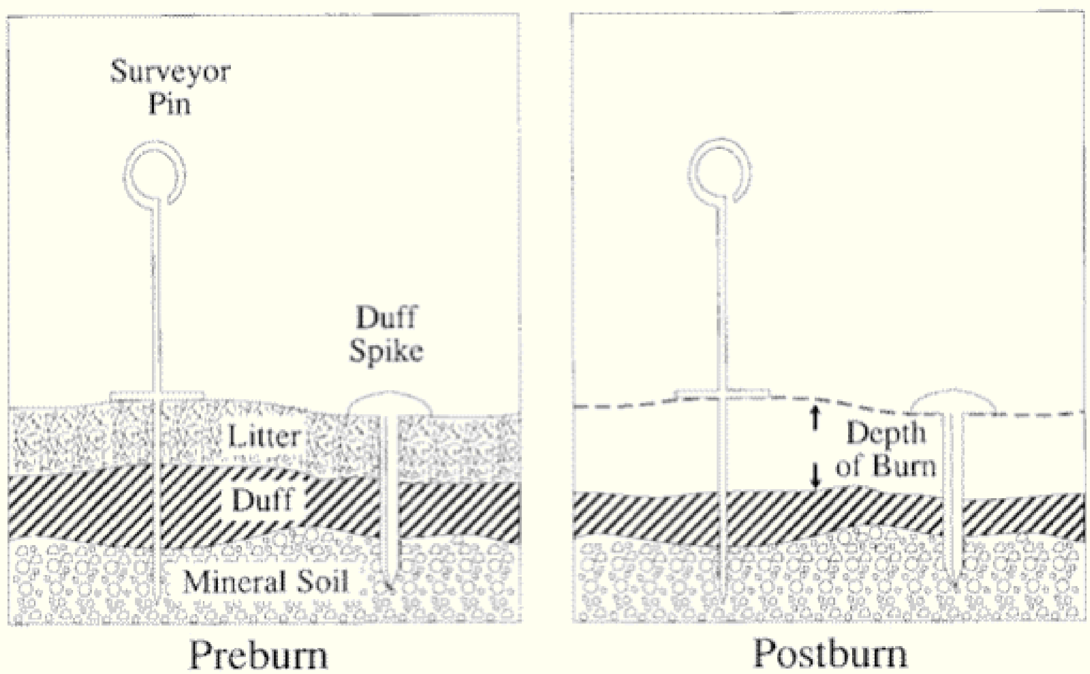
(2) Photography. Flame length can be documented with cameras and time and location of observation of each exposure recorded. Accuracy is enhanced by use of infrared film.

(3) Video camera. Not only are video cameras an excellent way of documenting fire behavior, the passive image analyzer mentioned above (McMahon et al. 1987) allows a very accurate measurement of flame length. After a grid of known size is established on the first frame, the tape is advanced until a representative flame is seen on the screen. The image is frozen on the screen, and the flame is outlined on the screen with a cursor. Computer software then calculates flame length.

e. Burn pattern. A map of the burned area can be made at both a gross and detailed scale. For general monitoring purposes, a map of the burned area can show areas where the tree or shrub canopy was removed, areas where the fire was an underburn, and areas the fire did not burn at all. Information on burn pattern can be obtained by a walk through the burned area, by long transects, or with photography. A low elevation aerial photo, or an oblique photo taken from a high vantage point such as a hill or a tree, can be measured with a dot grid to determine burn pattern. For large wildfires, satellite imagery can be used to obtain information on the pattern of burned and unburned areas, and where the fire was a surface fire or a crown fire. When choosing imagery for analysis, it must be remembered that up to about 2 weeks may pass before scorch damage to overstory tree foliage is apparent.

f. Burn severity/Depth of burn. The pattern of burn severity on the surface of the ground can be quite complex, because it varies with the distribution of prefire fuel loading and arrangement, thickness of litter and duff layers, and moisture content of surface and ground fuels. While mapping the pattern of burn in the surface fuels and vegetation for an entire burned area may be too large a task, burn severity, and the degree of canopy removal, should be noted in the areas where fire effects monitoring sites are located.

Surveyor pins or bridge spikes can be used in easy and practical way to monitor depth of burn. The pins or spikes are pounded into the ground before the fire, with a cross piece or top of the spike level with the top of the litter layer. After the fire, the amount of pin exposed is a measure of the depth of organic material removed. The amount of residual organic layer at each pin site can be measured to obtain an estimate of duff removal. Use of an inexpensive metal detector can make it much easier to relocate metal pins after the fire.



3. Potential Control Problems. The occurrence of any of the following during a prescribed fire should be noted and recorded and the Burn Boss or Fire Behavior Analyst notified.

a. Spotting. If spotting is occurring outside the burn perimeter, record the time of occurrence, distance from the fire front, and location on a map.

b. Torching or crowning. Torching or crowning trees may produce spots and may indicate that the situation requires extra caution. Note the time and location of occurrence and any relationship observed with surface fire behavior.

c. Firewhirls. The location and time of any firewhirls should be recorded. Observations about the fuels in the area of the fire whirls, or any relation to ignition method or technique, should be noted.

d. Fire behavior exceeding prescription limits. Any observation of rate of spread or flame length that exceeds specified limits could provide a potential control problem. Fire behavior less than that predicted is not necessarily a control problem, but can lead to an improper site treatment, and should be reported.

E. Summary

Knowledge of the behavior and characteristics of wildland fire are important both for managing fire and for understanding and interpreting the effects of fire. The heat regime created by a fire varies with the amount, arrangement, and moisture content of flammable materials on a site. Trained and experienced people can predict (within a factor of two) some aspects of the behavior and heat release of a flaming front of a fire, and some associated fire effects such as crown scorch. However, many fire effects are related to characteristics of fire that are not related to the behavior of the flaming front and cannot presently be forecast.

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CHAPTER III - FUELS

By Melanie Miller

A. Introduction

Fuel characteristics strongly influence how a given site will burn under specific environmental conditions. Fire also has an effect on fuels, because fire requires the consumption of fuel. Besides removing fuel, fire can result in the creation of additional surface fuel, as vegetation drops fire-killed leaves, needles, and twigs, and dead shrubs and trees fall and become part of the surface fuel layer.

All effects of fire on resources result from its effect on fuels, because the way that fuels burn determines the heat regime of a fire. Each fire varies in the amount of fuels that burn, the size class distribution of fuels that burn, the rate at which fuels burn, how much soil organic matter burns, and whether living plants become fuel. The nature of fuel consumption determines the peak temperatures reached, the duration of heat, and the stratification of heat above and below the surface.

Fuels such as litter, snags, and downed trees, have important effects on a site. Freshly deposited litter protects the soil surface from erosion by raindrops. Unburned logs and fallen fire-killed trees provide locations for mycorrhizae, nitrogen fixation, and habitat for birds, mammals, and insects. Standing snags provide habitat for many animal species that utilize this specific habitat.

This chapter will discuss the factors that regulate the effect of fire on fuels. Different types of fuels are defined, and the factors that control the amount of fuel and organic layer consumption are described. Dead and live fuel moisture content are discussed in great detail because moisture content is the most important determinant of the combustion process and the heat regime of the fire. Basic principles of fuel succession, the changes in the fuel complex over time, are summarized. Those properties of fuels that affect the behavior of a flaming fire are described in Chapter II of this Guide, Fire Behavior and Characteristics. Those aspects of combustion that affect smoke production are discussed in Chapter IV, Air Quality, this Guide. The role of downed logs and organic matter in regulating soil nutrients and their relationship to fire are discussed in the Soils chapter of this Guide, Chapter V. Wildlife use of dead woody material as habitat is described in Chapter VII, Wildlife Habitat.

B. Principles and Processes

1. Fuel Classification. Fuel is all vegetative biomass, living or dead, that can be ignited by lightning or an approaching fire front. Wildland fuels have been grouped into various classes.

a. Natural fuels vs. activity fuels. Natural fuels result from plant growth and death, loss of foliage, branch breakage, and tree blowdown. Activity fuels are similar to natural fuels but they are distributed differently in time and space due to human activity such as logging, thinning, chaining, and herbicide use.

b. Down, dead woody fuels. This class of fuels includes dead twigs, branches, stems, and boles of trees and shrubs that have fallen and lie on or above the ground (Brown et al. 1982). Wood can be either sound or rotten. Sound wood is essentially intact. It may have checks or cracks, but it still retains its structure. Rotten wood is partially decomposed. Material is punky or can be easily kicked apart. It can be important to distinguish between sound and rotten large diameter woody fuels because their moisture retention and combustion characteristics are very different. (See B.2.a.(3) and B.4.d.(3), this Chapter.)

c. Soil litter and organic layers.

(1) Litter. Litter is the top layer of the forest floor, typically composed of loose debris such as fine twigs, and recently fallen leaves or needles, little altered in structure by decomposition. Litter can also include loose accumulations of debris fallen from rangeland shrubs, and dead parts of grass plants lying on or near the surface of the ground. Some surface feather moss and lichen layers are also considered to be litter because their moisture response is similar to dead fine fuel.

(2) Organic layers.

(a) Duff. Duff is the partially decomposed organic material of the forest floor that lies beneath the freshly fallen twigs, needles and leaves. It is equivalent to the fermentation and humus layers of soil.

(b) Organic soils. Soils that are essentially composed of deep layers of organic matter form wherever production of organic matter exceeds rates of decomposition. They frequently develop in poorly drained areas where plant material partially decomposes in water or in saturated environments. Organic soils can be extensive in wetlands and in cool, moist climates (Buol et al. 1973). The amount of incorporated mineral material can vary significantly. The organic content of these soils can burn if soil moisture content is low enough.

d. Live fuels. Live fuels are living vascular plants that may burn in a wildland fire. Live fuels include trees, shrubs, grasses and grass-like plants, forbs, and ferns. Because of seasonal variation in their moisture content, the flammability of their foliage can vary significantly. Herbaceous plants, i.e., grasses and forbs, can cure, changing from a live fuel to a dead fuel. The leaves and older needles of trees and shrubs dry and fall from the plants, adding to the surface litter layer at the end of the growing season. Living plants may contain a large component of dead material, such as dead branchwood in older shrubs. This increases their flammability and the likelihood that the entire plant will be consumed by fire. Live fuel moisture cycles are described in greater detail in section B.5. of this chapter.

e. Fuel strata. Fuels have been classed as surface, ground, aerial, or ladder fuels. These terms are described in Chapter II.B.1.a., this Guide.

f. Total fuel vs. available fuel. Total fuel is the total amount of fuel present on a site. Available fuel is the amount that can burn, under a given set of conditions. The amount of available fuel depends on fuel size, arrangement, and moisture content (Brown and See 1981). Fuel size can affect availability if there are inadequate amounts of smaller sized fuels to burn and transfer enough heat to larger size fuels to raise them to ignition temperature. Standing tree boles are not considered to be available fuel because they are extremely unlikely to burn in wildland fires, except for smoldering in punky snags.

There can be long-term changes in fuel availability. The total amount of fuel within a stand increases as plants grow, while the distribution of fuel within a stand changes when snags or branches fall or foliage drops. There can also be short term changes in availability due to fuel moisture content. At any given point in time, the most important factor affecting fuel availability is its moisture content, because this determines whether fuel can ignite, and whether it can sustain combustion.

2. Factors Regulating Dead Fuel Consumption.

a. Relationship to physical and chemical properties of fuel. The key fuel properties that affect fire behavior were described in Chapter II.B.3.b. The following discussion explains how some of these factors influence fuel consumption.

(1) Fuel size. Fuels less than 1/4-inch diameter are almost completely consumed by fire over a wide range of burning conditions. Most branchwood between 1/4-inch and 3 inches is also consumed (Martin et al. 1979). A fair prediction of the consumption of large diameter dead woody fuels is possible if the average preburn diameter is known (Reinhardt et al. 1991).

(2) Fuel continuity. Fuel continuity relates to the proximity of individual pieces of fuel and also of different fuel strata. It affects fire spread, how much of an area ignites, and how much fuel is consumed. Breaks in fuel continuity contribute to patchy fire spread and may result in patchy fuel consumption.

(a) Forests. Large diameter fuels in local accumulations are more likely to be consumed than if these fuels are scattered. Anderson (1983) found that large downed woody fuels need to be within a distance of about 1.5 diameters of each other for interactive burning to occur.

(b) Rangelands/grasslands. Fuel consumption in range and grass types can be closely related to fuel continuity. If fuels are sparse, windspeed may not be adequate to spread the fire, limiting the amount of fuels that are ignited and consumed.

(3) Quality. Wood may be sound, rotten, or partially rotten. In north Idaho, consumption of rotten wood was greater than that of sound wood, even though moisture content of rotten wood was higher. Consumption of completely rotten pieces was higher than that of partially rotten pieces (Reinhardt et al. 1991).

(4) Heat content. The heat content of wood is about 8,000 Btu per pound (Albini 1976). Pitch adds to the flammability of wood because its heat content is about 15,000 Btu per pound (Carmen (1950 in Byram 1959). Pitchy fuels can burn at a much higher moisture content than those without pitch. A damp pitchy stump that is ignited is often completely consumed by fire.

(5) Fuel moisture content. The major effect of moisture on small fuel consumption is simply whether fuels are dry enough to ignite. Eighty to 90 percent of fine woody forest fuels are consumed wherever fire spreads (Brown et al. 1985). This is also true for fine rangeland fuels. The proportion of large diameter woody fuels consumed is more strongly influenced by their moisture content than by any other factor (Reinhardt et al. 1991).

b. Relationship to phase of combustion. The phase of combustion during which dead woody fuels are consumed is related to their size.

(1) Small diameter fuels. Fine fuels tend to be consumed during flaming combustion. However, the arrangement of small woody fuels sometimes does not provide enough mutual heating during the flaming state for complete consumption to occur. Blackened branches may burn off or fall into the ash and generate enough mutual heat for more flaming combustion to occur. Eventually the amount of heat that is generated decreases and can no longer support flaming, and the remaining consumption of these small pieces occurs by smoldering and glowing combustion (Norum 1992).

(2) Large diameter fuels. While the surface layer of woody fuels may initially support flames, most of the consumption of large woody fuels, both sound and rotten, occurs in the smoldering and glowing phases of combustion. Glowing combustion in large woody fuels commonly lasts for 10 to 20 times longer than the flaming phase (Anderson 1983).

3. Factors Regulating Consumption of Duff and Organic Soils.

a. Moisture content. As is true for large diameter woody fuels, moisture content is the most important variable influencing consumption of duff and soil organic layers. Duff and soil temperatures remain below the boiling point of water (100 C.) until all moisture is evaporated (Hartford and Frandsen 1992). Heating of organic layers to the high temperatures required for ignition cannot occur while moisture is present.

Specific relationships have been observed between duff moisture and duff consumption. At less than 30 percent duff moisture content, duff layers burn on their own once ignited, a threshold level observed in the southwest U. S., Pacific northwest, and the northern Rockies (Brown et al. 1985). At 30 to 120 percent duff moisture content, the amount of consumption of duff depends on the amount of consumption of associated fuel. When duff moisture content is greater than 120 percent, duff essentially will not be consumed.

Similar relationships have been found for organic soils. Peat is a deposit of slightly or non-decayed organic matter, while the organic content of muck is markedly decomposed (Buckman and Brady 1966). Peat burns well when its moisture content is below about 30 percent (Craighead 1974 in Hermann et al. 1991). Blocks of organic soil from south central Florida sustained smoldering up to 135 percent moisture content (McMahon et al. 1980 in Frandsen 1987).

Wet pocosin muck does not burn, but once the water table has lowered, these soils can ignite and sustain combustion. However, the moisture limits for ignition are not known (Frandsen 1993). Research is presently being conducted to determine factors affecting consumption in pocosin organic muck (Frandsen et al. 1993).

b. Surface fuel consumption. Heat generated by consumption of surface fuels can dry, preheat, and then ignite the duff layer. The amount of consumption of large diameter fuels was related to duff reduction and mineral soil exposure in north Idaho (Brown et al. (1991), and western Oregon and Washington (Little et al. 1986; Ottmar et al. 1990, Sandberg 1980).

c. Preburn duff depth. Duff consumption was strongly related to preburn duff depth in the northern Rocky Mountains (Brown et al.

(1991); in jackpine (Stocks 1989 in ibid.); Alaska black spruce (Dyrness and Norum 1983); white spruce/subalpine fir (Blackhall and Auclair 1982 in ibid.); and southwestern ponderosa pine (Harrington 1987), but not in deeper duff layers of the Pacific Northwest (Sandberg 1980; Little et al. 1986). **d. Inorganic content.** Mineral soil becomes mixed with soil organic layers by freeze-thaw cycles, insect and small animal activity, overland flow, windthrow, and management actions, particularly skidding of logs (Hartford 1989). Mineral material affects combustion of organic layers because it absorbs some of the heat that would otherwise preheat combustible materials (Frandsen 1987). The greater the amount of mineral material in the organic layer, the lower the moisture content of the organic layer had to be before it would burn (ibid.). If the ratio of mineral particles to organic matter (mass ratio) was greater than about 4 to 1, smoldering did not occur (ibid.).

e. Phase of combustion. Almost all consumption of duff and organic soils occurs during the smoldering and glowing phases of combustion. Combustion can continue for hours, days, and in the case of pocosin soils, for weeks after ignition, if organic layers are dry (Frandsen 1993).

4. Dead Fuel Moisture. Fuel moisture has a significant effect on fuel availability and fuel consumption because it suppresses combustion. Part of the heat produced by the combustion of wood is used to drive off moisture in adjacent woody fuel. If the moisture content is high, the heat generated may be insufficient to dry these fuels and heat them to ignition temperature, and the fire will not continue to burn.

Fuel moisture is the ratio of the weight of moisture in the fuel to that of the dry weight of the fuel. The formula for fuel moisture and its effect on fire behavior is described in Chapter II.B.4.b.(2), this Guide. Moisture effects on woody fuel consumption were discussed in B.2 a.(5), this Chapter, and on duff and organic consumption in B.3.a. The following discussion describes the most important factors affecting moisture content of dead woody fuels, litter layers, and duff and organic layers. Live fuels and their moisture cycles are discussed in B.5., this Chapter.

a. Wetting and drying process. Water in fuels can be present in liquid or vapor form.

(1) Liquid water. Liquid water comes from rainfall, snowmelt, or condensation. It can be present both on the surface, and within cell cavities (Schroeder and Buck 1970). At the fiber saturation point (about 30 to 35 percent of the fuel dry weight), the cell wall holds as much water as it physically can, but no liquid water is present within cell cavities (McCammon 1976).

Liquid water is readily absorbed by fuels through their surface, filling cell cavities and intracellular spaces (Schroeder and Buck 1970). In liquid water, molecules travel with different speeds and directions. A water molecule at or near the surface of a layer of water can attain a high enough speed after colliding with another molecule to escape from the liquid water into the air. By this process, called evaporation, a liquid water molecule becomes a water vapor molecule (ibid.). Evaporation is the primary drying process when fuels are saturated. It decreases in importance as fuels dry below the fiber saturation point.

(2) Water vapor. The following discussion is derived from Schroeder and Buck (1970), except where noted. Water present in the atmosphere in the form of a gas is called water vapor. That part of the atmospheric pressure due to the presence of water vapor is called vapor pressure. The maximum amount of vapor that the atmosphere can hold when it is saturated depends on the air temperature. Water vapor molecules move from an area of higher concentration to one with lower concentration until vapor pressure is equal.

Water molecules in fuels can be bound to cellulose molecules or held by capillary action in tiny openings in the cell wall (Simard 1968). Molecules closest to the cell walls are held the most tightly. Successive layers of water molecules are held with progressively weaker bonds until the cell walls become saturated. At less than saturation, water vapor moves between a fuel particle and the atmosphere if the vapor pressure of the layer of water in the fuel does not equal the vapor pressure of the atmosphere. If the vapor pressure within the outer layer of fuel is greater than that of the atmosphere, moisture escapes to the atmosphere, and fuel moisture content decreases. If the vapor pressure of the atmosphere is greater than the vapor pressure within the outer layer of fuel, the fuel takes water vapor from the atmosphere, increasing the fuel moisture content.

b. Equilibrium moisture content. Equilibrium moisture content (EMC) is the "value that the actual moisture content approaches if the fuel is exposed to constant atmospheric conditions of temperature and relative humidity for an infinite length of time" (Schroeder and Buck 1970). The EMC determines the amount of water vapor that a specific piece of wood can hold (Simard 1968). A unique EMC exists for each combination of atmospheric temperature and relative humidity, with the associated vapor pressure (Schroeder and Buck 1970). If fuel moisture content is greater than EMC, vapor diffuses out of the fuel, and the fuel becomes drier. If fuel moisture content is less than the EMC, water vapor transfers into the fuel particle and the fuel becomes wetter.

Atmospheric temperature and relative humidity are never constant and tend to vary diurnally. Equilibrium moisture content also varies. Because fuels usually take up and release moisture at a slower rate than the temperature and humidity changes, the actual fuel moisture content lags behind the equilibrium moisture content. The greater the difference between the equilibrium moisture content and the fuel moisture content, the more rapidly vapor diffusion occurs, and the more rapidly the fuel particle exchanges moisture with the atmosphere. As a particle approaches equilibrium moisture content, the exchange occurs more slowly. Fuel moisture content never reaches equilibrium moisture content, because other physical processes prevent a complete exchange of vapor (Schroeder and Buck 1970). A fuel that is gaining moisture stabilizes at a lower moisture content than a fuel that is drying (Simard 1968). Van Wagner (1987 in Viney 1991) noted a 2 percent lower EMC for wetting fuels compared to drying fuels.

c. Timelag theory.

(1) Timelag principle. Drying and wetting of unsaturated dead woody fuel has been described by the timelag principle. A timelag has been defined as the length of time required for a fuel particle to reach approximately 63 percent of the difference between the initial moisture content and the equilibrium moisture content.[(1)]

(2) Timelag period. Under standard conditions, defined as 80 F. and 20 percent relative humidity, the length of time that it takes a fuel particle to reach 63 percent of EMC is a property of the fuel and is referred to as the timelag period (Schroeder and Buck 1970).

(3) Timelag classification. The proportion of a fuel particle exposed to weather elements is mathematically related to its size. Small diameter fuel particles have large surface area to volume ratios. Moisture levels in these fine fuels can change rapidly with changes in temperature and relative humidity. Large diameter fuel particles have small surface area to volume ratios, and their moisture content changes very slowly in response to changes in temperature and relative humidity. Time lag thus increases with increasing fuel diameter.

(a) Dead woody fuel timelag classes. Downed dead woody fuels have been grouped into size classes that reflect the rate at which they can respond to changes in atmospheric conditions (Lancaster 1970). The classes relate to an idealized surface area to volume ratio and an average timelag that represents each fuel class. Classes relate to the theoretical length of time required to reach 63 percent of EMC.

i. 1-hour timelag fuels - less than 1/4-inch diameter (less than 0.6 cm).

ii. 10-hour timelag fuels - between 1/4-inch and 1-inch diameter (0.6 to

2.5 cm).

iii. 100-hour timelag fuels - between 1-inch and 3 inches diameter (2.5 to 7.6 cm).

iv. 1000-hour timelag fuels - between 3 and 8 inches (7.6 to 20.3 cm) diameter.

(b) Forest floor timelag classes. There is a loose correspondence between these timelag classes and forest floor litter and duff, although the deeper the duff layer, the more approximate is the relationship. The corresponding classes assigned for fire danger rating purposes were (Deeming et al. 1977):

i. 1-hour timelag fuels - dead herbaceous plants and uppermost layer of forest floor litter.

ii. 10-hour timelag fuels - layer of litter extending from just below the surface to 3/4 of an inch below the surface.

iii. 100-hour timelag fuels - forest floor from 3/4 inch to 4 inches below the surface.

iv. 1000-hour timelag fuels - forest floor layer deeper than 4 inches below the surface.

(4) Timelag of other fine fuels. Weathered aspen leaves, tree lichen *(Alectoria jubata)* and some cheatgrass fuel beds were shown to act as 1-hour timelag fuels (Anderson 1990). The surface layer of lichens and mosses that carries fire in Alaska responds as a 1-hour fuel to temperature/relative humidity changes (Mutch and Gastineau 1970). However, conifer needle litter of some species belongs in the 10-hour timelag category (Anderson 1990), despite its high surface area to volume ratio. Other factors such as surface covering influence the rate at which fuel moisture changes in response to environmental conditions.

d. Fuel properties that affect dead fuel moisture content.

(1) Surface covering. The presence of a surface coating of organic material can limit movement of water, whether liquid or vapor (Simard and Main 1982). Dead woody fuel with bark gained and lost moisture at two-thirds the rate of the same diameter fuels without bark (Simard et al. 1984).

Moisture exchange in recently cast conifer needle litter is inhibited by a coating of fat, waxes, and cutin deposits (Anderson 1990). Anderson (ibid.) noted timelags of 5 to 34 hours for recently cast conifer needle litter, rather than the expected timelag of 10 hours. Weathering causes the breakdown and removal of needle coatings that slow vapor transfer. Timelags of 2 to 14 hours were measured in weathered conifer litter, which is still slower than the timelag of less than two hours expected for that diameter of particle (ibid.).

(2) Composition. The material of which a fuel is composed affects its structure, porosity, ability to gain or lose atmospheric moisture, and the movement of vapor within the particle. Composition and fuel moisture response properties vary significantly among dead woody fuels, deciduous leaf litter, grass litter, and coniferous needle litter (Simard and Main 1982).

(3) Amount of decomposition. Woody fuels that have been affected by weathering and decomposition often develop deep cracks that increase their surface area to volume ratio. Both liquid water and vapor can enter or leave the fuel through these splits in the wood, increasing the rate of moisture exchange. There may be few naturally occurring forest fuels that are actually 1000 hour timelag fuels, because almost all large pieces of wood have cracks that effectively increase their wetting and drying rates (Miller 1988, personal observation).

The cell structure in highly decomposed wood, such as rotten logs, has broken down, and moisture can travel more easily through this material than through solid wood. The moisture content of rotten wood can be very different from that of sound wood of the same diameter.

(4) Thickness and density of litter or duff layer. Because litter and duff layers have porosities of 70 to 90 percent, air can diffuse through them at 60 to 80 percent of the diffusion rate in free air (Fosberg 1975). The particles of organic matter in these layers exchange moisture with the atmosphere in the void space in the litter and duff layer (ibid). The moisture within the voids seeks equilibrium with the external atmosphere (ibid.). Van Wagner (1979) observed that the drying environment within a 3 centimeter (1.2 inches) deep needle litter layer was less favorable at the bottom than at the top because the lower part of the layer was farther from the drying surface. Anderson (1990) noted that moisture diffusion rates were slower if litter fuel beds were deeper or more densely packed. The lower part of a litter and/or duff layer can become matted and tightly bound by fungal strands (Harrington and Sackett 1990). The wetting and drying response of this layer is likely to be slower than that of the more loosely packed material nearer the surface because of slower rates of water vapor diffusion.

e. Soil moisture effects on fuel moisture content. Afternoon moisture content of eucalyptus *(Eucalyptus spp.)* leaf litter placed on wet soils was much higher than litter placed on dry soils (Hatton et al. (1988). Moisture appeared to diffuse upwards from the wet soil, increasing the relative humidity environment of the leaf litter, causing higher litter moisture content (ibid.). The biggest effect of the wet soil was noted in early mornings, probably because wet soils made more moisture available to condense on dead leaves. Litter on the dry soils was dry enough for the litter to burn throughout the night, while litter on wet soil plots was too wet to burn.

Active surface fire behavior occurred throughout many night time burning periods during the 1988 fire season in Yellowstone National Park. Night time moisture recovery of lodgepole pine litter was much slower and reached lower maximum levels than expected (Hartford and Rothermel 1991). The limited amount of surface litter moisture recovery was partially attributed to the lack of moisture in the air and in the soil that could contribute to an increase in night time litter moisture content (ibid.).[(2)]

f. Effect of weather factors on fuel moisture content.

(1) Precipitation duration. Wood absorbs water as long as the surface is wet, so precipitation duration is usually more important than precipitation amount in determining moisture content of dead woody fuels (Fosberg 1971 in Simard and Main 1982). The rate of diffusion of liquid water into wood is usually less than the rate at which precipitation occurs, so much of the rain water drips off before it can soak into the wood.

(2) Precipitation amount. The amount of precipitation is more important than the duration of precipitation in determining the moisture content of duff, organic soils, and accumulations of organic materials that occur beneath isolated trees and shrubs. Duff layers and organic soils retain much of the precipitation that falls, allowing it to slowly soak into the fuel particles (Simard 1968 in Simard and Main 1982).

(3) Temperature. Temperature affects both the humidity of the air and its vapor pressure, and thus the equilibrium moisture content. Higher fuel temperatures decrease relative humidity in the microclimate near the ground (Rothermel et al. 1986), which also decreases the EMC. Higher fuel temperatures increase the tendency of bound water vapor to diffuse away from the fuel, thus drying it further (Schroeder and Buck 1970). Fuel temperature is affected by slope, aspect, time of day, cloud cover, canopy cover, sun angle, and the albedo of the fuel.

(4) Relative humidity. Relative humidity has a significant effect on moisture content of small diameter fuels because water vapor can readily penetrate into or escape from the center of small fuel particles. Diurnal changes in relative humidity have little effect on the moisture content of large diameter fuels because their large volume prevents rapid movement of moisture molecules between the surface of the fuel and its center. Relative humidity can have a major effect on large fuel moisture content if there is a long period of time without precipitation.

(5) Wind. Wind has its most important drying effect on woody fuels when liquid water is evaporating because it removes any layer of water vapor that may be adjacent to the fuel. Wind has a greater effect on wet fuel particles that are above the surface, causing them to dry more rapidly than material on the ground (Simard and Main 1982). When fuel is below the fiber saturation point and most vapor loss is by diffusion, the effect of wind becomes less important as the fuel becomes drier (Schroeder and Buck 1970). Wind has a more significant drying effect on small diameter fuels than on large diameter fuels, duff, or organic layers.

g. Relationship of topography to fuel moisture content.

(1) Fuel moisture tends to vary with topographic position. Fuels are less directly exposed to sun on north slopes than south slopes so their moisture content tends to be higher. Temperatures are generally cooler and humidities higher at upper elevations, so fuel moistures are usually higher than at lower elevations.

(2) Topography partially determines the strength of any night time inversion layer that forms. If a steep inversion and temperature gradient forms, fuel moisture recovery can be fairly high because of low temperatures and high relative humidities.

If an inversion forms in a valley, a thermal belt may form at the top of the inversion layer. In this belt, temperatures are warmer than at lower elevations within the inversion, and warmer than at higher elevations because temperature decreases with altitude. Higher night time temperatures, lower relative humidities, and lower fuel moistures occur within the thermal belt than at other locations along the slope. Fires can remain active throughout the night within the thermal belt, while activity is limited below the inversion layer (Schroeder and Buck 1970).

5. Live Fuel Moisture.

a. Effect of live fuel moisture on fire. Live fuels can either be a heat sink or a heat source in a wildland fire, depending on their moisture content. If live fuel moisture levels are high enough, they absorb some of the heat produced by associated burning fuels without themselves igniting, and thus do not contribute to the progress of the fire. If live fuel moisture is low, the combustion of dead fuels readily produces enough heat to desiccate and ignite the live fuels, which then add to the total amount of heat released by the fire (Burgan and Rothermel 1984). Live fuels can thus retard, stop, or contribute to fire spread.

b. Factors regulating live fuel moisture.

(1) Internal factors. Moisture content of living plants is controlled largely by species morphology and physiology. The amount of water in plant tissue, and thus its moisture content, relates closely to events during a plant's seasonal growth cycle (plant phenology). For a given species, the maximum and minimum moisture content values and the average values during different parts of the growing season are controlled more closely by the plant structure and its adaptations to the general climate of the area, than by daily weather. Seasonal timing of drying for specific deciduous shrub, forb, and grass species were found to be similar between wet and dry growing seasons, although moisture levels were generally higher in the wet season (Brown et al. 1989).

(2) Site factors. Site conditions can cause differences in moisture content within the same species, possibly because of physiological conditioning or even a genetic adaptation to the site (Reifsnyder 1961). Differences in foliar moisture content within a single species were related both to differences in substrate and the amount of shading provided by a forest canopy (Blackmarr and Flanner 1968).

(3) Climatic variation. Climate affects such factors as the timing and length of the growing season, the length of the green-up period, and the existence of seasonal periods of cold- induced dormancy or drought or heat-induced quiescence.

c. Differences among species groups. There are characteristic differences in seasonal moisture patterns for groups of species.

Deciduous leaved woody plants tend to have higher moisture content values than evergreen leaved plants, and the seasonal pattern of moisture changes tends to vary more. Coniferous trees have entirely different foliar moisture patterns than deciduous trees. Herbaceous species moisture levels can be higher or lower than that of associated shrubs, depending on the species present and the time of year. There are differences in average maximum and minimum moisture values among species within any group, depending upon the morphology of the species, and the relative amount of new and old growth on the plant.

d. Deciduous leaved shrubs. The general pattern for deciduous leaved shrubs is for moisture to rapidly increase to a peak level soon after bud break and begin to decrease after all new seasonal growth has occurred. Moisture then slowly declines for the remaining part of the growing season until leaves cure.

Data from Alaskan aspen stands illustrate variation in moisture content levels among deciduous species, as well as variability due to site differences (Norum and Miller 1981). Maximum spring moisture content of leaves and small twigs of highbush cranberry *(Viburnum edule)* (Illustration III-1, page III-24) was about 325 percent, but its moisture content dropped to about 225 percent by midsummer where it remained for most of the growing season. Rose *(Rosa acicularis)* on that same site in that same season had a spring maximum value near 375 percent, but its moisture content decreased to about 175 percent where it remained until fall curing. Maximum moisture levels for that same species of rose on a drier aspen site were less than 250 percent and persisted at about 165% for much of the growing season. Blueberry *(Vaccinium uliginosum)* (Illustration III-2, page III-25), a smaller stature deciduous species on a black spruce site nearby, had spring maximum moisture value of less than 250 percent and spent most of the summer at about 125 percent moisture content (Norum and Miller 1981).

For all of these species, moisture content did not significantly decrease as fall coloration appeared on the leaves. Moisture content began to drop markedly as the abscission layer formed at the bases of the petioles and cut off water transport to leaves, when obvious drying and browning of the leaves occurred (Miller 1981).

e. Evergreen leaved shrubs. The general pattern for broad-leaved evergreen shrubs is more complex than for deciduous species because evergreen shrubs sometimes retain old leaves for several years. They tend to have lower spring maximum values and much lower growing season average values than deciduous species. Values increase from an overwintering minima as new growth is added in the spring, or at other times of the year when precipitation triggers growth after a dry season. Values decrease significantly after new growth ceases. Some evergreen leaved species develop ephemeral leaves in late winter and early spring. Average foliar moisture content drops significantly as these seasonal leaves cure and drop from the shrub.

A typical profile for sagebrush *(Artemisia tridentata)* moisture content would be a rise from early to late spring from about 150 percent to about 250 percent, with a subsequent decline to 60 percent or less in mid to late summer (Schmidt 1992). Riedel and Petersburg (1989) found that the lowest summer levels for sagebrush moisture (Illustration III-3, page III-26) were reached one month earlier in one year than the previous summer. Sagebrush flammability has been related to threshold levels of moisture content. (See II.C.2., this Guide.)

In the Alaskan interior, maximum foliar moisture content levels for Labrador tea *(Ledum decumbens)* were only 145 percent, and that peak value occurred about a month after the maximum moisture values were reached in associated deciduous shrub species (Norum and Miller 1981). Moisture content of new leaves of chamise *(Adenostoma fasciculatum)* in California were at 125 percent in late May, dropped to about 60 percent in early September, and rose to about 90 percent when the plants again became physiologically active in early December (Dell and Philpot 1965). Maximum moisture levels for galberry foliage *(Ilex glabra)* averaged about 140 percent in North Carolina, while minimum values were about 100 percent (Wendel and Story 1962). Maximum values for redbay *(Persea borbonia)* foliage were about 120 percent, while fall and winter minima were around 60 percent (ibid.).

f. Herbaceous plants. Herbaceous moisture content can also vary significantly among species. Moisture levels can be much higher at the beginning of the growing season than for other species groups because all of the plant is new tissue. Also, because there is no residual material, all of the plant can become cured, sometimes before the end of the growing season. This is especially notable for grasses and other species in areas with hot, dry summer weather. In north Idaho, moisture content of cheatgrass *(Bromus tectorum)*, an annual grass, for example, was measured to be 150 percent on June 20, but was only 9 percent on July 20 (Richards 1940). All of the plant material, once cured, responds to atmospheric conditions as a dead fine fuel, as reflected by the 9 percent moisture level just cited.

Some species of grasses and forbs in some regions can produce new growth in the fall, after a summer of quiescence, thus causing fall green-up and associated increase in moisture content. Green-up is caused by renewed growth of perennial species and germination of seeds.

Some herbaceous species do not cure and dry out during the summer, rather only begin a significant amount of curing as frost occurs in the fall. In north Idaho, moisture content of fireweed *(Epilobium angustifolium)* plants was 426 percent on June 20 and 241 percent on September 10 (ibid.). In interior Alaska, bluejoint reedgrass *(Calamagrostis canadensis)* was first measured at about 400 percent moisture content on May 27 when the plants had about 1 to 1-1/2 feet of leaf growth. Moisture content of plants declined to about 260 percent by June 30 and was about 200 percent on August 28, just before the first frost (Norum and Miller 1981). In north central Michigan, large leaved aster *(Aster macrophyllus)* was measured at about 420 percent moisture content at the beginning of June, and the lowest moisture level observed for the rest of the summer fluctuated around 300 percent (Loomis and Blank 1981).

Data for most herbaceous species show only a slow decrease in moisture levels after early growing season maxima. However, in western Wyoming, grasses and forbs had some increase in moisture content in response to mid-summer rain. By September, however, the drying trend was not altered by rainfall (Brown et al. 1989).

g. Coniferous trees. Moisture content of coniferous foliage also varies significantly with season but the pattern is quite different than that shown by deciduous and herbaceous species. Coniferous species retain their needles for several years; the number of years is a species characteristic.[3] For most species, the lowest level of moisture content of needles formed in previous years occurs in late spring, during about the same time period in which buds expand, and new needles and twigs are formed. Moisture content of old needles increases during most of the growing season to a maxima during late summer and/or early fall (depending on species and region).

Moisture content of new needles is very high as buds break, needles grow, and stems elongate, but starts dropping significantly about the same time as the new terminal bud on the end of the current year's growth forms. The moisture content of new foliage drops to about the same level as that of old foliage late in the growing season. In the southeastern U.S., conifers may flush more than once during the growing season. The moisture cycle in older foliage may be different from that of conifers that grow in climates with winter cold and/or shorter growing seasons.

The difference between low and high moisture values for 1-year-old black spruce *(Picea mariana)* foliage in Alaska varied from 28 to 40 percentage points on different collection sites (Norum and Miller unpublished). Seasonal lows occurred in June and seasonal high values in August (Illustration III-4, page III-27). Seasonal low values for Douglas-fir foliage occurred in mid to late June in Montana, with a peak value reached by early September (Philpot and Mutch 1971; Rothermel 1980). The range between high and low values varied from about 20 to 40 percentage points.

Crown fires were much more prevalent in Douglas fir trees burning in late spring and early summer experimental fires than on those sites burned in late summer and early fall (Norum 1975). Low springtime foliar moisture values may explain the observed difference. The peak of the fire season in boreal latitudes is usually shortly after summer solstice, and the low foliar moisture content of black spruce may be a factor in tree crown ignition. However, the fire season in the western United States generally peaks in August, at a time when moisture content of conifers is increasing to a seasonal high. The readiness of western species of conifers to crown during extreme fire weather is not due to low foliar moisture values, although it may be enhanced by early drying of the oldest needles.

Measured moisture content of live foliage in northeast Oregon, southwest Idaho (Miller 1988), and northwest Wyoming (Hartford and Rothermel 1991) in the extreme fire season of 1988 was not different from normal moisture values for that time of the year. Experimental evidence suggests that conifers can rapidly transport water into their foliage when heated to temperatures that occur in a wildland fire (Cohen et al. 1990). This can delay branch and foliage drying and could inhibit crown heating and ignition. During drought conditions, trees may not be able to transport water into their crowns, increasing their flammability and hence their crowning potential (ibid.).

6. Fuel Succession. Vegetative biomass tends to accumulate over time. However, not all biomass is available fuel. Biomass is all of the vegetation on a site, while available fuel is what can burn. Fuel succession is the change in the fuel complex over the long term, including changes in loading, size distribution, availability, and live to dead ratios. These changes are the net result of the counteracting processes of accumulation and depletion (Brown 1987).

a. Accumulation.

(1) Litter layer. The amount of foliage that is produced each year affects the amount of new litter that accumulates. Because coniferous trees retain their needles for several years, there may be no relationship between the productivity in a particular year and the amount of needle litter added to the surface fuel layer.

(2) Dead woody fuels. Insects, disease, suppression of individual trees in young stands, and death of lower branches of trees can provide a source of dead woody fuels. These events, and the timing of the addition of the fuels, occur irregularly, as branch material is broken or entire trees fall because of wind, and heavy snowfalls (Brown 1975). Fire can kill trees and shrubs, and whatever woody material is not consumed can become surface dead woody fuels.

(3) Duff and organic layers. Material is added to these organic layers as the lower part of the litter layer, and moss and lichen layer, decompose. Rotten woody material is gradually incorporated into the forest floor, and becomes part of the duff layer.

(4) Live fuels. Shrubs, herbaceous plants, and young conifers can establish and/or increase in volume. Branches die, and increase the flammability of trees and shrubs.

b. Depletion.

(1) Litter. Dead plant material can oxidize and essentially disappear during one growing season. It can remain into the next growing season, be compacted beneath additional litter, and decompose enough to become part of the duff layer.

(2) Dead woody fuels. Dead woody fuels physically deteriorate and settle over time, and compactness increases as supporting branches decay (Brown 1975). A more compact fuel bed is less well aerated, and may dry more slowly, have a higher moisture content, and be a more favorable environment for additional decomposition.

(3) Live fuels. Productivity of an understory layer of shrubs and herbaceous plants can decrease significantly as the canopy closes, resulting in a much lower annual addition of litter. A coniferous fuel ladder can grow tall enough that its lower branches no longer provide a bridge between surface and crown fuels.

c. Patterns of fuel succession.

(1) Forests. The generality that downed woody fuels accumulate over time is, in many cases, not true (Brown and See 1981). The amount of forest fuel depends on stand history, whether the stand was visited by insects, disease, wind, and fire, and at what intervals. The size and pattern of disturbance, and amount of fuel that results, can vary with the event, and tree and branch mortality can be compounded by drought. Agee (1993) also relates the amount of forest fuel to stand disturbance. Changes in the amount of fine and coarse woody fuels over time relate to the amount of biomass present before a disturbance, the severity of the disturbance, and successional patterns after the stand is disturbed (ibid.).

(a) Relationship to stand disturbance. When a wildland fire occurs in a forested stand, the severity of the impact on the stand, and resulting amount of surface fuels and rate of their accumulation, can vary (Muraro 1971 in Brown 1975). For example, if a fire occurs in a lodgepole pine stand that burns only in surface litter layers, it can kill or weaken many of the trees but not consume much of the foliage. Surface fuels increase moderately as trees die and fall. A fire in a lodgepole pine stand that burns into the duff layer can consume many structural tree roots. This makes trees susceptible to rapid blowdown, and fine fuels are added to the stand at a much higher rate than after a lower severity fire. A high intensity crownfire in a lodgepole pine stand can burn off many of the fine branches in the tree crowns. If it also burns deeply into the duff layer, most of the trees will fall fairly quickly. Most of the fuel added would be large diameter material. Because downed trees are not supported by small diameter branchwood, they would come into contact with forest floor sooner and decompose more readily.

Whether the young stand of lodgepole pine that establishes after fire has a low or high dead fuel loading also depends on the frequency of fire. The stand that develops after a fire that caused rapid blowdown of trees with a lot of branchwood would have a high loading of dead fuel in all size classes. If a fire occurs in this young stand of trees, much of the crown-stored seed could be destroyed and most of the fuel consumed. A sparse stand of lodgepole pine could subsequently establish that has a much lower loading of dead woody fuel than the previous stand (Muraro 1971 in Brown 1975).

(b) Varying patterns among live and dead fuels. Fuel succession is more complicated if live and dead fuels are involved (Brown and See 1981). There may be an increase in one class of fuel while another is decreasing or becoming unavailable. Dead woody fuel may decompose while an understory of trees establishes. The loading of dead woody fuel may increase while some trees become tall enough to be much less available to surface fire (Brown and See 1981). Early successional herbs, such as bracken fern in western Oregon, can cause a high loading of fine fuels before the canopy closes and shades out these plants (Isaac 1940 in Agee 1993).

(c) Relationship to stand age. There is no clear relationship in the northern Rockies (Brown and See 1981) between stand age and amount of dead woody material. The amount of fuel in young and mature forests cannot be related to age because too many other factors are involved. The only generalities are that downed woody fuel loadings tend to become predictably high as stands acquire old growth characteristics, but loading is unpredictable from age alone in young, immature, and mature stands (ibid.).

In western Oregon and Washington, stand replacing fires generally occur at much longer intervals than they do in the northern Rocky Mountains. Fuels in the 0 to 3-inch (to 7.6 cm) range are usually at their highest levels in early stages of postfire succession (Agee 1993). 1000-hour fuel biomass is highest in mid-successional stages when some stems die because of naturally occurring self-thinning. Biomass of larger logs is greatest in the oldest stands.

(d) Relationship to site productivity. Fuel loading and site productivity are not well correlated (Brown and See 1981). In warm, moist forest types, productivity is fairly high, but fuel may not accumulate because the decomposition rate keeps up with fuel production (ibid.). In cool, dry forest types, productivity tends to be low, but a relatively higher proportion of biomass may accumulate as fuel because decomposition is limited (ibid.).

(e) Relationship to fire exclusion. In many areas of the western U.S., naturally occurring fires used to occur at a fairly high frequency. With the onset of organized fire suppression activities, and the removal of fine fuels by livestock grazing, wildland fires became an infrequent event in many forest types. If fire exclusion has removed several fire cycles from a forested stand, the ecological effect is much more profound than if fire has only been effectively suppressed for one-third of the length of a stand's natural fire rotation. In parts of the southwestern U.S., for example, the exclusion of fire from ponderosa pine stands that previously burned at intervals ranging from 2 to 10 years has resulted in higher loadings of litter, forest floor duff, and in some cases, down dead woody fuels (Harrington and Sackett 1990). While the amount of fuel may not be predictable from age, it is logical to conclude that there is more fuel in stands without understory fire for 80 to 100 years than if underburns had continued to occur at frequent intervals.

(2) Shrublands.

(a) Sagebrush. The percentage of dead stemwood in sagebrush *(Artemisia tridentata)* plants increases with age. However, when modelling the effect of higher proportions of dead branchwood on fire behavior, only a small increase was found (Brown 1982). The total amount of fuel correlates to the height of the stand, but stand height does not correlate well with age (ibid.). The amount of fuel in older stands of sagebrush is greater if the volume and density of shrubs has increased.

(b) Chaparral. Old stands of chaparral have been observed to be more flammable than young stands, and this difference has been attributed to an increasing proportion of dead branch material in older age classes of shrubs (Paysen and Cohen 1990). No correlation was found between the percentage of dead branch material and age of chamise in southern California (ibid.).

Because all leaves and fine branch material in the chaparral canopy tends to be consumed by fire when foliar moisture content is low, a stand with more leaves and twigs has more fuel. For any given site, the amount of biomass tends to increase with age of the stand, and it may be this increase in total biomass that causes the higher flammability observed in old stands. However, because of variability in site productivity and species composition, it cannot be said that every stand of chaparral of a certain age is more flammable than a stand that is younger.

C. Resource Management Considerations

The primary ways to manipulate fire effects on fuels are to modify fuel availability and to change the way an area is ignited and burned.

1. Fuel Availability.

a. Fuel moisture.

(1) Change the prescribed fuel moisture. When planning a prescribed fire, the moisture contents specified in the prescription can be chosen to achieve selected effects on fuels.

(a) Fine fuel moisture. Fine fuel moisture indirectly affects overall fuel consumption by determining which fuels ignite. Fine fuel moisture is defined by specifying different ranges of temperature and relative humidity in the prescription.

(b) Large fuel moisture. In forested areas, the moisture content of large diameter woody fuels is the chief factor affecting the amount of total consumption. Remember that rotten woody material can burn at a much higher moisture content than sound material of an equivalent size.

(c) Duff and organic layers. Consumption of soil organic material is also directly related to its moisture content (Brown et al. 1985).

i. At moisture content greater than about 120 percent, duff will not burn.

ii. At moisture content less than about 30 percent, duff will sustain combustion on its own once ignited.

iii. The amount of consumption of duff between 30 and 120 percent moisture content depends on the amount of consumption of associated fuels. **(d)** Live fuels. By prescribing the moisture content of live fuels in the surface fuel layer, the amount of their flammability and consumption is regulated. The amount of scorching of a conifer canopy may be greater early in the growing season when trees are just becoming physiologically active and foliar moisture content is lower than it is later in the year. Live fuels may be consumed, regardless of their moisture content, if a large loading of dry, dead woody material burns.

(2) Alter the fuel moisture. Use of water or foam changes the moisture and burning characteristics of fuel. These techniques are commonly used to build fireline and protect specific features, such as wildlife trees.

b. Fuel loading and distribution.

(1) Remove the fuels. Less fuel is available, and there is less potential for heat release, if fuels are removed from a site. Fuels can be removed by:

(a) Grazing.

(b) Commercial thinning of forests.

(c) Firewood sales.

(d) Yarding unmerchantable material to a central location during forest harvesting operations.

(2) Change the fuels. If fuel distribution or arrangement is changed, flammability, and the potential for heating, changes.

(a) Crushing. Crushing fuels increases fuel bulk density and can make the rate of burning slower. However, if crushing compacts fuels to a more ideal arrangement, it may enhance combustion.

(b) Lopping and scattering. Cutting and scattering of branches during a logging or thinning operation makes fuel continuity more uniform, but also decreases the potential for concentrated heating where piles of branches would have been located.

(c) Piling or windrowing. Piling or windrowing fuels breaks up the continuity and decreases the likelihood that fire can spread. A fire that starts (or is started) in a pile or windrow has a greater potential for subsurface heating if low moisture content of larger pieces and low amounts of intermixed mineral soil permit a high degree of consumption.

(d) Chaining. Chaining woodlands or shrub dominated areas alters the distribution and continuity. If removal of the trees or shrubs allows more grasses and forbs to grow (or if they are seeded), the flammability of the site will be significantly higher because of the presence of downed woody fuels.

(e) Herbicide. The use of herbicide to kill shrubs and woodland trees results in a large amount of standing dead vegetation. Intermixture of newly established grasses and forbs will result in a highly flammable site.

c. Fuel chemistry. Application of long term fire retardants inhibits fuel ignition and hence fuel consumption.

2. Ignition.

a. Backing vs. heading fires. Backing fires usually result in more complete fuel consumption, particularly of litter and duff layers, than heading fires.

b. Mass firing. Use of mass firing techniques, such as center firing or concentric firing, may result in more complete consumption of fuels, for a given moisture regime, than if a backing or heading fire were used.

c. Ignition devices. Use of ignition devices such as a heli-torch that can apply a lot of fire in a short period of time can result in a fire that causes more woody fuel consumption than if surface ignition were used.

D. Methods To Monitor Fire Effects

Fuels inventory data are collected to facilitate accurate prescription development, to determine if fuel consumption objectives are met, and to relate fuel reduction to fire effects on other resources. Fuel moisture data can determine whether prescribed conditions are met, and document the conditions that correlate with specific amounts of fuel consumption and related aspects of the heat regime of the fire. If smoke emissions are a critical factor in a prescribed fire program, both fuel moisture and fuel consumption data can be used to predict emissions, refine prescriptions, and obtain an accurate estimate of the amount of emissions produced by a particular prescribed fire. While mineral soil is not a fuel, soil moisture data can provide important information for documentation and interpretation of fire effects that are related to sub-surface heating.

1. Fuel Loading. The type and amount of fuels inventory should match the objective for

doing the inventory, because fuels data can be expensive and time consuming to collect. Specific techniques have been developed for inventorying or estimating living and dead biomass in forest and rangeland vegetative types, many of which were developed specifically for assessing fuels. The time of year when sampling is performed can be critical if any component of live vegetation is being measured, particularly grasses and forbs. Sampling performed before the full amount of seasonal growth has occurred can produce serious underestimates in fuel loading. Sampling during the normal fire season, or during the specific time of year when a prescribed fire is planned to occur, is recommended. Agency specific guidance for fuels measurement in forests and in grassland and brush is provided in USDI-NPS (1992).

a. Destructive sampling. Destructive sampling is the clipping, sorting by size category, and weighing of all fuel in a representative area. This is an extremely accurate way to collect fuels data but is also time consuming and expensive. All of the other procedures detailed here derive estimates of fuel loading from specific sets of measurements.

b. Estimating weight of herbaceous fuels. There are many techniques for estimation of weight and production of herbaceous rangeland vegetation because of its use as livestock forage. Most techniques for weight estimation can be placed into one of three categories:

1) clipping and weighing, 2) estimation, and 3) a combination of weighing and estimation (Brown et al. 1982). Details on use of these and related methods can be found in Hutchings and Schmautz (1969), and Chambers and Brown (1983).

c. Estimating shrub weight.

1) Rangeland shrubs. Average height of an entire stand of big sagebrush can be estimated by multiplying 0.8 times the average height of the tallest plants in that stand (Brown 1982). Average sagebrush height and percent can be converted to tons/hectare (tons/acre) (ibid.). Martin et al. (1981) developed estimates for average loading by percent of crown cover for big sagebrush, antelope bitterbrush *(Purshia tridentata)*, snowbrush ceanothus *(Ceanothus velutinus)*, and greenleaf manzanita *(Arctostaphylos patula)*.

2) Forest shrubs. Shrub biomass can be estimated from basal stem diameters for 25 species common in the northern Rocky Mountains (Brown et al. 1982).

d. Live/dead ratio. The live/dead ratio within plants can be obtained by ocular estimation or through more time consuming destructive sampling techniques.

e. Inventory of dead woody fuels and duff.

1) Direct measurement. Brown et al. (1982) provides comprehensive procedures for inventorying downed woody material, forest floor litter and duff, herbaceous vegetation, shrubs, and small conifers. Field sampling methods include counting and measuring diameters of downed woody pieces that intersect vertical sampling planes, comparing quantities of litter and herbaceous vegetation against standard plots that are clipped and weighed, tallying shrub stems by basal diameter classes, tallying conifers by height classes, and measuring duff depth (ibid.). All of these procedures can be completed at one sample point in about 15 minutes. The authors recommend that at least 15 to 20 sample points be located in an area where fuel estimates are desired. Although these procedures apply most accurately in the Interior West, techniques for estimating biomass of herbaceous vegetation, litter, and downed woody material apply elsewhere (ibid.).

Formulas for calculating fuel loading from field measurements are found in Brown (1974). Anderson (1978) provides graphs from which loading can be estimated. The calculation procedures are converted into a computer program listed in Brown et al. (1982). Agency fire management staff may have software that can be used to calculate fuel weights from these inventory data.

2) Photo series. A photo series developed for a specific fuel type in a defined geographic area can be used to obtain an estimate of fuels. The stand of interest is compared to pictures of similar stands in which fuel inventories have been conducted. Precision is intermediate when compared to other methods for obtaining fuels information. Photo series are more accurate for assessing fire potential than for estimating fuel loads (Fischer 1981a). Photo guides are available for natural and activity fuels for coastal and interior forest types in the Pacific Northwest (Maxwell and Ward 1976a, 1976b, 1980); for forest residues in two Sierra Nevada conifer types (Maxwell and Ward 1979); for natural fuels in Montana (Fischer 1981b, c, and d); for thinning slash in north Idaho (Koski and Fischer 1979); and for natural forest residues in the southern Cascades and northern Sierra Nevada (Blonski and Schramel 1981). Supplementary information on fire behavior and resistance to control were compiled for existing photo guides for Pacific Northwest coastal forest (Sandberg and Ward 1981); for two Sierra conifer types (Ward and Sandberg 1981a) and for Northwest ponderosa and lodgepole pine types (Ward and Sandberg 1981b). There are presently no photo series for the Great Basin or southwest U.S. Fischer (1981a) explains how a photo guide is constructed with enough detail for a field office to prepare a series on specific fuel types.

2. Woody Fuel Consumption. Fuel consumption is measured by comparing prefire fuel loading data with data collected after a wildfire or prescribed fire is extinguished. If a quantitative fuel reduction objective was set, and a related fuel inventory technique selected and performed before the fire, that same inventory must be conducted again. Changes in fuel loading can be less precisely estimated by comparing photo series pairs that match the appearance of the site before and after burning.

In some cases, total downed woody fuel increases after a fire because of the addition of branchwood and boles of trees that fell as a result of the fire. If this has occurred, the observation should be recorded with field data, as it will help interpret fuels data when the project is being evaluated.

3. Litter/Duff Reduction. Techniques for measuring litter and duff reduction are described in Chapter II.D.8., this Guide, "Burn Severity/ Depth of Burn."

4. Fuel Moisture.

a. What should be sampled. Categories of fuel moisture that can be related to the heat regime of a fire and to fire effects include the following:

- less than 1/4-inch diameter down dead woody fuels (1 hour fuels)

- 1/4 to 1-inch diameter down dead woody fuels (10 hour fuels)

- 1 to 3-inch diameter down dead woody fuels (100 hour fuels)

- 3 to 8-inch diameter sound down dead woody fuel (1000 hour fuels)

- large diameter rotten down dead woody fuel

- surface litter

- thin duff layer

- upper part of a deep duff layer

- lower part of a deep duff layer

- organic soils

- organic layers beneath isolated trees and shrubs

- mineral soil

- tree foliage

- shrub foliage

- herbaceous plants

Moisture data required varies with vegetation type, expected fire behavior and fire characteristics, the fuel situation on the site, and the objectives for conducting the fire. While not a fuel, mineral soil is included in this list because of its role in regulating heat transfer into soil. (See Chapter V.B.1.a, this Guide.)

b. Where fuel moisture should be sampled. The following discussion is derived from Norum and Miller (1984), and Sackett (1981). Fuel moisture samples should be collected within the proposed burn unit and be representative of the area. Samples should span the range of vegetative conditions, fuel conditions, elevation, aspect, and slope on a prescribed fire site, because these variables can lead to notably different fire characteristics and fire effects. Notably wet and dry microsites should be sampled, along with the areas between them. This also applies to shaded and exposed spots, greater and lesser concentrations of fuel, older and younger stands, and any other within-plot variations that might influence fuel moisture content.

If fuels inside and outside of the prescribed fire unit are notably different, as in the case of a clearcut, fuel moisture outside the burn unit should also be monitored and documented. Differences in anticipated fire behavior within and outside of the intended fire area help to determine the probability of a spot starting a fire outside of the unit and the needed contingency suppression forces in case the fire escapes.

c. The number of samples to collect. Prefire variability in moisture content of fuels can be fairly high. Prefire samples can be used to determine how many samples must be collected to guarantee the needed sampling precision. See Chapter XI.B.1., this Handbook, for an example of how to determine how large a sample size is required.

d. Direct sampling. Detailed discussions of fuel moisture sampling methods and drying procedures are given in Norum and Miller (1984) and Countryman and Dean (1979). While these two publications were designed for specific geographic locations, the general principles involved can be applied to other parts of the country.

(1) Containers. Commonly used containers are aluminum soil sample cans, paint cans, nalgene bottles, and wide-mouth glass jars. Plastic bags, even if they have a tight seal, are not suitable for sample collection. Moisture can escape through small pores in the plastic, especially if the sample sits for a while before processing. Moisture from the sample can condense on the bag, and be lost when the sample is transferred to another container for drying. Use of plastic bags for sample collection can result in underestimation of sample moisture content.

(2) General field procedures. Detailed procedures for collecting fuel moisture samples in Alaska were developed by Norum and Miller (1984). The publication contains many general procedures which can be followed in any part of the country. Some general guidelines include:

(a) If recent rain, frost or dew have left obvious moisture on the surface of the plants, sample moisture content may be overestimated.

(b) Material collected from living plants, leaf litter, and upper duff layers becomes fairly stiff as it dries, and may expand, causing it to spring from the sample containers during the drying process. Material must be loosely packed into sample containers. Stems and leaves of live fuels can be cut into small pieces as they are placed in the sample can.

(c) Samples must be kept cool, dry, and out of direct sunlight until they are processed. Countryman and Dean (1979) recommend placing samples within an ice chest until they can be brought back to the lab for processing. Lunch coolers with a container of ice can also be used. If samples cannot be processed immediately, refrigerate them, still sealed, until they can be weighed.

(e) Live fuels. Guidelines for collecting specific species of plants are given in Norum and Miller (1984), and can be adapted to other species. Plant material sampled should consist only of living foliar material, not dead branches, dead leaves, flowers, or fruits. A consistent manner of sampling is most important, both for each species of plant and throughout the growing season. Plant growth stage at the time of sampling should be noted.

(3) Processing samples. A basic requirement for processing of fuel moisture samples is a top-loading beam or torsion balance scale, capable of measuring to 0.1 gram. If many samples must be processed over the course of a field season, or several seasons, the cost of an electronic balance may be justified because of the time saved and accuracy that is gained.

Several different means exist for determining fuel moisture content in the office or lab once samples have been collected.

(a) Xylene distillation. The xylene distillation method is a laboratory procedure which produces extremely precise estimates of moisture content for both live and dead fuels. However, this method is comparatively expensive and takes a significant time to perform. It will not be discussed further here.

(b) Microwave oven. Microwave ovens have been used successfully to dry dead woody fuels (Norum and Fischer, 1980). McCreight (1981) did not recommend use of a microwave oven for drying live fuels.

(c) Computrac®. The Computrac, Model FS-2A is a moisture analyzer that weighs and dries a small sample and provides a moisture content on a dry-weight basis. Material is dried in an automatically controlled oven chamber, continuously weighed, and moisture content calculated. Results are obtained within about 10 to 20 minutes for dead woody fuels, or about one hour for live fuels. Fuels can be dried at 95 C. (203 F.), minimizing any loss of volatiles.

While quite accurate, a major disadvantage of the Computrac is the very small size of the sample which can be processed, approximately 3 to 10 grams of material. In order to obtain a representative sample, many samples must be subsequently processed. A second major disadvantage of the Computrac is its high purchase price.

(d) Drying ovens. Detailed procedures for use of a scale and drying oven can be found in Countryman and Dean (1979) and Norum and Miller (1984). Processing of fuel moisture samples in a drying oven has long been the standard for measurement of fuel moisture content. Samples are weighed on a scale to the nearest 0.1 gram, dried in the oven, and then weighed again to determine the amount of water lost. Ovens are customarily set to 100 C. (212 F.) for dead woody fuels, and 80 C. (176 F.) for live fuels. The standard drying time is 24 hours. Major advantages of a drying oven are that many samples can be processed simultaneously, and accurate values are obtained if proper procedures are followed. The disadvantage is the 24 hour delay in arriving at the values for moisture content.

e. Fuel moisture meters. Several brands of fuel moisture meters are presently available that provide a direct measurement of fuel moisture. Most meters work by measuring the electrical resistance between two probes which are inserted into a piece of wood. Most of these meters were developed for testing the moisture content of kiln dried lumber and are most accurate at lower moisture values. Some of these probes are calibrated on a wet weight basis, not a dry weight basis, and will not give answers that can be used as input to fire behavior prescriptions. Most of the probes are less than an inch in length and cannot penetrate deeply enough into large diameter wood to measure its moisture content. However, a fairly accurate measurement of large fuel moisture content can be made by cutting across the diameter of a large piece of woody fuel and inserting the probe into the freshly exposed surface. Because meters were developed to measure moisture content of wood, a fairly dense substance, they cannot give an accurate reading of moisture content within litter or duff layers, or of soil. These meters are not suitable for live fuel moisture estimation because the probes cannot be adequately inserted into the live fuels, and most meters do not operate at high moisture contents.

f. Ways to estimate dead fuel moisture content.

(1) Calculation.

(a) Fine fuels. The moisture content of fine dead woody fuels can be estimated with several different computation models. All models use inputs which describe the environment in which the fuel is located, temperature, relative humidity, slope, and time of year. The most simple but marginally accurate calculation method is available in tabular form in the course materials for S-390, Intermediate Fire Behavior, and S-590, Fire Behavior Analyst. A more accurate estimate can be made using the fine fuel moisture model (MOISTURE) in the BEHAVE system. (See XII.C.1.B.)

(b) Large diameter downed fuels. There is a regionally specific model that accurately predicts the moisture content for large diameter dead woody fuels, the ADJ-Th (Adjusted Thousand Hour) model developed by Ottmar and Sandberg (1985). This model applies to 3 to 9-inch diameter Douglas-fir and western hemlock logging slash in western Washington and Oregon.

(2) Fuel sticks. A standard set of fuel moisture indicator sticks consists of four, 1/2 inch diameter ponderosa pine sapwood dowels spaced one-quarter inch apart on two 3/16-inch- diameter hardwood pins. They do not measure any specific fuel but rather "measure the net effect of climatic factors affecting flammability" (Davis 1959). When completely dry, the sticks weigh 100 grams. Their moisture content can be obtained by weighing them, using any of several types of commonly available scales. Procedures for use of fuel sticks are described in detail in Finklin and Fischer (1990).

Fuel sticks have important limitations. The differing density of the wood of which the sticks are made can cause dowels made from the same board to give different fuel moisture values when exposed to the same environment. Response characteristics of the sticks can change significantly with continued exposure and wood aging. A fuel stick should be discarded after one season's use, and more often if rapid weathering or checking has occurred. A fuel stick must be exposed at least five days before moisture readings will be accurate. Because of the variation in fine fuel moisture content caused by microsite differences, use of only one set of fuel sticks to represent moisture conditions for a prescribed fire may give a very inaccurate estimate.

E. Summary

Fuels are an integral part of most wildlands. At some time after death, or while still alive, all vegetation becomes potential fuel. The single most important factor controlling the flammability and consumption of fuels is their moisture content. The moisture content of dead wildland fuels is regulated by environmental factors, while that of living plants is largely controlled by physiological processes. Other fuel properties can also affect the degree of consumption. All direct effects of fire result from the characteristics of the heat regime of the fire, which is controlled by the manner in which fuels burn. Management of fuels is important because by doing so, the heat regime of a fire is also regulated.

1. 0.63 approximates the value 1 minus 1/e, where e is the base for natural logarithms (Schroeder and Buck 1970). This value is used to describe fuel moisture relationships because the shape of the drying and wetting curve as a function of time is approximately logarithmic.

2. The presence of unweathered organic coatings that limited vapor movement in and out of the most recently cast needle litter was another likely cause of the slow moisture response (Hartford and Rothermel 1991).

3. Conifers of the Larix genera (larches and tamarack) have deciduous needles, and their moisture content will not be discussed here.

Fire Effects Guide

CHAPTER IV - AIR QUALITY

By Larry Mahaffey and Melanie Miller

A. Introduction

Wildland fires produce smoke, an air pollutant. Smoke that is a result of human activities is subject to legal restrictions imposed by state, Federal, and local governments. Prescribed fire is a planned event, and Federal land managers have a mandate to manage prescribed fire smoke. Land managers must have a clear understanding of the regulations and processes that must be complied with to manage smoke. The liability for downwind effects is the responsibility of the prescribed fire managers who produced the smoke.

The National Environmental Policy Act (NEPA) is the law that establishes fundamental environmental policy for the U.S. and provides the process for considering the full range of impacts in planning land use activities. Agencies have the responsibility to disclose possible air pollution impacts from land management projects. The Federal land manager is required to conduct NEPA analysis if the project includes a "significant" amount of burning, may have impacts on sensitive vistas or visibility, or is located near a public roadway.

The 1977 Clean Air Act (CAA) mandates the protection of human health and the prevention of significant deterioration of air quality, and establishes acceptable levels of emissions. States are charged with the responsibility for protecting air quality. States write State Implementation Plans (SIPs) to interpret and enforce the Clean Air Act, including the identification of Designated Areas (DA), principal population centers or other areas requiring protection of air quality.

Designated Class I Areas include specific National Parks, Wilderness Areas, and certain Indian reservations. A goal for Federal Class I Areas is to prevent any future impairment of visibility and remedy any existing impairment of visibility that results from human-caused air pollution. The 1990 Amendments to the Clean Air Act specify that individual States must consider smoke from wildland fires in their SIPs. Requirements for prescribed fires can be established by States in the SIP that are more stringent than those in the CAA.

Anyone using prescribed fire must consider smoke management. Smoke management requirements and procedures vary because of the different amounts of fuel burned, fuel type, topography, meteorology, and presence of smoke sensitive areas (Mathews et al. 1985). The following questions can help a manager determine the level of smoke management that is needed, and whether an increased emphasis on smoke management is required.

1. Is the public informed of agency resource objectives for using prescribed fire?

2. Is the amount of acreage treated with prescribed fire predicted to change significantly?

3. Does topography or meteorology cause poor smoke dispersion?

4. Will prescribed fires cause or contribute to increased levels of air pollutants?

5. Will smoke from prescribed fires result in public health and safety problems or complaints?

6. Are Best Available Control Measures (BACM) used to manage prescribed fire smoke?

The effects of smoke on the airshed and the public and the opportunities to reduce these impacts will be discussed in this chapter. Managers have the responsibility to do the best job possible to control and mitigate the impacts of smoke that result from their actions or treatments.

B. Principles and Processes of Fire Effects

1. Combustion Process.

a. Chemistry of combustion. The following is a summary of information provided by Byram (1959). Wood is a chemically complex substance, composed primarily of cellulose and lignin, of which carbon, hydrogen, and oxygen are the primary constituents. When wood burns in a completely efficient manner, it combines with atmospheric oxygen, and produces water, carbon dioxide, and energy. Some of the water that results from combustion is evaporated from the fuel, but a larger proportion is a product of the chemical reaction.

b. Phases of combustion. The four phases of the combustion process are described in Chapter II.B.2, this Guide. Some strategies for smoke management rely on manipulation of the amount of fuel consumed in each combustion phase. The types of emissions and factors regulating their production will be discussed with respect to the phases of combustion. For a more complete discussion of the phases of combustion, see Sandberg et al. (1978).

(1) Pre-ignition phase. During the pre-ignition phase, gases, vapors, tars and charcoal are produced. The proportions and amounts vary widely according to the conditions under which pyrolysis occurs. If rapid heating occurs during pyrolysis, less charcoal, a lot of tar, and highly flammable gases are produced. Slow heating during the pyrolysis process results in the production of more charcoal, little tar, and lower amounts of flammable gases (Sandberg et al. 1978).

(2) Flaming phase. The following is from Ryan and MacMahon (1976 in Sandberg et al. 1978). The principal chemical by-products of flaming combustion are carbon dioxide and water. However, some pyrolyzed substances cool and condense without passing through the flaming zone. Other substances are only partially oxidized as they pass through the flames, and many combustion by products are produced. Low molecular weight organic compounds may remain as gases and are dispersed by wind. Tar droplets and particles of soot result from the cooling and condensation of compounds with higher molecular weights. Visible smoke consists of mostly tar, soot, and water vapor.

(3) Smoldering phase. The lower temperatures of the smoldering phase allow some gases to condense as visible smoke. Smoldering fires produce at least twice the emissions of flaming fires. Heat release is inadequate to loft the smoke as a convection column, so smoke stays near the ground and may persist in relatively high concentrations. Most of the smoke produced consists of tar droplets less than one micron in size (Johansen et al. 1985).

(4) Glowing phase. During the glowing phase, combustion is fairly efficient. Carbon monoxide and carbon dioxide are released, but no visible smoke is formed (ibid.).

c. Combustion efficiency. If combustion of fuels in wildland fires was 100 percent efficient, the burning of one ton of wood would release 3,670 pounds (1,665 kilograms) of carbon dioxide and 1,080 pounds (490 kilograms) of water (Sandberg and Dost 1990). All of the carbon in the fuel would oxidize to carbon dioxide. However, the combustion of fuels in wildland fires is not a completely efficient process. The most important reason for incomplete combustion is that wind cannot deliver enough oxygen to the combustion zone to mix efficiently with all of the flammable gases produced (Ryan and McMahon 1976 in Sandberg et al. 1978). There are differences between heading fires and backing fires in the proportion of time spent in the different combustion phases listed above (ibid.).

(1) Heading fires. A heading fire is one in which the flaming front moves ahead rapidly. The fire may be pushed by the wind, move upslope, or be influenced by both factors. These fires burn with relatively high fireline intensity, moving quickly from one fuel element to another. The main combustion zone moves before most fuel elements are completely consumed by fire. The flames continue ahead, leaving behind a large area of smoldering fuel (ibid.).

(2) Backing fires. A backing fire burns into the wind or downslope. Because the flames move more slowly, a higher proportion of fuel is consumed in the flaming zone of the fire, leaving less fuel to smolder after the flaming front has passed.

(3) Smoke production. For a given fuel bed and set of burning conditions, a heading fire causes more total smoke production than a backing fire. A heading fire generally results in more fuel consumed in the smoldering phase of combustion than does a backing fire, and smoldering fuels produce more smoke than fuels burned in flames. A backing fire is a more efficient fire because more fuel is consumed in flaming combustion, and less smoke production results.

d. Fuel properties that affect smoke production. Fuel properties that affect smoke production are those that influence the phase of combustion in which fuel consumption occurs, and the total amount of fuel consumed. These factors are discussed more completely in Chapter III. Fuels.

(1) Fuel particle size, arrangement, and continuity. The smaller the size of the fuel particle, the more quickly it can ignite and be consumed. The arrangement of fuel particles affects the amount of oxygen that reaches them. More tightly packed fuel, such as a bed of juniper or spruce needles, burns less efficiently, and produces more smoke than a loosely packed fuel bed, such as one of ponderosa pine needles. Fuel continuity is a factor because if fuel particles are too widely spaced, sustained ignitions cannot occur; flames are unable to ignite adjacent fuels.

(2) Fuel loading. A site with large amounts of fuel can generate more smoke than a site with little fuel. The size class distribution of the fuel is also important, because the proportion of fuel in each size class affects the proportion that may be consumed in flaming versus smoldering combustion. Smaller diameter fuels, such as loosely packed grass litter, fine branchwood, and live moss and lichens burn almost entirely in flames with little residual smoldering. In contrast, large diameter downed woody fuels such as those found in logging slash are rarely consumed in flaming combustion, and thus have higher potential to emit large amounts of residual smoke.

(3) Fuel moisture. The moisture content of the different size classes of fuel affects smoke production because it influences fuel availability and combustion temperatures. Extremely dry fuels burn rapidly and completely, while wet fuels burn slowly or not at all. Any moisture released from the fuels absorbs some heat energy from the fire, limiting combustion temperatures (Ryan and McMahon in Sandberg 1978). If larger size classes of fuels have a high moisture content, most or all of the heat released by flames will be expended evaporating water, and little consumption of large diameter fuels occurs. Fuel moisture, its role in combustion, and its relationship to past and present atmospheric conditions, is discussed more completely in Chapter III, Fuels.

2. Emissions. Emission products from fires vary greatly, depending upon the type of fuel, fireline intensity, fuel moisture, wind, and temperature of the fire.

a. Combustion products. Hundreds of different compounds are emitted in the smoke from wildland fires. More than 90 percent of the mass of smoke emitted from wildland fires consists of carbon dioxide and water. Carbon in the fuel is also converted to particulate matter, carbon monoxide, aldehydes, and hydrocarbons, as well as complex organic materials (Johansen et al. 1985). Nitrogen oxides and hydrocarbons produced by the fire can react together in the presence of sunlight and produce ozone and organic oxidants. Ozone production occurs in the top of a smoke plumes where there is more light, and in downwind areas where smoke is less dense (Sandberg and Dost 1990).

Because most of the adverse effects of smoke are related to the amount of smoke produced, fire managers need to know how much smoke is generated. The answer can be estimated from two numerical expressions: emission factor and emission rate.

b. Emission factors. An emission factor is the mass of contaminant emitted to the atmosphere by the burning of a specific mass of fuel, and is expressed in pounds per ton in the English system or grams per kilogram as the metric equivalent (Johansen et al. 1985). An emission factor can be calculated for a single fire, or a single combustion stage of one fire, or it can be a statistical average for a geographical area or a set of similar fires (Sandberg and Dost 1990).

(1) Carbon dioxide. The carbon dioxide emission factor for prescribed fires ranges from 2,200 to 3,500 pounds per ton of fuel consumed (1098 to 1747 g/kg) (Sandberg and Dost 1990). The combination of carbon in the fuel with atmospheric oxygen during combustion results in the production of a greater weight of carbon dioxide than the original weight of the fuel. Carbon dioxide is a "greenhouse gas", i.e., it may have an effect on the global radiation budget and may be a factor in potential global climate change. However, carbon dioxide is also released when wood and other organic matter decays. Logging removes forest fuels from sites and can reduce the amount of carbon dioxide that would be released if the site burned. Fire suppression is not an effective way to mitigate this carbon dioxide release from many wildland fuels because in most cases, suppression only postpones burning. Decomposition by fire has occurred for millions of years in most of the vegetation types in western and northern North America. In the absence of fire, fuels tend to accumulate, ignition eventually occurs, and more carbon dioxide may be released than would have occurred under a natural fire regime. More fuel may be present, and fuel consumption may be more complete.

(2) Particulate matter. Particulate matter is the most important category of pollutants from wildland fire, because it reduces visibility and can absorb and transmit harmful gases. Particles vary in size and chemical composition, depending upon fireline intensity and the character of the fuels. Proportionately larger particles are produced by fires of higher fireline intensity (longer flames) than are found in low intensity and smoldering combustion fires (Ward and Hardy 1986 in USDA Forest Service and Johns Hopkins University 1989). Particulate matter emission factors for forest fuel types range from 4 to 180 pounds per ton (2 to 90 g/kg). For prescribed burning of logging slash, particulate production ranges from 18 to 50 pounds per ton (9 to 25 g/kg) for broadcast burning and 14 to 30 pounds per ton (7 to 15 g/kg) for piled slash. The amount of particulate released when burning sagebrush/grass fuel types averages 45 pounds per ton (22.5 g/kg), mixed chaparral ranges from 24 to 30 pounds per ton (12 to 15 g/kg), and emission factors for pinyon-juniper (slashed) range from 22 to 35 pounds per ton (11 to 17.5 g/kg) (Hardy 1990). The exact amount depends on the fuel type, the fuel arrangement, and the manner of combustion.

Emission factors for particulate matter less than 2.5 microns in diameter ($PM_{2.5}$) range from 9 to 32 pounds per ton (4.5 to 16 g/kg) for prescribed fires in the Pacific Northwest, averaging about 22 pounds per ton (11 g/kg). Emission factors are highest during the inefficient smoldering combustion stage and lowest during flaming combustion.

The amount of smoke produced depends on the total amount of fuel consumed. For example, even though the emission factor for sagebrush is higher than that for chaparral or pinyon-juniper, total smoke production from burning sagebrush is often lower because the total amount of fuel on a sagebrush site is generally less than on a chaparral or pinyon-juniper dominated site.

(3) Other emissions. Emission factors are available for other products of combustion such as the invisible gases. Emission factors for carbon monoxide range from 70 pounds per ton (35 g/kg) during flaming combustion to 800 pounds per ton (399 g/kg) for some smoldering fires.

Volatile organic compounds are a diverse class of substances containing hydrogen, carbon, and other elements such as oxygen. They include methane, polynuclear aromatic hydrocarbons (PAH's), and aldehydes and related substances. PAH's are not free in the environment as vapor, but are incorporated in fine particulates that are respirable. Methane and aldehydes are emitted as gases. Emissions for volatile organics vary from 4 to 50 pounds per ton (2 to 25 g/kg) of fuel burned, about half of which is commonly methane.

c. Emission rate. An emission rate is the amount of smoke produced per unit of time (pounds/minute or grams/second). The portion of the total amount of combustible fuel that a fire will consume for a given set of conditions is called available fuel, and is usually measured in tons per acre (kg/sq m) for forest fuels, and pounds per acre (kg/ha) for rangeland fuels. The land manager can make better estimates of emission rates from a prescribed burn if the amount of fuel consumed in each combustion phase is known. (See B.1.b.)

Fuel consumption rates are expressed as area burned per unit of time: acres per minute. Combustion rates can be calculated whether line-type ignition is used for backing or heading fires or area-type ignition is used in natural or activity fuels.

In order to estimate the emission rate, the following variables are required: available fuel (tons/acre), the combustion rate (acres/minute), and the emission factor (pounds/ton). The emission rate (pounds/minute) can be calculated by the following equation:

Emission Rate = Available Fuel x Combustion Rate x Emission Factor

The emission rate is used as an input to models that predict air pollutant concentrations. Such models can be used to assess the impact of smoke on visibility sensitive areas such as highways, cities, airports, and parks (Johansen et al. 1985).

3. Human Health Risk from Smoke. There is a growing awareness that smoke from wildland fires can expose individuals and populations to hazardous air pollutants. Concern is increasing over the risk to firefighters and the general public from exposure to toxins, irritants, and known carcinogens in smoke. A rigorous risk assessment is needed to address this increasingly sensitive issue. Although there is a low probability that public health is at risk, fireline workers are more likely to be harmed. Firefighters can be exposed to high levels of lung toxins such as aldehydes, acids, and particulates; to carcinogens such as polycyclic aromatic hydrocarbons, formaldehyde and benzene; and to carbon monoxide. These exposures may be at high levels for short periods, or at low levels for weeks at a time. The amount of some hazardous components of smoke, such as formaldehyde and respirable particulate matter, is well correlated to the amount of carbon monoxide (Reinhardt 1989). Relatively inexpensive devices for measurement of carbon monoxide (CO dosimeters) may provide a practical means to help recognize and prevent exposure of firefighters to dangerous levels of smoke.

The most likely effects of smoke on health are the aggravation of existing diseases or increased susceptibility to infection. Those most susceptible to exposure to air toxins include very young children and individuals with chronic lung disease or coronary heart disease. The effects of smoke on human health are discussed in detail in Sandberg and Dost (1990), Dost (1991), and the comprehensive study plan prepared by the USDA Forest Service and Johns Hopkins University (1989). The following discussion is summarized from these sources.

a. Criteria pollutants. The National Ambient Air Quality Standards are a set of goals established by the Environmental Protection Agency for acceptable levels of six air pollutants that are potentially harmful to public health. These criteria pollutants are particulate matter, carbon monoxide, sulfur dioxide, nitrogen dioxide, ozone, and lead.

(1) Particulate matter. The size class distribution of particles produced by forest fires is bimodal. Most of the particles have an average diameter of either 0.3 micrometers or greater than 10 micrometers (USDA Forest Service and Johns Hopkins University 1989). The proportion of particles in wood smoke less than 2.5 micrometers in diameter ranges from 50 to 90 percent (Sandberg and Dost 1990). Particles less than about 10 micrometers in diameter are able to traverse the upper airways (nose and mouth) and enter the lower airways starting with the trachea (Raabe 1984). As the particle size decreases below 10 micrometers, increasing proportions of particles are able to enter the trachea, and penetrate to the deeper parts of the airways prior to deposition. It should also be noted that once such particles reach the lower airways, it is likely that they will deposit on surfaces in the deepest parts of the lungs, the "pulmonary" zone--that part of the respiratory tract most sensitive to chemical injury (Morgan 1989 in Sandberg and Dost 1990).

National air quality standards assume that the components of particulate matter are essentially the same, regardless of location and source. However, the constituents of particulate matter vary widely. The particulate emitted by burning of vegetation has a much different composition and effect than that present in urban areas (Dost 1990). Particulate matter from vegetation fires consists mainly of condensed organic compounds. In urban areas, particulates contain compounds that rarely occur in rural vegetation smoke, such as masonry dust, fly ash, and asbestos. Also, other compounds present in urban air lead to a variety of chemical reaction products not likely to be found in association with wildland smoke. Smoke from wildland fuels is not as environmentally damaging as urban smoke.

(2) Carbon monoxide. Carbon monoxide is a product of combustion that is rapidly diluted at short distances from a fire and therefore poses little or no risk to community health (Sandberg and Dost 1990). However, carbon monoxide can be present at high enough levels near a fire to pose a hazard to firefighters, depending upon the concentration, duration, and level of activity of the firefighters at the time of exposure. Carbon monoxide is a chemical asphyxiant that interferes with oxygen transport in blood. Pilots exposed to carbon monoxide have developed headaches, fatigue, decreased concentration and impaired judgement. Data also suggest that long-term exposure to low levels of carbon monoxide produce accelerated arteriosclerosis, increasing the risk of cardiovascular diseases such as heart attack and stroke (USDA Forest Service and Johns Hopkins University 1989).

(3) Oxides of sulfur and nitrogen. Because forest fuels contain minute amounts of sulfur and somewhat higher levels of nitrogen, it is expected that these criteria pollutants are formed when wildland fuel is burned. Increased levels of oxides of sulfur have never been measured near wildland fires. Some oxides of nitrogen form, but the amount produced by forest burning is not significant enough to be of concern (Sandberg and Dost 1990).

(4) Lead. While a serious problem in urban pollution, lead is not a natural constituent of smoke from wildland fuels. It is assumed that lead may be only a minor component of wildland fire smoke when it has been deposited onto fuels from atmospheric sources, such as contaminated urban air that has moved into wildland areas (Ward and Hardy 1986 in Sandberg and Dost 1990).

(5) Ozone. Much of the following discussion is summarized from Dost (1990). At lower altitudes, ozone is a common component of air, but at low enough levels to have an insignificant impact on human health. At high concentrations, ozone is a respiratory irritant, and can have a significant impact on individuals who already have serious respiratory impairment. The atmospheric chemistry of ozone formation is quite complex. It can form in the presence of atmospheric hydrocarbons generated in large quantities by the combustion of vegetation. The photochemical reactions that create ozone occur in areas of a smoke column that are penetrated by ultraviolet wavelengths of sunlight, particularly in the upper part of the plume. Ozone is therefore not likely to be a pollutant of concern to people in the immediate vicinity of a fire, although fire crews working at high elevations may find increased levels of this substance (USDA Forest Service and Johns Hopkins University 1989). Ozone may pose a problem in downwind areas affected by smoke, particularly in urban areas where ozone concentrations from other sources may already be high.

b. Non-criteria pollutants. Ambient standards have not been specifically identified by the Environmental Protection Agency for all components of smoke, although some of these substances can have negative effects on human health. The following discussion, taken largely from Dost (1990), describes the two groups of volatile organic compounds most likely to impact human health.

(1) Aldehydes. Aldehydes are classed as irritants, and some are potentially carcinogenic. The two aldehyde compounds found in smoke that are most likely to pose health problems are formaldehyde and acrolein.

(a) Formaldehyde. Formaldehyde is a very common atmospheric contaminant, found in association with building materials, textiles, preservatives, and medical activities. It has been measured as a by-product of burning wood, although little is known about its production in wildland fires. Formaldehyde is probably the most abundantly produced aldehyde, and is likely responsible for nose, throat and eye irritation in firefighters exposed to smoke. At higher concentrations, it may cause a reflexive decrease in breathing rates. Formaldehyde may not only thus contribute to mucosal irritation commonly experienced by firefighters, it also may interfere with their ability to obtain adequate oxygen at times when energy is most needed. Formaldehyde is rapidly transformed in the body to formic acid, a known toxin with a very slow removal rate. Formaldehyde also may be present in decreasing amounts in the smoke plume downwind, being slowly removed by chemical reactions.

(b) Acrolein. Acrolein is formed by few natural processes other than combustion. It has been measured in emissions from fireplace smoke, and studies suggest that greater amounts are produced in inefficient fires. Acrolein is a more potent irritant than formaldehyde. It has similar effects as formaldehyde to the respiratory system, but may also have severe toxic effects on cells. Individuals exposed to acrolein may have a decreased ability to repel respiratory infections. Acrolein is degraded by sunlight, and it is assumed that it slowly dilutes downwind with other components of smoke in the plume. If initial concentration levels are high, acrolein could be a significant irritant at a considerable distance from its source.

(2) Polynuclear aromatic hydrocarbons (PAH). Polynuclear aromatic hydrocarbons are a class of products that have been detected in wood smoke. These benzene containing compounds are incorporated as fine particles that are respirable. Some PAH compounds have carcinogenic properties. The likely risk to the general public of developing cancer because of exposure to these chemicals from prescribed fire is very small because of the rapid dilution of these products in the smoke plume (Sandberg and Dost 1990). However, very little is known about potential effects on firefighters from these compounds due to a lack of research on their production in wildland fires.

C. Resource Management Considerations

1. Control Strategies. When wildland fires occur, managers must consider the impacts on air quality and mitigate adverse effects whenever possible. Wildfire is evaluated through the Escaped Fire Situation Analysis, and prescribed fire through the Environmental

Assessment and Prescribed Fire Planning process. There are strategic and tactical measures that can limit the amounts and mitigate the impacts of smoke from fires. The mitigation of adverse impacts can be accomplished through the selection and implementation of an appropriate control strategy. Managers can use these strategies to allow the burn to take place and yet reduce the risk of adverse effects of smoke. Clear resource management objectives and careful monitoring and evaluation of smoke impacts are keys to successful smoke control. Managing smoke from wild or prescribed fires requires a daily prediction of smoke accumulations and whether they will reach unacceptable levels. Choice of suppression strategies and tactics must include a consideration of smoke effects on safety and visibility.

a. Avoidance. Avoidance is a strategy that considers meteorological conditions when scheduling burns to avoid incursions of smoke into sensitive areas. Burning should occur on days when weather conditions allow the transport of smoke away from populated areas. Smoke may not be such a limiting factor in sparsely populated areas, but any downwind effects should be considered when burning. The wind direction during both the active burning period (flaming stage) and the smoldering period must be considered. At night, downslope winds can carry smoke toward smoke sensitive areas, or allow valley bottoms to fill with smoke. Residual smoke emitted during the smoldering stage is especially critical.

b. Dilution. The dilution strategy controls the amount of emissions or schedules the rate of burning to limit the concentration of smoke in sensitive areas. The concentration of smoke can be reduced by diluting it through a greater volume of air, either by scheduling during good dispersion periods or burning at slower rates (burning narrow strips or smaller areas). However, burning at a slower rate may mean that burning continues into the late afternoon or evening when atmospheric conditions may become more stable. Burn when weather systems are unstable, but not at extremes of instability. The time of day at which ignition occurs is also important. Consider early morning ignitions to take advantage of weather conditions where improved mixing will occur as atmospheric heating takes place. Avoid days with low morning transport wind speed, less than 4 miles per hour (6.5 km/hr). Use firing methods to rapidly build a smoke column to vent smoke up to the transport wind and larger volumes of air. Using mass-ignition or rapid ignition will loft the column up and away from the unit, allowing for better dispersion and reduced emissions during the smoldering phase. Generally, a burn early in the day encounters improving ventilation; an evening burn encounters deteriorating ventilation.

c. Emission reduction. Emission reduction is an effective control strategy for decreasing the amount of regional haze and avoiding smoke intrusions into Designated Areas (DA's) (Sandberg et al. 1985). It reduces the smoke output per unit area, and is a concept applicable in both forest and rangeland areas. Most emission reduction techniques are based on limiting the consumption of larger fuels and soil organic layers. Large fuel consumption can be reduced by physically removing or scattering the larger fuels or burning when the larger fuels and duff are too wet to carry fire. Burning when the larger fuels or duff are wet will produce fewer emissions and allow rapid extinguishment of the fire. When windrowing and piling debris, allow fuels to dry before piling, and avoid mixing dirt into the pile. Emissions can also be reduced by use of a backing fire that results in more fuel consumption in the flaming stage, producing less smoke (Sandberg and Peterson 1987).

2. Techniques to Minimize Smoke Production and Impacts. Some smoke management techniques have application to both wildfire and prescribed fire situations, while others apply specifically to prescribed fire management.

a. All fire situations.

(1) Be sure that each burning operation has clear and concise management objectives that consider the impacts of smoke.

(2) Ensure that burn prescriptions and ignition plans provide for optimal smoke dispersion for the specific circumstances of the fire.

(3) Use the best weather data available to ensure adequate smoke dispersal. This includes obtaining spot weather and transport wind forecasts from the National Weather Service, taking weather at the burn site for several days prior to ignition, and validating the fire prescription and spot forecast with onsite weather observations. Wind speed and direction over the area can be checked by release of a helium balloon, or by observing the smoke from a test fire.

(4) Burn when conditions allow rapid dispersion. The atmosphere should be unstable so smoke will rise and dissipate, but not so unstable that control problems result.

(5) Burn when fuel moistures are higher and consume only those fuels that are specified in the treatment objectives. Higher duff moisture shortens the smoldering phase, thereby reducing residual smoke and particulate production.

(6) Mass ignition allows burning to occur with higher fuel moistures. Higher temperatures generated by mass fire cause smoke to rise to a greater height above terrain than if a line ignition is used.

(7) Use a backing fire. The slow rate of spread and long residence time result in a higher fraction of fuel consumption in the flaming stage of combustion rather than in the smoldering stage. Since total smoke production per unit of fuel burned is considerably less during flaming combustion, backing fires favor lower total smoke production.

(8) The volume of smoke in a geographic area must be considered when making management decisions about prescribed burns, prescribed natural fires, or wildfires.

b. Prescribed fire.

(1) Burn other than in the "traditional" late summer and fall season. The impact on the air resource can be spread over a longer period, thereby reducing the possibility of a heavy smoke load on a particular day. Be careful of night burns because predicting smoke drift is more difficult, although night burning can be successful if properly planned and implemented.

(2) Burn fuel concentrations, piles, landings, and jackpots outside of the prescribed burning season. This increases the number of units that can be burned without overloading the airshed on days with good dispersal conditions.

(3) Public criticism of a burn program can be decreased by limiting its impact on recreational users. Avoid burning on days when smoke may affect Class I Areas and heavily visited recreational areas, or on holidays when many visitors may be using public lands.

(4) Using prescribed natural fire requires close monitoring of fuel loadings, fuel moistures, normal weather patterns, and down wind receptors in the area that may be affected by smoke drift.

(5) For prescribed natural fires, daily certification that the fire remains in prescription must include an assessment of smoke dispersal.

3. Participation in State and Local Smoke Management Programs. State and some local air quality agencies have mandatory smoke management programs. Programs are tailored to the needs of local and regional prescribed fire managers, while working to minimize adverse impacts of smoke.

a. Comply with air pollution and smoke management regulations. Know the regulations for your State and local area when developing the prescription. Details on State and local laws and regulations can be obtained from agency fire management or air quality staff.

b. Be pro-active in protecting air quality. Take part in the development (or update) of the State Implementation Plan that contains rules that govern prescribed burning. Working with State and local air quality agencies provides an opportunity for field input and some control over the future of prescribed fire.

D. Methods to Monitor Fire Effects

This section suggests methods for monitoring smoke effects that are practical for management purposes. Although there may be few State regulations that require monitoring of prescribed fire smoke, there are stewardship principles and ethical reasons that make monitoring a compelling aspect of a smoke management policy. As the first step, managers must develop and maintain an awareness of air quality monitoring techniques. Monitoring allows the evaluation of program adequacy and the effectiveness of communication with local air quality personnel. Implementation of air quality monitoring does not require having an elaborate array of monitoring instruments or hiring a monitoring contractor to evaluate fires.

While no readily available operational smoke monitoring techniques accurately predict the effect of a specific fire on air quality, understanding principles of air quality monitoring can result in better smoke management decisions. Some states are currently charging fees for burning, such as one fee to register each acre and an additional fee to burn the acre. This money is used to support the smoke management program and provide monitoring services for agencies doing prescribed burning. Local fire management officers should determine the proper level of monitoring and incorporate it into the burn plan. They should develop an objective method to monitor and evaluate the effectiveness of their smoke management efforts. Monitoring practices can range from simple to very complex programs as determined by managers or by the states. Agency specific guidance that identifies smoke management monitoring techniques and frequencies is provided in USDI-NPS (1992). The following are some practical procedures for monitoring and modelling smoke.

1. Visual Techniques.

a. Visual estimation. Visual estimation is the most common smoke monitoring method in use. Although most visual methods are subjective and limited, they are still very useful. When burning near smoke sensitive areas, a spotter on a hill away from the fire can watch where the smoke goes and relay information to the Burn Boss.

b. Aircraft tracking. Aircraft tracking of smoke plumes can be used to verify the source and trajectory of the smoke. It is used by some regulatory agencies to detect violations of air quality/smoke management regulations. This procedure provides a means to observe the loading of the airshed and to determine if additional burning should be limited.

2. Instrumentation.

a. Nephelometer. A nephelometer is an electronic device that measures the amount of particulate in a sample of air. This optical device measures the amount of light reflected from particles in the enclosed sample space. A nephelometer can be useful for safety monitoring, such as by measuring the amount of smoke on a highway. The machine could be programmed to flash lights as a warning when visibility is poor.

b. Filter sampler. Filter samplers draw a known volume of air through a filter. The filter is weighed before and after the sampling period, and the weight of particulate per volume of air can be calculated.

3. Computer Models.

a. SASEM. The Simple Approach Smoke Estimation Model (SASEM) is a screening model developed by the Bureau of Land Management and approved by the States of Wyoming and Arizona for estimating smoke impacts from prescribed fires. This model calculates emissions, and uses the emission figure to calculate down-wind concentrations of particulates. Estimated particulate loadings are compared quantitatively against ambient air quality standards to see if standards may be exceeded. (See Chapter XII.E.1., this Guide.)

b. TAPAS. The Topographic Air Pollution Analysis System (TAPAS) is a system of models for predicting the dispersion of air pollution over flat or mountainous terrain. Data on topography, wind speed, and direction are used to model plume direction and speed of smoke. Documentation and more information is available from the air quality staff, National Biological Survey, Environmental Science and Technology Center, Fort Collins, Colorado.

c. TSARS. The Tiered Smoke/Air Resources System (TSARS) is a group of computer programs that allows smoke management to be performed in a series of increasingly advanced levels of proficiency (Riebau et al. 1991). Tools with varying degrees of sophistication are available to model smoke production from wildland fires, producing results with different degrees of resolution. The level of analysis conducted can be matched to the complexity of the problem, or the expertise of the person using the model. Simple to use tools which produce easily interpreted results can be used at field levels, while more central offices in an agency would have access to more elaborate techniques. The components of the TSARS system were all derived from existing models, but have been modified for fires as the emission source and to have a consistent appearance to the user. See Chapter XII.E.2. for a more complete discussion of TSARS.

d. PUFF. PUFF is a plume trajectory model for multiple fires being developed for the Pacific Northwest. PUFF uses input on emission production, and models smoke dispersion for a specific grid of atmospheric temperature and pressure. Atmospheric conditions are derived from a National Weather Service model. These data can be input automatically from a computer that is operated by a private contractor. For more information, contact the U. S. Forest Service, Global Environmental Protection Project, Forestry Sciences Laboratory, Seattle, Washington.

E. Summary

The effects of smoke on health, air quality, and regional haze is very important to all land managers. They must recognize the need to manage smoke from wildland fires using the Best Available Control Measures. Every manager must determine the level of smoke management necessary to provide the least impact on the public, both in terms of health and visibility. The effects of smoke on firefighters also must be considered when managing wildland fires. If federal agencies do not take a rational, voluntary approach to smoke management, a mandatory approach may be provided that makes it more difficult to meet resource management goals and objectives.

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CHAPTER V - SOILS, WATER, AND WATERSHEDS

By Dr. Bob Clark

A. Introduction

Fire, either wild or prescribed, may have a wide range of effects on the soils, water, and watershed resources of forestlands, shrublands, grasslands, and wetlands. The wide range of effects is due to the inherent preburn variability in these resources, and to fire behavior characteristics, season of burning, and prefire and postfire environmental conditions such as timing, amount, and duration of rainfall. Further, effects of fire on some soils and watersheds are poorly documented and poorly understood. Thus, generalization about effects of fire on these resources is likely to be more risky and overstated than with any other managed resource.

This chapter, in keeping with the theme of this Guide, will discuss principles and processes that contribute to the effects of fire on soils, water, and watersheds. Where applicable, the opportunity to manage or influence these processes will be discussed. Also, methods for monitoring the effects of fire on these resources will be described, recognizing fire management investigation and monitoring needs for management purposes are not normally required to the degree and precision that are required at the research level. Finally, other factors are critical to "correct" prediction and evaluation of fire effects on soils and water; Chapter III.D. in this Guide is particularly relevant.

Excellent texts that provide basic information on soil taxonomy, properties, physics, and hydrology include those written by Soil Survey Staff (1975), Pritchett (1979), Hanks and Ashcroft (1980), and Branson et al. (1981). The ecology of the soil nitrogen cycle is well described in (Sprent 1987). Soil descriptions used in this chapter follow the nomenclature of the Soil Survey Staff (1975) unless otherwise noted. References to litter layers are described in Youngberg (1981). Important terms are identified in the Glossary.

B. Principles and Processes of Fire Effects

1. Soils. Most information about the effects of fire on soils is from forested land and chaparral; also, much information is predicated on the effects of wildfire, not prescribed fire. By extrapolation, this situation has frequently led to the conclusion that fire is always detrimental to soils, including shrubland and grassland soils. However, in a history of fire research, Schiff (1962) indicated that researchers began documenting about five decades ago that in addition to negative effects, fire occasionally had beneficial effects on soil, and often had no measurable effect; further, the negative effects often were short-lived. These data are not meant to imply that the effects of fire are unimportant, because any negative effect, however small, can have substantial postfire consequences. The effects of fire on the soil resource are induced by soil heating, by removal of the protective cover of vegetation, litter and duff, or by the concentration of plant material substances in the soil. These effects are described in detail in Chandler et al. (1983), Wells et al. (1979), Wright and Bailey (1982), and other references listed in the Bibliography.

a. During the fire.

(1) Soil heating. The magnitude of the heat pulse into the soil depends on fuel loading, fuel moisture content, fuel distribution, rate of combustion, soil texture, soil moisture content, and other factors. The movement of heat into the soil is not only dependent upon the peak temperature reached, but even more so upon the length of time that the heat source is present. Because fuels are not evenly distributed around a site, a mosaic of soil heating occurs. The highest soil temperatures are associated with areas of greatest fuel consumption and the areas that have the longest duration of burning. In forested areas, high subsurface soil temperatures usually occur beneath fuel accumulations, with the highest temperatures most likely to be found in association with consumption of large piles of dry harvest residue or windthrow, or very thick duff layers. Because the pattern of soil heating varies significantly around a site, with differences in both the amount and duration of soil heating, a range of fire effects on soils can occur on one burned area.

Duff and soil moisture contents are critical regulators of subsurface heating. In a controlled soil heating experiment, the heat load into wet duff and mineral soil averaged 20 percent of the heat load that penetrated dry duff and mineral soil (Frandsen and Ryan 1986). Peak temperatures were more than 1000 F (538 C) greater where duff and soil were dry. DeBano (1977) estimated that about 8 percent of the heat generated in California chaparral fires is absorbed and transmitted downward into the soil. In general, "lightly burned" forests will cause maximum soil surface temperatures between 212 and 482 F (100 and 250 C) and the temperature 0.4 to 0.8 inches (1.0 and 2.0 centimeters) below the surface will not exceed 212 F (100 C) (Chandler et al. 1983). In "moderately burned" areas, surface temperatures are typically in the 572 to 752 F (300 to 400 C) range and may be between 392 and 572 F (200 and 300 C) at the 0.4 inch (1.0 centimeter) depth (Chandler et al. 1983). A "severely burned" area may result in surface temperatures approaching 1400 F (760 C) (Chandler et al. 1983).

In contrast, rangelands support considerably lighter fuel loadings and frequently result in fires of shorter duration that produce less subsurface heating. Rangeland fires typically result in soil surface temperatures from 212 to 730 F (100 to 388 C) although extremes to 1260 F (682 C) have been reported. The highest surface temperatures are probably associated with local accumulations of loosely arranged litter and intense winds created by the fire (Wright and Bailey 1982). The greatest subsurface heating likely occurs where thick, dry litter layers are consumed beneath shrubs and isolated trees. The soil heat pulse, including both amount and duration (DeBano 1979), is instrumental in eventual effects of fire on plants (see Chapter VI.B.1.c., and VI.B.2.c., this Guide) and in physical, chemical, and biological effects on soils.

Less is known about heat effects on wetland soils. Due to the high water content of wetland soils, penetration of heat generated by a surface fire can be significantly less than in mineral soils. Since many wetland soils are composed of significant amounts of organic materials, and organic matter has a lower thermal diffusivity than mineral soil, penetration of heat can be further reduced. However, organic soil layers can become dry enough to burn. Significant amounts of heat can be generated when organic soils burn, particularly in drought situations when the fire burns deeply into organic layers.

(2) Postfire temperature increases. Soil temperature may increase after a fire because of the removal of vegetative cover, consumption of fuels, thinning or removal of the litter and/or duff layer, and the enhanced "black body" thermal characteristics of charred material on the surface. This is of great significance in Alaska where permafrost (permanently frozen soil) is present. The soil layer above the permafrost thaws each summer, and is called the "active layer." Soil temperatures usually increase after a fire because fire removes the overstory vegetation, blackens the surface, and consumes some of the layer of moss, lichens, and semi-decomposed organic matter that insulated the soil from summer warmth. Soil temperatures were 9 to 11 F (5 to 6 C) greater at depths of 4 to 20 inches (10 to 51 centimeters) after fire in a black spruce/feathermoss stand in interior Alaska (Viereck and Foote 1979). Eight years after this fire, the depth of the active layer had increased from about 18 inches to 72 inches (46 to 183 centimeters) (Viereck and Schandelmeier 1980). The depth of the active layer eventually stabilizes, and then decreases to its original thickness. The length of time before this occurs depends upon the rate at which new vegetation grows and shades the soil surface, and how long it takes for a soil organic layer to develop that has the same insulating properties as the organic layer that was removed by the fire.

Under similar moisture regimes, warmer soils increase the rate of decomposition, and nutrient availability to postfire vegetation. Within physiological limits, higher soil temperatures also improve growing conditions for plants. In Alaska, deeper annual soil thawing increases the depth of soil available for rooting. This makes additional nutrients, especially nitrogen, available to plants, simply because they are not in frozen soils (Heilman 1966; 1968). Postfire vegetation productivity generally increases significantly after fire on permafrost sites (Viereck and Schandelmeier 1980), although the duration of this effect is undocumented.

b. Physical effects. Heating may cause changes in some physical properties of soils, including the loss or reduction of structure, reduction of porosity, and alteration of color. Most frequently, however, the important consequences include the reduction of organic matter, exhibition of increased hydrophobicity (nonwettability), and increased erosion due to the loss of protective plant and litter cover. Organic matter and hydrophobicity are discussed below under the heading "c. Direct chemical effects."

Erosion by wind (aeolian), water, or gravity often, but not always, increases following fire. The severity and duration of the accelerated erosion depend on several factors, including soil texture, slope, recovery time of protective cover, the amount of residual litter and duff, and postburn precipitation intensity. Raindrop splash, sheet and rill erosion, dry ravel, soil creep, and even mass wasting can occur. In extreme cases, such as steep, chaparral sites in the San Gabriel Mountains of southern California, erosion rates of more than 150 tons of debris per acre have been measured after wildfires (Krammes and Osborn 1969). It is reasonable to assume that hydrophobicity contributed to the extreme erosion rates reported from these areas (DeBano 1979). Extreme rates, up to 165 tons per acre, have also been reported following severe wildfires on timbered and chaparral sites with 40 to 80 percent slopes in Arizona (Wright and Bailey 1982). More commonly, erosion rates, even on steep slopes, range from about 23 to 52 tons per acre on granitic, sandstone, and shale-derived soils, and 7 to 10 tons per acre on limestone-derived soils (Wright and Bailey 1982). It is unclear from the literature how much of the soil movement is attributable to fire, because preburn soil movement or soil movement from unburned "control" areas is seldom reported.

Excessive erosion may not occur for several years after burning (Wright and Bailey 1982) because root systems of top-killed shrubs can maintain soil stability. Mass wasting apparently occurs when root systems begin to decay. If this occurs, it is reasonable to assume that rapid reestablishment of soil-stabilizing, deep-rooted shrubs (rather than shallow rooted grasses) is critical, especially on steep slopes. It has also been reported that coarse-textured soils are more erodible than fine-textured soils (Wright and Bailey 1982). This may explain why little soil movement occurs, even on steep slopes, following prescribed fires on sites with fine-textured Mollisol soils in Wyoming and elsewhere. In Alaska, however, fine textured permafrost soils tend to be much more erosive than coarse textured permafrost soils. Coarse textured soils usually have a low water content, while fine textured soils may contain as much as 50 percent ice. Postfire erosion on ice-rich permafrost soils occurs much more frequently where firelines have been constructed than on sites that have burned, because fires are seldom severe enough to completely remove the organic layer (Viereck and Schandelmeier 1980).

c. Direct chemical effects. Several chemical changes in soils may occur as a direct result of fire, including an increase in pH on some sites; the formation of water repellant soil layers, hydrophobicity, on some sites; and reduction in organic matter.

(1) Organic matter. The reduction of incorporated organic matter is critical if it occurs, on arid, semi-arid, and forested sites, because organic matter is a basic reservoir of the site nutrient (especially nitrogen) budget (Sprent 1987; Harvey et al. 1987). Organic matter helps regulate the hydrologic cycle and the carbon/ nitrogen ratio, provides a site for nitrogen fixation by N-fixing bacteria, and maintains soil structure porosity and the cation exchange capacity. The amount of soil organic matter consumed by fire depends on soil moisture content, amount and duration of heating, and amount of organic matter available for combustion or distillation. For example, peat soils may burn extensively, whereas fire rarely affects most rangeland soils. Similarly, saturated soils rarely loose any organic matter whereas substantial losses may occur in dry soils.

(2) Hydrophobicity. The hydrophobicity phenomena is most common in the chaparral soils of southern California. Although not completely understood, the process by which hydrophobic soil layers form has been described in some detail by DeBano (1981). Organic compounds in litter, probably aliphatic hydrocarbons, are distilled during combustion, migrate into the soil profile, and condense on soil particles, forming a water repellant layer. The phenomena is most severe in dry, coarse textured (sandy) soils that are heated to 349 to 399 F (176 to 204 C). It is least severe in wet, fine textured soils where temperatures remain below 349 F (176 C). It also appears that high temperatures, above 550 F (288 C), destroy the compounds. These data suggest that fires that heat soils to an intermediate range of temperature are more likely to cause the formation of a non-wettable layer than fires that only heat the surface of the soil, or those that cause deep penetration of high temperatures; and that certain plant communities, such as those containing chaparral species, are more likely to be affected.

It is important to recognize that hydrophobicity occurs naturally, in the absence of fire, on forestlands, shrublands, grasslands, agricultural lands, and even golf greens around the world (DeBano 1969a, 1969b, 1981). In addition to the potentially severe problem in southern California, it has also been reported, although less severe and of shorter duration, in every western State except Alaska, New Mexico, and Wyoming (Branson et al. 1981, DeBano 1969a). There are several reported "benefits" of hydrophobicity, including evaporation control and water harvesting (DeBano 1981). One additional, unreported benefit occurred in central Oregon where precipitation limited reestablishment of lodgepole pine *(Pinus contorta)* following a severe wildfire. The presence of hydrophobic layers beneath large burned logs channeled water to inter-log areas, providing adequate soil moisture for seedling establishment.

(3) Acidity/alkalinity. pH is a standard measure of acidity or alkalinity, with 7.0 (i.e., the concentration of H^+ ions is 10^{7} equivalents per liter) being neutral on the pH scale of 1 to 14. The scale is logarithmic, so that water or soil with a pH of 5 is ten times more acidic than water or soil with a pH of 6. "Pure" water is neutral, although "pure" rainfall may have pH values between 5.4 and 5.6 due to absorption of CO_2 that reacts to form one or more weak acids. Understanding the pH concept allows understanding of the mechanisms by which fire alters soil pH and thus the soil nutrient regime.

The combustion process releases bound nutrients, many in elemental or radical form. Certain positive ions, collectively called cations, are stable at typical combustion temperatures and remain onsite after burning. They are subsequently washed into the soil where they exchange with H^+ ions; the resulting increase in H^+ ions in solution increases the pH. Nutrient availability is related to soil acidity (c. f., Tisdale and Nelson, 1975). Elements critical for plant growth, such as nitrogen and phosphorus, become more available to plants after a fire that raises the pH of an acidic soil. Fire can significantly enhance site fertility when it raises the pH on cold, wet, acidic sites.

Fire-induced increases in soil pH are widely reported (Chandler et al. 1983, Wright and Bailey 1982). Most cases of increased pH occurred on forest soils where the initial pH was acidic, and a large amount of organic material burned. Increases in

nutrient availability may be highly significant. Rarely do arid or semi-arid soils, which are typically alkaline, exhibit increased pH after burning. Those that do are near neutral initially, may increase a few tenths of a pH unit, then return to preburn pH levels within a year or two after burning. Little effect on the soil nutrient regime occurs.

d. Soil biota. Soil fauna are variously affected by fire (Ahlgren 1974, Chandler et al. 1983, Daubenmire 1968a, DeBano 1979, Mueggler 1976, Wright and Bailey 1982). Aboveground, soil-related herbivores and carnivores usually suffer drastic, but temporary declines, and may be eliminated by "clean" fires (Wright and Bailey 1982). Sub-surface animals respond differently, depending on both amount and degree of soil heating, the size of preburn populations, and the specific organism in question. One study of Douglas-fir *(Pseudotsuga menziesii)* residue reduction burning found that the bacteria *Streptomyces* were not affected by burning but mold populations were significantly reduced. In contrast, prescribed burning in jack pine *(Pinus banksiana)* resulted in greatly increased *Streptomyces* populations that were still increased into the third postburn growing season. Even where bacterial populations immediately decrease after burning, they typically increase dramatically following the first significant postburn rainfall (Chandler et al. 1983).

Fire induced changes in the soil environment may favor one soil microorganism to the detriment of another. Reaves (et al. 1990) reported that growth of populations of species of *Trichoderma*, a soil fungus, was encouraged in soils sampled from a ponderosa pine *(Pinus ponderosa)* site that had been burned by prescription. In a laboratory study, these fungi inhibited growth of *Armillaria ostoyae*, one of several species of *Armillaria* responsible for serious root diseases in coniferous forests and plantations.

(1) Soil moisture content. Fire-caused mortality of soil microorganisms can be related to the amount of moisture in the soil when a fire occurs. *Nitrosomonas* and *Nitrobacter*, two bacteria groups critical to nitrification (Huber et al. 1977, Sprent 1987), are killed at 284 F (140 C) in "dry" soil but at 167 and 122 F (75 and 50 C), respectively, in "wet" soil (Chandler et al. 1983). This suggests that this sensitivity to heat may be critical to the recovery of low-nitrogen ecosystems.

Water in soil increases the rate of conductance so that elevated temperatures are reached more quickly in surface layers, especially in coarse soils. Therefore, the premise that soil temperature cannot exceed 212 F (100 C) until all moisture is evaporated is academic with respect to certain organisms that have lethal thresholds below the boiling temperature of water. It is important to note that susceptibility to the heat pulse is usually dependent on time-temperature interaction rather than peak temperature alone. If nitrogen fixing bacteria are a concern, the best treatment may be to burn when soils are wet or moist because they restrict the heat pulse to deeper soil layers.

(2) Mycorrhizae. Fire can have a significant, although indirect, effect on soil mycorrhizae. Mycorrhizal fungi form a symbiotic relationship with roots of most higher plant species of both forests and rangelands. The fungal strands absorb water and nutrients (particularly phosphorus) from the soil and translocate them to the roots of the host plant. The host plant provides photosynthetic products to the fungi. The presence of mycorrhizae can lengthen root life and protect them against pathogens (Harley and Smith 1983 in Perry et al. 1987), and can be critical for the establishment of some species of trees. Most mycorrhizal roots occur in surface soil horizons, particularly the organic soil layer, and decaying wood, especially large diameter decomposing logs. If fire removes most of the organic matter on a forested site, productivity may be significantly reduced for many years (Harvey et al. 1986). If fire kills all species of plants that sustain mycorrhizal associations, spores of these fungi may die after several years. It may then be difficult for desired species of plants to reestablish, either by natural regeneration, planting, or direct seeding.

An important mechanism for reintroduction of mycorrhizal fungi on burned forested areas is dispersal by chipmunks *(Tamias spp.)*. These animals eat fruiting bodies of mycorrhizal fungi in adjacent unburned areas, and spread spores in burned areas when they defecate (Maser 1978b and McIntyre 1980 in Bartels et al. 1985). Downed logs provide important travel lanes and home sites for chipmunks. Therefore, the presence of residual logs after a wildland fire enhances the reestablishment of mycorrhizal fungi, both by enhancing habitat for chipmunks, and providing suitable microsites for mycorrhizal infection and growth.

Little is known about the ecology of mycorrhizae in rangelands (Trappe 1981). Most plants of arid and semi-arid rangelands are mycorrhizal, and many of these same relationships may be true, particularly the association of mycorrhizae with organic matter.

e. Soil nutrients. Nutrient changes occur during combustion. Two distinctions germane to the discussion of nutrients include total site nutrient budgets vs. soil-borne nutrients, and total nutrients vs. available nutrients. For example, sites with large volumes of woody material have considerable portions of site budgets bound in organic matter, in forms unavailable to plants. When this material burns, a large amount of nutrients may remain on the site in ash, may leave the site in fly ash or via overland flow, or may volatilize and leave the site in gaseous form. In any event, if bound nutrients leave the site, the site budget decreases but the soil reservoir may remain unchanged (Owensby and Wyrill 1973). Second, even though part of a nutrient's budget may be removed, the remaining portion may be converted into a different, more available form. This latter case is common with nitrogen, which volatilizes at low temperatures; when volatilization occurs, the site budget decreases, but usually the ammonium (NH_4^+) form increases. The ammonium form is directly usable by plants. It is also converted to nitrite by *Nitrosomonas*, then to nitrate, which is also directly usable by plants, by the *Nitrobacter* group. The net result is that while the total amount of nitrogen on a site decreases, the amount of available nitrogen frequently increases.

Postfire nitrogen accretion occurs by such means as fixation by heterotrophic bacteria and symbiotic fixation by nodulated plant roots. On forested sites, many "nitrogen fixers" such as alder *(Alnus spp.)* and ceanothus *(Ceanothus spp.)*, provide rapid recovery of nitrogen (Farnsworth et al. 1978, Raison 1979, Rodriguez-Barrueco and Bond 1968). Bacterial fixation in decomposing wood can also provide an important postfire nitrogen source. In contrast, on chronically nitrogen-deficient sites, including many semi-arid rangelands (Whitford 1986), nitrogen may be depleted by burning too frequently. Burning at intervals of less than 5 to 8 years depleted nitrogen on tobosagrass *(Hilaria mutica)* sites (Sharrow and Wright 1977).

Nitrogen is often the growth-limiting factor on many sites, and is therefore of major interest. Sulfur also volatilizes at low temperatures and its loss also may be important (Tiedemann 1987). Most of the remaining nutrients typically increase or remain unchanged after burning (Chandler et al. 1983, Mueggler 1976, Wright and Bailey 1982).

The cations released to the soil during combustion may be substantial where fire consumes heavy fuel loads on forest sites. However, this so-called "ash effect" is probably minimal on most rangelands. A rangeland site supporting 1,000 pounds (454 kilograms) of completely consumed vegetation per acre that contained 1 percent calcium, would only add about 10 pounds (4.5 kilograms) of calcium "fertilizer" per acre. Most vegetation contains about 3 to 6 percent cations.

2. Water. Wildland fire may affect both water quality and water quantity. The effects are summarized in Chandler et al. (1983), Tiedemann et al. (1979), Wright (1981), and Wright and Bailey (1982).

a. Water quantity. Plants, especially phreatophytes, transpire enormous quantities of water. It follows that breaking the soil-plant-atmosphere continuum should result in a net reduction in water loss. This concept has been applied, with mixed results, in attempts to increase water yield from watersheds (Branson et al. 1981, Davis 1984, Sturges 1983). For example, conversion of shrublands to grasslands has been thought to increase off-site water yield. More recently, Hibbert (1983) suggested that such practices in areas with annual precipitation less than about 15 to 20 inches (38 to 51 centimeters) will probably not result in increased off-site flow. It may be difficult to increase off-site water yield by any practical means in areas where evapotranspiration greatly exceeds precipitation.

There are no conclusive studies that clearly demonstrate that fire causes long-term increased water yield (Settergren 1969). Temporary (for a few years) increases may occur following large, "clean" fires because although direct evaporation may increase, water detention by litter and debris, and transpiration, both decrease. However, the effect is quickly reduced as vegetation and litter return. Demonstration of the "increased yield" is difficult because the effect is often temporally shorter than natural variation in climatic events, and because increased evaporation from the soil surface may compensate for reduced transpiration. There is good circumstantial evidence that greater accumulations of snow may occur following fires that remove some tree cover because of decreased interception of snow by the canopy. However, if the burned area exceeds about four times the height of surrounding cover, snow accumulation may decrease due to wind scour (Haupt 1979). In contrast, water quality may be dramatically affected by fire.

b. Water quality. The literature is replete with evidence of fire-induced changes in water quality, including increased sedimentation and turbidity, increased stream temperatures, and increased concentrations of nutrients resulting from surface runoff (Buckhouse and Gifford 1976, DeByle and Packer 1972, Feller and Kimmins 1984, Helvey et al. 1985, Nissley et al. 1980, Richter and Ralston 1982, Striffler and Mogren 1971, Tiedemann et al. 1979, Wright et al. 1976). The implication is clear: wild and prescribed fires, on forestlands, shrublands, and grasslands, have the potential to decrease on and off-site water quality, and should be mitigated. Effects may be short or long-lived. In a study on 26 to 28-inch (66 to 71 centimeters) annual precipitation rangeland with Mollisol and Inceptisol soils, Wright et al. (1976) found that level areas were unaffected, but adverse effects lasted for 9 to 15 months on moderate (8-20 percent) slopes and 15 to 30 months on steep (37 to 61 percent) slopes. Wright et al. (1976) further found that the average sediment yield was less than 0.01 tons per acre during the first six months after burning from the level sites but was about 10-fold greater on moderate slopes and 100-fold greater on steep slopes.

Mesic, forested sites revegetate much more quickly, but also may be exposed to greater, and often more intense, rainfall. In a study following a wildfire on a ponderosa pine site in central Washington, where annual precipitation is about 23 inches (58 centimeters), Helvey et al. (1985) found that annual sediment yields increased as much as 180-fold above prefire levels. The yields were still 12-fold greater after seven years. A carefully controlled study on a larch *(Larix* *occidentalis)*, Douglas-fir, and Engelmann spruce *(Picea engelmannii)* site in western Montana (DeByle and Packer 1972) found that sediment returned to preburn levels after about four years. Erosion rates in the Montana study remained below 0.01 tons per acre per year throughout the study.

Methods for mitigating accelerated sedimentation due to fire have not been fully developed. Sedimentation may be reduced by the protection of steep slopes, retention of wide buffers along water courses, rapid revegetation, the presence of residual fuel and duff, and the exclusion of use until recovery.

Fire may induce sudden changes in water chemistry. Such changes probably result from nutrients that are carried into water courses from burned areas. Typically, several forms of nitrogen, phosphorus, and most cations show increases in stream water after burning (Tiedemann et al. 1979). Chemistry is most often altered during the first few storms following fire. Changes include increases in bicarbonates, nitrates, ammonium, and organic nitrogen (Chandler et al. 1983). These nutrients usually are not hazardous to humans but may contribute to eutrophication or algal blooms. Water quality typically returns to preburn levels within one to two years. Some fire retardant chemicals used during fire suppression may be toxic to aquatic animals; the addition of these chemicals near or in water courses should be avoided until specific consequences are clarified.

Stream temperatures also often increase after fire occurs. Usually the temperature increase is due to the removal of overhead protective vegetation rather than direct heat flux from the fire. Elevated stream temperatures are detrimental to most cold water fish species. Therefore, protection of streamside vegetation, and quick revegetation of burned areas, are critical to stream rehabilitation.

C. Resource Management Considerations

1. Expertise on Interdisciplinary (I. D.) Teams. Expertise in soils and hydrology is required on interdisciplinary teams.

a. A soil scientist, knowledgeable about fire effects, should be assigned to interdisciplinary teams involved with fire prescription development, site selection, emergency fire rehabilitation projects, and wildland fire suppression activities.

b. A hydrologist should be assigned to the I.D. team, or at least consulted, if wild or prescribed fire might affect water quality, on or off-site.

2. Statistical Analysis. Statistical analysis is necessary to assess the effects of fire on soils and hydrology.

a. Physical and chemical characteristics of soils typically are extremely variable. Fire effects can vary significantly around a site because of differences in the amount of soil heating. A biometrist or statistician should be consulted before any sampling is undertaken.

b. Adjacent, unburned "control" sites should be used for comparison with burned sites whenever possible to evaluate the effects of fire on soils or water. A biometrist or statistician should be consulted for appropriate sampling and comparison methods. **3. Limited Ability to Extrapolate to Other Sites.** Much of the fire literature describes the effects on soils and hydrology of intense wildfires. Such information should be extrapolated to different regions, soils, environmental conditions, types of fire behavior and characteristics, and to prescribed fires with caution.

4. Variability of Effects. Because fire effects on soils and water are highly variable, consideration should be given to locally documenting effects and relating the effects to fireline intensity, burn severity, fuel, duff, and soil moisture content at the time of the fire, and other appropriate factors.

5. Factors Related to Postfire Erosion. Potential for wind, water, or gravity (especially dry ravel) erosion should be given strong consideration in the timing (i. e., fall vs. spring) of prescribed fires, and in the methods, timing, and species proposed for emergency fire rehabilitation.

a. Delayed recovery of vegetation and slope steepness appear to be important factors in accelerated erosion.

b. The presence of large woody debris and duff after a fire helps to protect the soil from erosion.

6. Management of Soil Heating. The amount of soil heating caused by prescribed fires in forest or woodland areas can be managed.

a. The distribution of soil heating is affected by the choice to broadcast burn, pile burn, or burn windrows. Also, the piling method may be important because machine piles tend to be "dirtier," and hold heat longer, than hand piles.

b. Small diameter, unmerchantable trees (whips) can be slashed just before fire, when they are still green and will not burn well, and thus can contribute little to soil heating.

c. Higher levels of utilization or yarding some unmerchantable material in areas with heavy dead and down fuel loads can decrease the amount of potential soil heating.

d. Burning an area while moisture content of large diameter fuels, lower duff, and soil is high will limit the duration of the fire and the amount of heat penetration into lower soil layers.

e. Rapid ignition techniques (e.g., aerial drip torch) can sometimes be used to shorten the duration of the burn, and thus the amount of soil heating.

7. Leaving Woody Material. When prescribed burning, it is important to leave some coarse, woody debris on the site for nutrient cycling and mycorrhizal function. Agencies may have specific requirements for retention of downed, woody material.

8. Riparian Areas.

a. Buffer strips. When prescribed burning, leave unburned strips of vegetation along riparian areas to serve as slope stability buffers, and decrease the potential for stream sedimentation. Width of buffer strips should be in accordance with applicable agency policy.

b. Season of fire. Riparian areas should be burned, if necessary, in spring when conditions are favorable for rapid recovery of adjacent vegetation.

c. Use of fire retardant. Use of fire retardant chemicals in or near waterways should be avoided. Fire retardant has the greatest impact on small or slow moving bodies of water.

d. Firelines. On erosive soils and/or steep slopes, restrict the location of firelines that lead directly into water courses. Rehabilitate any firelines that were constructed as soon as possible. Replacement of soil and plant material removed during construction is an effective method of fireline rehabilitation.

9. Salvage Logging. Know the potential for soil erosion when considering or planning salvage logging operations after wildfire.

a. Road construction may increase the amount of soil erosion and mass movement. Also, some areas (e.g., Western Oregon) have restrictions to limit "off road" use to minimize compaction. These restrictions may dictate the appropriate logging method.

b. A choice may be made to helicopter log or to not log at all.

10. Need for Closures. It may be necessary to close burned areas to all types of vehicular use, and other uses, for several years because of increased erosion potential.

D. Methods to Monitor Fire Effects

The effects of fire on soils and water are usually extremely variable over time and space due to variations in soil characteristics and plant communities; in the intensity, duration, and timing of postfire precipitation; and in the heat regime of the fire. Many methods used to monitor changes in soils or water quality are time consuming, expensive, and often require elaborate laboratory facilities. Therefore, methods used to monitor fire effects for day-to-day management purposes are usually less extensive and intensive than methods used for research. This section suggests methods for monitoring fire effects that are practical for management purposes. A more complete understanding of soil monitoring techniques can be gained from Black (1965) and Golterman and Clymo (1969).

1. Soil Temperature. Soil temperature, by itself, may not be particularly revealing. However, it may add valuable insight when used in conjunction with other information.

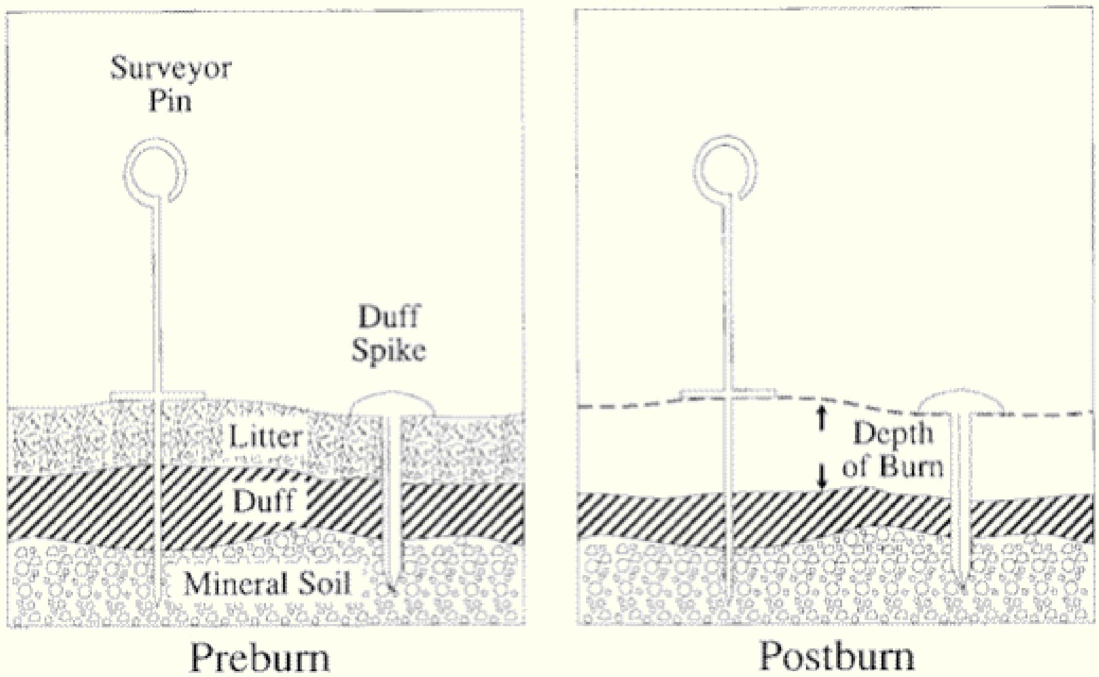
a. Heat sensitive paint. Temperatures can be monitored by placing chips covered with heat sensitive paints at the duff/soil surface and at various depths below the surface. These paints turn color at a temperature specific to each kind of paint, but do not indicate duration of heat. However, it is likely that the presence of high temperatures may increase the certainty of impacts. Temperature sensitive devices and paints are available from many forestry suppliers.

b. Electronic equipment. Extremely accurate data can be obtained through use of sophisticated electronic equipment such as thermistors and thermocouples. A thermocouple can be wired to a strip chart recorder which provides a continuous record of temperature. These are expensive, and can be unreliable unless properly used. Unless research is being conducted on a prescribed fire, their use is probably not warranted. If they are used, advice should be obtained from the research community on appropriate composition, size, number, and placement of thermocouples.

2. Soil Physical Properties. The primary physical effect of fire on soil is the removal of protective cover, which allows accelerated erosion. Erosion can be estimated using predictive models, qualitative guides, or quantitative methods. To isolate fire effects from other effects, burned areas should be compared with adjacent, unburned control areas. The following practical, quantitative methods are suggested for obtaining direct estimates.

a. Erosion.

(1) An appropriate number of "depth-of-burn" pins can be randomly placed onsite before burning to measure duff removal and/or subsequent soil movement. The pins may be of the v-notched survey pin type (with the pin inserted such that the notch is at duff or soil surface level), or the t-bar survey pin type (with the pin inserted such that the cross member rests on the duff or soil surface) (McRae et al. 1979). Bridge spikes also work well. Remeasurements over time will provide an indication of soil movement. Frost heaving and pin disruption by animals may produce erroneous values. Depth of soil removed can be expressed as volume or mass by using appropriate mathematical conversions. This method of estimating soil movement appears to work well for relatively uniform erosion of minor depth, such as wind erosion, but does not work well for irregular soil movement, such as gully erosion, or for mass wasting.



(2) Soil erosion bridges (Blaney and Warrington 1983, Ranger and Frank 1978) are excellent devices for estimating the amount of soil leaving the site, but may require special or additional equipment. Staff soil scientists, or soil scientists from the USDA Soil Conservation Service, universities, or experiment stations should be consulted.

(3) Soil catchments or erosion troughs (Ryan 1982, Wright et al. 1976) are used to collect material after it leaves the site. Commonly, paired watersheds (one member of the pair receives the treatment and the other serves as an untreated control) are used to estimate off-site movement of soil. This method requires the construction of catchments and may not be practical on wildfires or on most prescribed fires.

(4) Other methods are available for estimating accelerated erosion, including models such as the Revised Universal Soil Loss Equation (Renard et al. 1991), radioactive markers (Lance et al. 1986), and photogrammetry (Lyon et al. 1986). These methods are especially useful for research and special management needs, but may not be practical in most fire situations.

b. Hydrophobicity. Hydrophobicity is most easily estimated by the water drop penetration time method (DeBano 1981). A water drop is placed on the sample surface and the length of time to be absorbed is monitored. DeBano suggests that water droplets remaining longer than 5 seconds indicate water repellency. A further refinement of this method uses the surface tension of various ethanol solutions; a water repellency index is then obtained by dividing the critical surface tension into the time (up to 600 seconds) required for water drop absorption. An index value greater than 10 indicates extreme repellency, 1 to 10 indicates moderate repellency, 0.1 to 1 indicates slight repellency, and less than 0.1 indicates wettability.

c. Other physical properties. Fire-induced changes in other physical properties of soils, including soil structure, porosity, and rate of infiltration can be measured using standard methods (Black 1965) for soil analysis. A soil scientist familiar with the methods should perform these analyses.

3. Soil Chemical Properties.

a. Soil water content. Soil moisture content partially regulates the heat pulse into the soil. Because of this importance it is discussed separately here. Several methods of soil water determination are readily available (Roundy et al. 1983) but the gravimetric method (Gardner 1965) is probably the most reliable and commonly used method. An appropriate number of 1 to 100 gram samples are collected in soil cans, weighed (wet weight), oven dried to constant weight (normally at 212 F [100 C]), and reweighed (dry weight). Soil water content is then calculated according to:

soil water content (percent) = (wet weight - dry weight x 100) / dry weight

Drying at temperatures greater than 212 F (100 C) can cause volatilization of soil organic matter, resulting in a loss of materials other than water from the sample, and an overestimation of soil moisture content.

b. Soil pH. The acidity of soil is readily determined using soil paste or aqueous soil suspension and glass electrode pH meters (Peech 1965). Although "standards" are used for meter calibration, it is important to concurrently analyze soil samples from adjacent, untreated soils for comparison, because variations occur among meters and investigators.

c. Soil conductivity. The electrical conductivity of soil caused by the presence of soluble salts is readily determined by using a solu-bridge (Bower and Wilcox 1965). Extracted soil solution is read on the bridge, corrected for temperature, and reported in millimho (unit of conductance). High soil salt content is an indicator that salt-tolerant species should be planted.

d. Other chemical properties. Measurement of other chemical properties of soils that are likely to be affected by the fire require special laboratory equipment and procedures. These are probably beyond practicality for routine fire effects analyses. Bureau soil scientists or soil scientists of other agencies, universities, or experiment stations should be contacted if such analyses are necessary.

4. Water Quantity. Increases in off-site water yield due to burning are most easily determined by measuring changes in streamflow volume before and after burning. If available, paired watersheds should be used. Other agencies, such as the USDA Soil Conservation Service or DOD Army Corps of Engineers, often have gaging stations or use other methods to determine flow volumes on many streams and rivers. In addition, these agencies and many universities and experiment stations often have portable devices that can be used to assess changes in water yield.

5. Water Quality. Several descriptors of water quality can be estimated with minimal investment of time, equipment, training, and personnel, and include turbidity, conductivity, dissolved oxygen content, and temperature. Kits and relatively inexpensive instruments are commercially available for sampling these properties. Experiment stations, universities, and Federal and State water quality agencies can provide assistance.

a. Sedimentation and turbidity. Sedimentation and turbidity reduce the quality of spawning areas and reduce photosynthetic activity. These effects can be amplified by fires that occur near water and may persist for several years or longer. Platts et al. (1983) described general methods for sampling and evaluating stream conditions. Specific procedures for the nephelometric turbidity estimation method are contained in the EPA (1979) publication on water quality evaluation methods.

b. Conductivity. Changes in the specific conductance due to increased ionic composition of the water may provide a useful estimate of the addition of nutrients or contaminants to water. Specific procedures for the use of conductivity meters are found in EPA (1979).

c. Dissolved oxygen. A dissolved oxygen content of about 5 milligrams or more per liter may be necessary to maintain aerobic conditions and support cold water fisheries in Western streams (EPA 1976, Thurston et al. 1979). Because the addition of sediment and nutrients following fire may reduce the oxygen content below acceptable levels, oxygen contents can be monitored to estimate potential impacts on fisheries. Inexpensive kits and meters for measuring dissolved oxygen contents are readily available from chemical and forestry equipment suppliers. The EPA (1979) described specific procedures for using the membrane electrode and modified Winkler methods of dissolved oxygen analysis. A hydrologist, fisheries biologist, or chemist should be contacted for recommendations of preferred methods and equipment in specific locations.

d. Temperature. Reasonably correct estimates of temperature may be important because water temperature, outside of some fairly narrow ranges, can dramatically influence algal blooms, fish survival and reproduction, and a host of other biological activities. However, precise estimates of temperatures in streams can be difficult to obtain because such factors as diurnal variation, angle of the sun, shading, and flow can contribute to error. These factors, as well as thermal layering, can cause equally bad estimates in lakes and ponds. Therefore, depending on the significance of temperature in a particular situation, a temperature sampling scheme should be carefully designed. It should also be noted that data obtained from monitoring and recording devices are usually more reliable than "grab samples" obtained with hand-held mercurial thermometers. Specific procedures for estimating the temperature of water are found in EPA (1979).

e. Other chemical properties. Measurement of other chemical properties of water, such as the concentrations of specific chemicals or nutrients, are probably beyond the practical reach of most land management agencies. Such analyses require special and expensive laboratory equipment and training. If such analyses are necessary, a hydrologist, fisheries biologist, or chemist should be contacted, and appropriate procedures (EPA 1979, Golterman and Clymo 1969, Hem 1970) applied. Analyses can sometimes be completed using inexpensive soil or water testing kits. Results from such testing are not definitive and should remain suspect until confirmed by standard laboratory procedures.

E. Summary

The effects of fire on soils, water, and watersheds are extremely variable. In some cases, such as accelerated erosion, the outcome is reasonably predictable and mitigating measures such as rapid revegetation are necessary. In other cases, such as change in off-site water yield after burning, the outcome is much less predictable because it appears to depend on site-specific characteristics and on unpredictable climatic events. The application of mitigating measures must be based on local experience and local research. In almost all cases, the establishment of a local data base would provide useful information for future events.

CHAPTER VI - PLANTS

By Melanie Miller and Jean Findley

A. Introduction

This chapter discusses the interaction of fire with plants. It explains the basic principles and processes that determine how plants are affected by fire, and the factors that control plant response after the fire. Documentation of burning conditions and fire characteristics provides important information for understanding postfire vegetative response. Use of appropriate techniques when monitoring specific effects of fire on vegetation is necessary to detect changes that occur in the postfire plant community. The goal is to enable managers to predict fire effects on plants based upon knowledge of burning conditions and prefire species and community characteristics, and to interpret the causes for observed variability in postfire vegetative response.

The response of plants to fire can vary significantly among fires and on different areas of the same fire. Both variability in the heat regime of the fire and differences in plant species' abilities to respond affect the postfire outcome. Fireline intensity, burn severity, total duration of combustion, soil heating, time of the year, and time since the last fire all influence mortality or survival of the plants, and thus subsequent recovery. Postfire effects also depend upon the characteristics of the plant species on the site, their ability to resist the heat of a fire, and the mechanisms by which they recover after fire. Plant recovery can be affected by factors that vary with growing season, or age of the plant. Whether the plants that first appear after a fire successfully establish on the site can be influenced by external factors such as postfire weather, postfire animal use, and plant competition.

The inherent abilities of plants to respond to fire depend partially on the fire regime to which the plant community has adapted. For example, a community may characteristically have been subject to frequent, low intensity, low severity understory fires, or the site may have experienced infrequent high intensity fires that killed all standing vegetation. Knowing the "natural" role of fire on a site gives an indication of the type of plant adaptations to fire that may be present.

The most significant sources of heat from most fires are downed dead surface fuels, litter, and duff layers. However, dead branches, leaves, or needles within a plant itself can produce a considerable amount of heat. Old decadent stands of shrubs may produce a more intense fire than a young shrub stand, which may have little dead or dry material and cannot be ignited. The amount of dead woody fuel, thickness of litter and duff layers, and amount of dead material within or around a living plant may be greater than "natural" if fire has been excluded from an environment in which fires used to occur at a moderate to high frequency. In this situation, the impact of fire on the vegetation may be different than it would have been under natural conditions because of the potentially higher temperatures and longer duration of fire that can occur.

B. Principles and Processes of Fire Effects

1. Plant Mortality. Fire-related plant tissue mortality is dependent upon both the temperature reached and the duration of time it is exposed to that temperature. The lowest temperature at which plant cells die is between about 50 to 55 C (122 to 131 F) (Baker 1929 in Wright and Bailey 1982). Some plant tissue may be able to withstand an exposure to 60 C (140 F) for a few seconds, but dies if exposed for about 1 minute. Plant tissue can sustain higher temperatures for greatly decreasing periods of time. Douglas-fir *(Pseudotsuga menziesii)* needles can tolerate temperatures of 70 C (158 F) for only about 0.01 second (Silen 1960 in Martin 1963). Additionally, some plant tissues, particularly growing points (meristems or buds) tend to be much more sensitive to fire heat when they are actively growing and their tissue moisture is high, than when tissue moisture content is low (Wright and Bailey 1982). Thus, plant tissues more readily die after exposure to a specific temperature for a certain length of time when actively growing than when they are physiologically dormant or quiescent, or have finished active growth for the year. Susceptible plant tissue may not be directly exposed to fire heat, because it is protected by other tissues such as bark or bud scales, or is buried in duff or soil. Plant mortality depends on percentage of tissue killed, location of dead tissue, reproductive mechanisms, and species ability to recover from injury.

a. Crown mortality. Both structural and physical characteristics affect the likelihood that the aboveground part of a woody plant will be killed by a given fire. Important crown characteristics include branch density, ratio of live to dead crown material, location of the base of the crown with respect to surface fuels, and total crown size (Brown and Davis 1973). Small size buds are more likely to be lethally heated because of their small mass. Large buds, such as on some of the pines, are more heat resistant. For conifers, long needles provide more initial protection to buds than short needles that leave the bud directly exposed to fire heat (Wagener 1961 in Ryan 1982).

The moisture content of new needles, leaves, and small twigs, the foliar moisture content, fluctuates throughout the growing season. It is highest during the period of active leaf formation and shoot elongation (greenup), subsequently declines to a lower level during the remainder of the growing season, and drops again when foliage cures (Norum and Miller 1984). For conifers, the moisture content of new foliage follows the above pattern, while moisture levels in older needles drop in the spring, and rise again in late spring and early summer (Gary 1971; Chrosciewicz 1986). Moisture content influences foliar flammability because leaves and twigs containing more water require a greater amount of heat to raise them to ignition temperature. Coniferous tree crowns seem to be more susceptible to crown damage in the spring than they are in the fall because tissue moisture of new growth is highest at about the same time the moisture content of old foliage is near its seasonal low and more flammable. The foliage of some shrubs, particularly those with evergreen leaves, contains flammable compounds that allow foliage to burn more readily than if these compounds were not present (Countryman and Philpot 1970; Shafizadeh et al. 1977).

The scorching of a tree crown is primarily caused by peak temperatures associated with the passage of the flaming fire front (Wade 1986). The height above the surface to which crowns are scorched, (crown scorch height), can be estimated from flame length, an output of the Fire Behavior Prediction System, ambient air temperature and windspeed (Albini 1976). (See XII.D.1.a., this Guide, for a more complete discussion of how this model works.) Long-term heating caused by burnout of fuel concentrations after the flaming front has passed can also scorch crowns. The percent of crown volume with scorched foliage is a better indicator of fire impact than crown scorch height because it considers the proportion of live foliage remaining (Peterson 1985). For conifers with short needles, and trees and shrubs with small buds, crown scorch is often equivalent to crown death because of lack of protection afforded the buds (Wade 1986), and the low heat resistance of small buds and twigs.

Crown consumption is the result of the ignition of needles, leaves, and twigs. Needle ignition occurs at about 400F (220C) (Wade and Johansen 1986). For fire resistant conifers with long needles, such as ponderosa pine *(Pinus ponderosa)*, and/or large or well protected buds that are buried in wood such as western larch *(Larix occidentalis)*, crown consumption is often a better indicator of crown mortality than crown scorch. For these species, bud and twig death generally only occurs where foliage is consumed by fire (ibid.).

b. Stem mortality. Trees and shrubs can be killed by lethally heating the cambium, the active growth layer that lies beneath the bark. Bark surface texture can affect its likelihood of ignition, whether stringy and flammable, or smooth. Fire resistance of tree stems is most closely related to bark thickness, which varies by species and with age. The cambium layer of thin barked trees such as lodgepole pine *(Pinus contorta)*, subalpine fir *(Abies lasiocarpa)*, aspen *(Populus tremuloides)*, madrone *(Arbutus menziesii)*, or most of the spruces *(Picea spp.)* is usually dead beneath any charred bark. Heat released in the flaming front, and hence flame length, can be a good indicator of the amount of injury sustained, and even the mortality of thin barked species. External char is not a good indicator of cambium damage on thick barked trees such as ponderosa and Jeffrey pine *(Pinus jeffreyi)*, Douglas-fir, or western larch (Ryan 1982). The cambium beneath thick bark layers is usually only killed by heat released over a long duration, such as from burnout of logs, and deep litter and duff layers, which cannot be predicted by the Fire Behavior Prediction System. The amount of bole damage was a better indicator of postfire survival of Douglas-fir after a series of spring and fall underburns than either scorch height or the percentage of crown volume scorched (Ryan et al. 1988). Once tree cambium is wounded by fire or mechanical damage, it is often more susceptible to additional injury by fire, both because the bark is thinner near the scar, and because of pitch that is often found in association with wounds. A model that estimates tree mortality based on species, and the amount of crown and bole damage is described in XII.D.1.b., this Guide.

Bark thickness, texture, and the presence of wounds or pitch also can affect the likelihood of mortality of shrub stems. However, because of the relatively small diameter of most shrub stems, most stems are girdled by any fire that reaches into their canopy, unless heat is present for only a very short period of time.

c. Root mortality. As with tree and shrub crowns and stems, there are physical and structural characteristics that affect root damage. Structural support roots growing laterally near the surface are more susceptible to fire damage and consumption than those growing downward. Roots found in organic layers are more likely to be lethally heated or consumed than those located in mineral soil layers. This makes shallow-rooted trees more subject to postfire windthrow. Most plants have feeder roots. Tree feeder roots collect most of its water and nutrients, are very small in diameter and are usually distributed near the surface. If most of the feeder roots are located in soil organic layers rather than in mineral soil, they are much more subject to lethal heating and consumption. While this may not always kill the tree, it can place the tree under significant stress. If fire has been excluded for a long time from areas that formerly had a high fire frequency, increased amounts of root (and bole) damage may result from fires smoldering in accumulations of litter beneath trees (Herman 1954 and Wagener 1955 in Wade and Johansen 1986).

Damage to roots and other subsurface plant parts cannot be predicted by the general behavior of the surface fire, nor by any specific descriptors of surface fire activity, such as fireline intensity, flame length, or rate of spread. Temperatures reached in the flaming front may be extremely high, but most of that heat is directed upwards. The mortality of buried plant parts is much more dependent on the total residence time of the fire, the length of time a heat source is present (Wade 1986), not just the length of time flaming combustion occurs. The subsurface heat regime of a fire is influenced by the amount of surface dead fuel, the amount and compactness of litter and duff, and the moisture content of those materials.

Burn severity (see II.B.6.e.), a qualitative measure of the amount of consumption of surface fuels and duff layers, is an indicator of subsurface heating. Soil moisture also retards penetration of heat into soil layers (Shearer 1975; Frandsen and Ryan 1986), thus protecting subsurface plant structures. There is some relationship between heat per unit area, the total amount of heat released in flaming combustion, and root damage, particularly if only a thin layer of combustible fuel is present. However, if moderate to heavy accumulations of surface dead fuel or organic layers exist, their consumption in smoldering and glowing combustion is the best indicator of significant amounts of subsurface heating. (Factors that regulate fuel and duff consumption, and thus burn severity, are discussed more completely in III.B.2. and III.B.3., this Guide.) There may be considerable damage or consumption of roots when little or no damage is apparent in tree or shrub crowns (Geiszler et al. 1984 in Wade and Johansen 1986). The amount of subsurface plant mortality can be indirectly estimated by knowing the location of roots and other buried reproductive structures, and relating this to classes of burn severity.

Plant mortality is often the result of injury to several different parts of the plant, such as crown damage coupled with a high percentage of cambial mortality. Mortality may not occur for several years. Death is often the result of secondary infection by disease, fungus, or insects, because the resistance of plants to these agents is often lowered by injury, and wound sites provide an entry point for pathogens (Littke and Gara 1986). A plant weakened by drought, either before a fire or after wounding, is also more likely to die.

2. Vegetative Regeneration. Sprouting is a means by which many plants recover after fire. Sprouts can originate from plant parts above the ground surface or from various levels within the litter, duff, and soil layers. Where sprouts originate and the depth below the surface at which buried plant parts are found can be species specific characteristics (Flinn and Wein 1977). Heat released in the flaming front of the fire can have a direct impact on mortality of sprouting sites that are above the ground surface. The same factors that control mortality of roots affect mortality of buried reproductive structures of woody plants, grasses, and forbs.

a. Location of dormant buds. Dormant buds are often located on laterally growing stems. Stolons are stems that run at or near the surface of the ground, producing plants with roots at intervals, such as a series of strawberry plants. Rhizomes are laterally growing underground stems located at varying depths in litter, organic, and mineral soil layers. They have a regular network of dormant buds that can produce new shoots and roots. Rhizomes are a structure common to many plants, including blue huckleberry *(Vaccinium globulare)*, thimbleberry *(Rubus parviflorus)*, Oregon grape *(Mahonia spp.)*, common snowberry *(Symphoricarpos albus)*, shiny-leaf spiraea *(Spiraea betulifolia)*, heartleaf arnica *(Arnica cordifolia)*, gambel oak *(Quercus gambelii)*, bittercherry *(Prunus emarginata)* and chokecherry *(Prunus virginiana)*.

Many plants have buds located in the tissue of upright stems, above or below the surface of the ground, such as bitterbrush *(Purshia tridentata)*, bigleaf maple *(Acer macrophyllum)*, rabbitbrush *(Chrysothamnus spp.)*, winterfat *(Ceratoides lanata)*, and mountain-mahogany *(Cercocarpus spp.)*. Bud masses may also be present in branch axils. Paper birch and madrone are species that have root collar buds located in stem tissue at the point where roots spread out from the base of the stem. Lignotubers, burls, and root crowns are names for masses of woody tissue from which roots and stems originate, and that are often covered with dormant buds (James 1984). Dormant buds may be deeplyburied in wood, and may be located far below the surface if the tissue mass is large. Chamise *(Adenostoma fasciculatum)*, serviceberry *(Amelanchier alnifolia)*, scrub oak *(Quercus dumosa)*, tanoak *(Lithocarpus densiflora)*, alder *(Alnus spp.)*, and mallow ninebark *(Physocarpus malvaceus)* all produce sprouts from these buried woody structures.

A caudex is an upright underground stem common in many forb species, such as arrowleaf balsamroot *(Balsamorhiza sagittata)* and lupine *(Lupinus spp.)*, that develops new leaves and a flowering stem each year. Other stemlike reproductive structures are bulbs and corms, which are essentially buried, short thickened stems with a bud or buds covered with fleshy leaves. Some species have dormant buds or bud primordia located along the surface of roots from which new shoots can originate, such as aspen, fireweed *(Epilobium angustifolium)*, and horsebrush *(Tetradymia spp.)*.

b. Postfire sprouting process. Postfire sprouting occurs by a very orderly process. The following discussion describes a likely model of the interactions that control postfire shoot development in woody plants. Similar processes probably regulate sprouting in grasses and forbs. The growth of most dormant buds or bud primordia of woody plants is controlled by a phenomenon called apical dominance. Growth hormones, particularly auxin, a plant hormone manufactured in actively growing stem tips and adjacent young leaves, are translocated to dormant buds, which prevent them from developing into new shoots (Schier et al. 1985). If these plant parts are removed, the source of growth hormones is eliminated. The balance of plant hormones within the buds changes (ibid.). Growth substances in roots, particularly cytokinins, that are translocated to the buds can cause dormant buds to sprout, or stimulate bud primordia to differentiate into shoots (ibid.). Cytokinins may already be present in buds, and a decrease in the ratio of auxins to cytokinins provides the stimulus for bud outgrowth (ibid.). The buds that become shoots are usually those nearest to the part of the plant killed by the fire. If dormant buds are destroyed, new buds may form in wound tissue, called callus, and subsequently produce shoots (Blaisdell and Mueggler 1956). Once new shoots are actively growing, they produce growth hormones that are translocated to other dormant buds that are farther away from the point of damage, suppressing their growth (Schier 1972; Bilderback 1974).

If the organic layer is thinned or disturbed, additional light may reach the tips of rhizomes and stimulate them to grow towards the surface and produce shoots (Barker and Collins 1963; Trevett 1956; Miller 1977). It has also been observed that decapitating a rhizomatous plant causes laterally growing rhizomes to turn upwards and become shoots (Schier 1983). Additional rhizomes often form in response to vigorous aerial plant growth (Kender 1967), which may subsequently produce aboveground shoots. Sprouts from new rhizomes or lateral roots may recolonize areas where all reproductive plant parts were killed by a fire. Plants may sprout soon after a fire, or not until the following spring if the fire occurs after the plants have become dormant for the winter (Miller 1978). Warmer soil temperatures after burning may enhance the amount of sprouting that occurs (Zasada and Schier 1973). The initial energy required to support growth until the sprout is photosynthetically self-sufficient comes from carbohydrates and nutrients stored in the reproductive structures or in adjacent roots (James 1984).

Postfire sprouting ability can vary with plant age. Young plants that have developed from seed may not be able to sprout until they reach a certain age, which varies by species (Smith et al. 1975; Tappeiner et al. 1984). For a given species such as bitterbrush, an older plant may be able to produce few, if any, sprouts that survive (Ferguson 1988). Other factors also may lead to decreased amounts of postfire sprouting in older bitterbrush. These include the higher amount of dead material within old crowns, and the deep organic layer found beneath some old plants that cause increased potential for lethal heating during a fire (Clark 1989; Miller 1988).

Aspen produces sprouts from healthy roots. Decreased amounts of postfire sprouting observed from older aspen stands (Schier 1975) may be because the condition of many of the roots has deteriorated to the point where they cannot sprout (Zasada, pers. conv. 1989). Aspen stands in Alaska can resprout vigorously after fire when they are 150 to 200 years old, perhaps because the incidence of pathogens in Alaskan aspen stands is relatively low (ibid.). In areas such as the Lake States, aspen stands are often killed by cankers by the age of 50 to 70 years (ibid.) An aspen stand that is producing a few understory suckers still has the capacity to sprout after a fire (DeByle 1988a).

Some plants therefore replace themselves, forming a new aboveground stem, but use essentially the same root system as before -- vegetative regeneration. Some plants may spread and develop new individuals from different locations along their roots or rhizomes. Shoots may form their own root system and become separate individuals.

This is called vegetative reproduction by some, but these plants are genetically the same as the parent plant, and represent growth of the clone (Zasada 1989). True reproduction only occurs when a new genetic individual is formed, by establishment and growth of a new seedling (ibid.). Sexual reproduction of new individuals of gambel oak occurs when plants establish from seeds. Gambel oak can also regenerate vegetatively, replacing itself by sprouting from a lignotuber, and extending the clone by developing new plants from buds on rhizomes (Tiedemann et al. 1987).

c. Relationship of sprouting to burn severity. A strong relationship exists between burn severity, a measure of the amount of heating at and below the ground surface, and postfire sprouting in forested areas (Miller 1977; Dyrness and Norum 1983; Ryan and Noste 1985; Morgan and Neuenschwander 1988).

(1) A light severity fire occurs under moist fuel conditions, or where little fuel is present. Woody debris is partially consumed but some small twigs and much of the larger branchwood remain. Leaf litter may be charred or consumed, and the surface of the duff layer also may be charred. A light severity fire may kill reproductive parts at or very near the surface such as stolons, or stem buds that are not well protected by bark layers. It has little effect on most buried plant parts and significant amounts of postfire sprouting can occur.

(2) A moderate severity fire occurs when fine and smaller diameter dead fuels and surface litter and organic layers are dry, but large dead fuels and lower organic layers are still moist. Foliage, twigs and the litter layer are consumed. Duff, rotten wood, and much of the woody debris are removed. Logs are deeply charred. This type of fire kills or consumes plant structures in litter and in the top part of the duff layer, such as stolons and shallow rhizomes, and may kill buds on portions of upright stems that are beneath the surface, and buds on the upper part of root crowns. Sprouting occurs from buds in deeper duff or soil layers. Moderate severity fires frequently cause the greatest increases in stem numbers of rhizomatous shrubs (Miller 1976), and of root sprouters, such as aspen (Brown and Simmerman 1986).

(3) A high severity fire occurs when large dead fuels and organic layers are dry. It consumes all litter, twigs, and small branches, most or all of the duff layer, and some large diameter dead, down woody fuels, particularly rotten material. Significant amounts of soil heating can occur, especially near fuel concentrations. This kind of fire can eliminate plants with reproductive structures in the duff layer, or at the duff-mineral soil interface, and may lethally heat some plant parts in upper soil layers. Sprouting can only occur from deeply buried plants parts, which may still be a significant amount for species with deep roots such as aspen, or deep rhizomes such as gambel oak. Killing all belowground reproductive structures usually occurs only where there is a long duration surface heat source, such as beneath a large pile of woody debris that sustains almost complete combustion. Observations show that the concept of burn severity also can be related to fire effects on sprouting rangeland shrubs. The severity of burn relates to the depth of the litter layer beneath a shrub (Zschaechner 1985), and its moisture content when the fire occurs. A light severity fire may scorch litter beneath the shrub crown, but causes little or no damage to reproductive buds buried in stemwood or soil, although it can kill buds at the surface of the soil or those not protected by wood. Most sprouting plants will likely regenerate after this type of fire. A moderate severity fire consumes some basal litter and organic matter, and can kill some reproductive buds. Buds located in deeper litter layers may be lethally heated even if the litter is not consumed, and sprouting of some species may be reduced or eliminated. A high severity fire can consume all litter and organic matter beneath a shrub, and kills all buds and roots in or near the organic layer. This kind of fire favors shrubs with buds and roots buried so deeply in the soil beneath the plant that they do not receive a lethal dose of heat. Fires which occur where there are deep accumulations of litter beneath shrubs and isolated trees, or significant amounts of dead lower branches that burn off and smolder beneath a shrub crown, are more likely to lethally heat roots and reproductive structures than a fire that occurs where there is sparse litter and few dead branches. Reproductive buds of rangeland shrubs that are located on roots or rhizomes at some distance away from the parent plant are not likely to be killed by fire because fuels are often sparse in these locations.

d. Postfire sprouting of grasses. Grass meristems, growing points, are the point where new leaf tissue is formed during the active growing period, and resumes after summer quiescence or winter dormancy. New growth also may occur by "tillering," branching from dormant axillary buds in the plant crown or on rhizomes. Burning of all live leaves may stress the plant, and cause subsequent death. However, a more common cause of death of grasses is the lethal heating of meristems and buds. Sensitivity of meristems and dormant buds to heating relates to their location with respect to the soil surface and the fuel provided by dead grass and shrub litter, and other associated fuels, including shrub canopies. Meristems of some grasses form on long shoots which are elevated above the surface and are readily exposed to fire heat. Their postfire recovery depends upon growth form and whether any basal meristems and buds survive. A detailed description of the vegetative regeneration process in grasses can be found in Dahl and Hyder (1977).

Physiologically active meristems are more susceptible to heat than when they are dormant or quiescent (Wright 1970). Mortality of cool season grasses which green up early in the growing season can be caused by the burning of the litter of associated warm season grasses that are still dormant and hence more heat resistant. A high mortality of perennial grasses also may occur if fire burns in cured litter of annual grasses while perennials are still actively growing.

(1) Response of stoloniferous and rhizomatous grasses. Stoloniferous grasses, those which spread by stolons, such as black grama, are sensitive to heating. Many species of grass are rhizomatous, with meristems and buds buried beneath the litter, duff, or soil surface. Whether rhizomatous grasses are stimulated or killed by fire depends on rhizome location with respect to the surface, whether rhizomes are located in mineral soil or in organic layers, the moisture content of the litter, organic, and soil layers, and the amount and duration of heat generated by the surface fire. Rhizomatous grasses often respond positively to rangeland fires because meristems and buds are usually protected by soil, and a long-term surface heat source over large, contiguous areas is rarely present (Wright and Bailey 1982). In forested areas, grass rhizomes are more likely to be located in litter or duff layers or in association with dead woody fuels, and the potential for lethal heating is higher than it is in rangeland situations.

Litter and decomposed organic matter derived from rhizomatous graminoids such as cattails *(Typha latifolia)*, reeds *(Phragmites communis)*, and rushes *(Juncus spp.)* can accumulate to such thick levels that they completely fill areas of open water in wetlands. Occasional severe fire can have a criticalrole in maintenance of these wetlands. Fires which occur after long dry periods when water levels are low can consume much of this organic accumulation, restoring areas of open water. Prescribed fire is recognized as a management tool for this purpose in the Delta Marshes of Manitoba (Ward 1968). This same role in wetland maintenance for wildland fire has been noted in Alaska (Kelleyhouse 1980), and in the coastal plain of the southeast U. S. (Hermann et al. 1991).

(2) Response of bunchgrasses. The location of meristems and dormant buds of bunchgrasses can be near the surface of the bunch above the level of the soil, or at various depths below the soil surface within or below the bunchgrass litter. Buds and meristems can be readily exposed to lethal temperatures, or be fairly well protected if deeply buried in unburned organic materials or in soil. Fuel and moisture characteristics affect the amount of heat generated. Wright (1971) discusses the relationship between stem coarseness and the rate at which a bunchgrass clump burns. Fine stemmed grasses with a dense clumping of basal stems can burn slowly and generate a fair amount of heat that can be transferred to meristems and buds. Fire tends to pass fairly quickly through coarse stemmed bunchgrasses, which usually have little material concentrated at their base near reproductive structures. Fires tend to burn more rapidly through small diameter bunches in comparison to large diameter bunches, with larger bunches more likely to have enough fuel to release significant enough amounts of heat to affect growing points (Wright and Klemmedson 1965). The amount of surface litter, i.e., the amount of fine fuel, depends on the amount of use by livestock and wildlife, production in this and previous seasons, and the time since the last fire in areas receiving little utilization.

(3) Relationship of moisture conditions and fire behavior to mortality. The moisture content of fine aerial litter, accumulations of basal litter, dead bunchgrass centers, adjacent shrubs and shrub litter layers, and dead woody fuels all affect the amount and duration of heat that the meristems will receive. Mineral soil moisture can control how much heat is received by plant parts located in soil layers. While it is true that moist soil conducts heat better than dry soil, the moisture in surface soil layers must first be evaporated before heating of deeper layers occurs (Albini 1975 in Miller 1977). Moist heat, i.e., steam, may more effectively heat meristems than dry heat, and may be a cause of higher mortality when fires occur where greenup has begun in some plants. However, wet fuel doesn't burn, so the likelihood of a long duration fire under damp fuel and soil conditions that will kill all active bunchgrass meristems and dormant buds is very low, and heat penetration into organic and soil layers is minimal under these conditions (Frandsen and Ryan 1986). If flammable shrubs ignite, dry and preheat adjacent bunchgrass clumps, bunchgrass mortality may be higher than on a similar site with few shrubs that burned under the same conditions (Zschaechner 1985).

For a given litter moisture content, windspeed controls how quickly a fire passes over a plant and the rate at which the litter burns. Fires have been observed in northwest Colorado burning at windspeeds of 10 to 14 miles per hour (16 to 22.5 kilometers per hour) with rates of spread greater than 88 feet/minute (27 meters/ minute) during dry summer conditions. These fires charred only the tops of the crowns of bluebunch wheatgrass and Indian ricegrass plants that were 4 to 5 inches (10 to 13 centimeters) in diameter. Fire may have moved through grass litter too quickly to have a long enough residence time to ignite grass crowns, and little grass mortality occurred (Petersburg 1989).

(4) Relationship of damage to postfire sprouting. A fire may move quickly through a bunchgrass stand with little residual burning. At the other extreme, the dead center of a bunchgrass plant may ignite, smolder, and burn for hours. Conrad and Poulton (1966) developed damage classes for bunchgrasses: 1) unburned, although foliage may be scorched; 2) plants partially burned, but not within 2 inches (5 centimeters) of the crown; 3) plants severely burned, but with some unburned stubble less than 2 inches; 4) plants extremely burned, all unburned stubble less than 2 inches and mostly confined to an outer ring; 5) plants completely burned, no unburned material above the root crown.

Postfire response of a bunchgrass plant can be related to these damage classes, particularly for those species with meristems above the mineral soil surface (ibid.). The highest postfire sprouting potential usually is found in those plants with only some surface litter removed. The amount of sprouting tends to decrease as the amount of basal litter consumption increases, with new shoots most likely to appear from the outside edge of the bunch when little unburned stubble remains. Plant mortality is most likely if all plant material above the root crowns is consumed. Survival and recovery after a specific amount of fire caused damage must also be considered with respect to phenology and other seasonal factors that affect plant response. (See Sections B.4.a.; B.4.c.)

3. Seedling Establishment.

a. Seedbed. Requirements for successful germination and establishment vary for different species. Organic seedbeds, even rotting logs, may be able to successfully support seedling establishment and survival if water is not limiting during the growing season (Zasada 1971). However, moss, litter, and duff are poor seedbeds in many climates because they frequently dry out in the summer, killing the seedling if the root has not yet reached mineral soil. Other attributes of organic seedbeds may also inhibit seedlings (Zasada et al. 1983). For many species, the best seedbed is exposed mineral soil, and microsites where most or all of the organic layer has been removed by fire provide the greatest chance for seedling survival. Soil does not dry out as readily as organic material, and nutrients may be more readily available in ash. Competition from sprouting plants may be reduced.

On hot, dry, exposed sites, seedling germination and establishment may occur more readily if some organic material remains as mulch, especially if the seeds are covered (Clark 1986). Ponderosa pine seedlings are more likely to establish if seeds land on bare mineral soil, and the ungerminated seeds are subsequently covered by litter (McMurray 1988). Allelopathic chemicals, those that inhibit the germination and/or establishment of seeds of plants of other species, are commonly found in the litter beneath certain plant species, including chamise (McPherson and Muller 1969), Utah juniper *(Juniperus osteosperma)*, and singleleaf pinyon *(Pinus monophylla)* (Everett 1987a). Fire can volatilize these chemicals and allow additional seed germination. Some species that must establish from seed may be temporarily eliminated from a burned area because their establishment is not favored by conditions created by a fire.

They may require shade, have slow growth of their primary root, or a high water requirement. Some tree species such as pinyon and juniper, may establish a few years after a fire in the shade of plants that established first, but subsequently can grow in full sun (Everett 1987b).

b. Seedbank. The seedbank, the supply of seeds present on a site, is composed of buried seeds, those stored in the tree canopy, and those that are deposited annually. Seeds of some species, such as willow, are very short-lived, and are part of the seed bank for only a short time. Other species have extremely long-lived seeds, and become a fixed member of the soil seedbank, once their seeds are dispersed.

Seed dispersal mechanisms vary. Light seeds may be windblown while heavier seeds may skid across the surface of the snow. Some seeds have wing-like structures which enhance their movement through the air. Seeds with barbs or hooks may be carried by animals. Hard-coated seeds ingested along with their fruit may pass through the bird or animal, with an enhanced likelihood of germination. Seed dispersal from unburned areas depends on the amount of available seed, the distance of the seed source from the burned area, the prevailing wind direction, and the type of seed.

The supply of seeds of a specific species can be greatly influenced by the amount of annual seed production, which can vary significantly (Zasada et al. 1978). Regeneration of conifers may be limited because cone crops are poor during the period of time when exposed mineral soil seedbed is present.

Surviving plants on or near the burned area may not be old enough to produce seed (Zasada 1971; Barney and Frischknecht 1974), or may be too old to produce much viable seed.

The dispersal of seeds from plants occurs at a time that is characteristic for that plant, and can last for different durations of time (Zasada 1986). The time of fire occurrence with respect to seed dispersal can determine whether a species can regenerate promptly. Heat from the fire may kill seeds in the canopy and seeds that have recently been distributed onto the site. Seeds of a certain species may require a period of cold before they can germinate, so seedlings of that species will not appear until the following spring.

Seeds in immature cones in tree canopies may have survived the fire, and may continue to ripen even though the foliage was killed (ponderosa pine) (Rietveld 1976), or the bole was completely girdled by fire (white spruce) (Zasada 1985). Serotinous lodgepole pine cones retain their seeds because of the presence of a resin bond between the cone scales. These cones do not open and release their seeds unless heated to 45 to 50C (113 to 122F), a temperature that melts the bond (Lotan 1976). Numerous lodgepole pine seeds are often released after heating of the canopy during a fire. However, there is considerable variation in the amount of cone serotiny, both on individual trees, and geographically (ibid.). Black spruce *(Picea mariana)* cones are "semi-serotinous", i.e., they open and release their seeds over a period of years (Zasada 1986). Because cones are usually bunched near the top of the tree, some cones are often shielded from fire heat and provide a postfire seed source.

c. Stimulation of buried seed. There may be an enormous reserve of seed stored in litter, duff, and soil. Seed may accumulate on the surface and be gradually buried by litter, or may be cached by rodents and birds (West 1968; Tomback 1986). Seed of some species may remain viable for many years, with dormancy imposed by an impermeable seed coat (Stone and Juhren 1953). Plants such as snowbrush ceanothus *(Ceanothus velutinus)*, raspberry *(Rubus idaeus)*, geranium *(Geranium bicknellii)*, and corydalis *(Corydalis sempervirens)*, as well as many annuals of California chaparral may appear on a site after a fire where they were not apparent before the fire. Seeds of snowbrush ceanothus remain viable for 200 to 300 years (Gratkowski 1962 in Noste and Bushey 1987). Germination of some species is enhanced by fire that can melt or crack the seed cuticle or otherwise scarify the impermeable seed coat (Keeley 1987; Rasmussen and Wright 1987).

Requirements for optimum germination may be very specific, such as redstem ceanothus that has the highest amount of germination after exposure to moist heat at 80 C (176 F) (Gratkowski 1973), explaining its higher germination after high severity fires than low severity fires (Leege 1968). Chemicals leached from charred materials stimulate germination of many species of California chaparral and coastal sage scrub (Keeley 1987). Increased light levels caused by removal of vegetation can induce or enhance seed germination (Keeley 1987). Some species, such as chamise and hoaryleaf ceanothus *(Ceanothus crassifolius)*, produce a certain proportion of seeds that will only germinate after fire treatment, while other seeds from the same plant will germinate under any suitable moisture and temperature conditions (Christensen and Muller 1975a). Annual species may appear from stored seed after a fire, but may disappear in a few years as site conditions change, a common phenomenon in California chaparral (Sweeney 1956; Muller et al. 1968; Christensen and Muller 1975b).

Germination of seeds of chaparral communities is adapted to wildfires that normally occurred during fairly hot, dry, late summer or fall conditions. Seeds of some species of chaparral communities require dry heat to induce germination, but are killed by lower temperatures if they have imbibed moisture. Other seeds require higher temperatures for a longer duration to induce germination than generally occur under spring burning conditions (Parker 1989). If chaparral sites are burned under moist spring conditions, germination of both of these types of seeds is often very much reduced. This is a particular concern for maintenance of a seed bank of chaparral "fire-following annuals" as well as shrub species that can only reproduce from seed (Parker 1987).

d. Dual response plants. Some plants will recover after a fire both by resprouting and by germination of duff stored seeds, while obligate seeders reproduce by seed only. Obligate seeders often have seedlings with better potential for establishment than seedlings from species that sprout (Parker 1984). Other plants have a two-stage response to fire. They sprout from surviving reproductive structures, then produce seed, right onsite, that can readily utilize available seedbed. Fireweed and rabbitbrush, for example, can sometimes gain temporary dominance over a site for these reasons.

4. Factors Influencing Postfire Plant Recovery and Growth.

a. Climate and weather. Different parts of the country have characteristic seasonal distribution of temperature and precipitation. The overall pattern of seasonal plant growth (phenology) relates to climate, such as the time of the year when most growth occurs; occurrence of late summer quiescence, and the onset of winter dormancy. However, the timing and rate of plant development and total amount of growth can vary greatly with seasonal weather (Mueggler 1983). The date when plants begin growth, flowering, and cease growing all relate to seasonal weather (Sauer and Uresk 1976). The average annual occurrence of the wildfire season in various parts of the country is closely related to climate, while the actual timing and severity is related to fuel amount and conditions, and the weather that occurs that year. Generalizations can be made about weather trends and patterns for a particular region, but there are always exceptions. Long-term averages do not reflect the wide range of conditions possible.

(1) Prefire weather. Prefire weather can affect the plant growth stage at the time of burning. The amount and availability of fuel is influenced by weather. Fires in the cheatgrass region tend to be much larger in years with high winter precipitation and spring rain, resulting in high production of fine fuel. Burned acreage in the Sonoran Desert tends to be higher after two winters of above average precipitation that promotes growth of winter annuals, which subsequently dry and provide fuel (Rogers and Vint 1987). The moisture content of heavy fuels and deep litter and duff layers is closely related to temperature and precipitation in previous months, and thus the likelihood that these fuels are available to burn and provide a long-term heat source is weather dependent (Brown et al. 1985). Fire size, and its degree of impact on vegetation, is influenced by fuel availability, and burning conditions at the time of the fire. Drought, anomalous high winds and low humidity, or high summer precipitation all affect the immediate impact of a fire in a particular area in a certain year.

(2) Postfire weather. Postfire weather can affect plant survival. Sprouting plants must produce enough growth to restore food reserves before the next period of high use, and this growth can be enhanced or limited by weather. Without restoration of carbohydrate reserves, the plant may die. Plants which sprout late in the season also can die because they have too little time or energy to harden off for the winter. The amount of autumn rain can determine whether germination of seed of some species occurs in the fall or the following spring. Late summer rains (Thill, Beck, and Callihan 1984) followed by a dry period can cause germination, and subsequent death, of many seedlings. Weather in the following years affects the rate of recovery from burning by influencing productivity. Drought can place additional stress on injured plants, and increase the likelihood that they will die. Postfire weather is a primary factor in determining range readiness for postfire grazing use. The weather cannot be controlled, but it is important to document it. Fires burned on similar sites in different years with the same burning weather may have widely varying results because of differences n prefire and postfire weather. Analysis of these records may explain the reasons for significant variations in postfire response, and the "success" or "failure" of a specific prescribed fire project.

b. Carbohydrates.

(1) Carbohydrate cycle. Carbohydrates are starches and sugars manufactured by plants and used to provide energy for metabolism, and structural compounds for growth (Trlica 1977). Carbohydrates which are manufactured in excess of those used are stored in various parts of the plant, such as roots, rhizomes, root crowns, stem or leaf bases (Cook 1966a), or evergreen leaves. There is a seasonal cycle of depletion and restoration of total available carbohydrates (TAC) that relates to events in the growth cycle of the plant. The most rapid depletion usually occurs during greenup, to support initial development and growth of leaves and shoots. Stored carbohydrates levels also may be lowered during the period of flower and fruit development. Carbohydrates are required to prepare plants for winter, the "hardening off" process, as well as for respiration and cellular maintenance during winter dormancy (McCarty and Price 1942 in Trlica 1977), and quiescence during late summer drought conditions (Hanson and Stoddart 1940 in Trlica 1977). Roots must be maintained even while the aboveground part of the plant is not actively growing. A major depletion also can be caused by heavy or repeated grazing or browsing, as the plant may need to use reserves to support subsequent new growth if inadequate leaf area remains on the plant to provide energy for growth and new tissue formation. "In general, too heavy, too early, or too frequent grazing or defoliation result(s) in declining vigor of vegetation" (Hedrick 1958 in Trlica 1977).

Restoration occurs when production by photosynthesis exceeds demands for growth and respiration. The beginning and length of the restoration period varies. Cook (1966a and b) discusses the seasonal carbohydrate cycle. Some plants rapidly deplete, but then quickly restore carbohydrate reserves, all within about the first month of growth. Squirreltail *(Elymus elymoides)* is a plant that exhibits this V-shaped carbohydrate cycle. U-cycles are shown by plants that deplete carbohydrate reserves over a much longer period of time, and don't begin to make a significant restoration of reserve carbohydrates until later in the growing season. Bitterbrush, a species with a U-cycle, does not show a major increase in its level of reserves until August or September, only accumulating carbohydrates from the period of seed formation until leaf fall (McConnell and Garrison 1966). The timing of highs and lows in the carbohydrate cycle thus corresponds with the growth states of the plant. The cycle can differ from year to year because the timing of phenological events can vary significantly among years (Sauer and Uresk 1976; Schmidt and Lotan 1980; Turner and Randall 1987). The amplitude of the cycle will vary with growing conditions, the amount of growth produced, and the amount of carbohydrate used for other physiological processes, all of which affect the amount left for storage.

(2) Relationship to fire. Energy and material for initial plant regrowth after a fire depend on the availability of reserve carbohydrates. The biggest negative impacts from burning may occur during the lowest point in a plant's annual carbohydrate cycle, usually during the early seasonal growth period. The low survival of chamise sprouts after spring prescribed fires has been attributed to low winter and spring carbohydrate reserves because of high spring demand for growth, flowering, and fruiting (Parker 1987). For other species, the effects are most negative if the plant is burned late in the growing season when reserves are being rapidly replenished because the plant uses a considerable amount of stored carbohydrates to sprout, but does not have enough time to restore reserves before winter dormancy (Trlica 1977; Mueggler 1983).As a result of burning during an unfavorable growth period with respect to stored carbohydrates, a plant or any sprouts that it produces may die during the next long period of carbohydrate demand, such as summer quiescence or winter dormancy. If the plant survives, its productivity in the next few years may be greatly reduced. An additional consideration when burning old stands of woody plants is that energy reserve levels of these plants may be low, because annual production is low, and/or much of the plant's carbohydrate production is used to maintain old plant tissue. Meager amounts of sprouting observed from old bitterbrush plants may be partially due to low levels of stored root carbohydrates.

The degree of dependency for regrowth that a plant has on carbohydrate reserves after fire depends on whether any photosynthetically capable material, such as sheath leaves on stubble, survived. If some plant tissue that can photosynthesize remains or rapidly regenerates, newly grown leaf material soon manufactures all of the carbohydrates that the plant needs for growth and respiration. However, the initial spurt of growth after a fire likely requires use of some stored carbohydrates, even if only for a day or two. Evidence from clipping and grazing studies has shown that the recovery of grass plants is more related to the removal of growing points than to the carbohydrate level at the time of defoliation (Caldwell et al. 1981; Richards and Caldwell 1985). However, fire may have a greater impact on grass plants than severe defoliation because a majority of the carbohydrates used to initiate regrowth are derived from the basal portion of the older tillers, and these may not survive a fire.

c. Postfire plant competition. Plant competition occurs when growth and reproduction of one plant is hampered by the presence of another, or, when the resources of a site required by one plant are reduced by another (Harris 1977). Plants compete the most for whatever is in shortest supply - particularly water, nutrients, and light. Whether competition occurs and the degree to which it occurs depends on the species present on the site, the number of plants present, and the site conditions (Samuel and Depuit 1987; Brand 1986). Simultaneous requirements for limited resources such as water and light can place individuals in competition with each other. Whether certain species compete depends on the timing of germination and growth, germination and establishment requirements, rate of growth, and requirements for water and nutrients. Some species have an innately high ability when in a seedling state to compete with seedlings of other species (Samuel and DePuit 1987). The ability of a plant to respond to changes in the supply of nutrients or water varies by species (ibid.). Some species can take better advantage of changes in the postfire environment than other species can, which may give them a competitive advantage.

Fire affects plant competition by changing the numbers and species of existing plants, altering site conditions, and inducing a situation where many plants must reestablish on a site. In a postfire situation established perennial plants that are recovering vegetatively usually have an advantage over plants developing from seed because they can take up water and nutrients from an existing root system while seedlings must develop a new root system (ibid.). Natural regeneration of shrubs may severely limit growth of naturally occurring or planted conifers because of competition for light or moisture (Stein 1986; Haeussler and Coates 1986). If perennial plants are few, or their postfire survival is low, and a seed source is present, seedlings may establish and dominate the community for varying periods of time. Certain species may be favored, such as ceanothus (Parker 1984), because of the sheer volume of seeds on a site. Cheatgrass *(Bromus tectorum)* has such a great postfire advantage over seedlings of most native grasses because roots of cheatgrass seedlings can grow at much cooler soil temperatures than those of most native perennial grasses, and can proliferate much more rapidly at warmer soil temperatures than can roots of natives. Cheatgrass seedlings can deplete soil moisture in the spring before other species get their roots down into the soil profile (Thill, Beck, and Callihan 1984).

Grass seeded for postfire erosion control in forested areas may easily overtop conifer seedlings. In chaparral areas, seeded grasses compete with sprouts and seedlings of native plants (Barro and Conard 1987). Litter from seeded grasses may increase the flammability of these sites to higher levels than would occur if only native vegetation recovered on the site (Cohen 1986 in Barro and Conard 1987). A second fire after a short time interval might kill all seedlings of native species, often before they have produced much seed, decreasing the number of seeds in the soil seed bank. Conversely, if seeded crested wheatgrass establishes on a cheatgrass site after it burns, the amount of litter, and fire frequency, can decrease.

A lack of fire can also increase plant competition. One hundred year old stands of juniper usually have very low cover of shrubs and grass (Barney and Frischknecht 1974), probably because of juniper's superior ability to extract soil water, as well as the inhibitory effect of juniper litter on germination and establishment of seedlings of shrub and herbaceous species (Everett 1987b). Herbaceous production in the vicinity of sagebrush plants decreases as sagebrush cover increases, because of root competition (Frischknecht 1978). Young stands of conifers that develop in the absence of fire beneath mature overstories of ponderosa pine compete for moisture and nutrients with the mature trees (Wyant et al. 1983), weakening them and making them susceptible to insects and disease.

d. Animal use. If burning occurs in close association with heavy use of the plant community by livestock or wildlife, either before or after the burn, plant recovery may be delayed or prevented. Heavy postfire use of perennial plants in the first growing season after a fire is likely to cause the most harm, particularly in arid and semiarid range communities (Trlica 1977). Depending upon the plant community and its production capabilities, some use after the first full growing season may not have a negative impact, and may even be desirable, as in tobosagrass communities. Two full growing seasons of postfire rest are necessary before plants can sustain much utilization in the Intermountain west after wildfire (Wright and Bailey 1982). A longer recovery period is necessary if weather has been unfavorable for growth, or if establishment of plants from seeds is required to completely revegetate the site. Desert plants required more than seven years of recovery after moderate defoliation (Cook and Child 1971 in Trlica 1977), and some shrubland sites may require this long a period of postfire rest if recovery of browse species is desired. See Chapter IX.B.2 and B.3 for additional discussion on this topic.

5. Plant Productivity. Fire can affect postfire plant productivity. Short-term decreases can be caused by plant mortality, reduction in basal area of grasses, forbs, and shrubs, changes in species composition to less productive plants, and reduced availability of soil nutrients. Increases are caused by fire induced vegetative reproduction and regeneration, fire enhanced seedling germination and establishment, improvements in the soil nutrient regime, and increases in soil temperature. Warmer soil temperatures often result in earlier greenup on burned areas, particularly in grassland and rangeland environments.

Removal of thick layers of litter and organic matter in tall grass, wetland, and boreal environments increase soil temperature and nutrient availability, enhancing plant growth (Vogl 1973 and Hulbert 1969 in Young 1986). An occasional fire is very important for rejuvenating cold, nonproductive forest sites in interior Alaska (Yarie 1983), and this is likely also true for many tundra sites. Where permafrost is present, many nutrients are tied up in frozen organic layers, and are unavailable to plants (Heilman 1966; 1968). Fire's removal of insulating organic matter and the blackened surface cause deeper annual soil thawing, and a greater depth and higher temperature of the rooting zone. Soil acidity decreases and rates of nutrient cycling increase. Vegetatively regenerating plants and seedlings use these nutrients, significantly enhancing growth. Eventually, organic matter accumulates and becomes an effective soil insulator, causing a decline in both growing season soil temperatures and associated plant productivity.

There may be a significant decrease in productivity during the initial postfire recovery period, then an increase in production after one or several years. Some conifers have reduced growth the first growing season after the fire, but show increased growth rates in subsequent years caused by the removal of competing trees (Reinhardt and Ryan 1988a). Total productivity may not change, but can shift among classes of plants on the site, such as from conifers that are killed by a fire to shrubs, grasses, and forbs (Volland and Dell 1981). Total site productivity may actually decrease, but production of shrubs, grasses, and forbs often increases over prefire levels (Harniss and Murray 1973; Dyrness and Norum 1983). On sagebrush sites, total prefire productivity may not be reached until sagebrush again dominates the site (Bunting 1985), because its deep root system can allow it to utilize site resources that are physically unavailable to other plants.

The length of productivity changes depends on the ecosystem, the degree of change caused by burning, and the resulting amount of change in species composition in the postfire plant community. A low intensity, low severity fire may have little effect, while a shift from an old coniferous forest to a shrubfield may result in long-term changes in plant production. Site productivity in the first few years after fire will likely be higher if a significant amount of vegetative regeneration occurs, than if plants on the site must reestablish from seed. Sprouts can obtain nutrients and carbohydrates for initial growth from the parent plant while a seedling often has access to only a small nutrient reserve in seed, and may initially grow fairly slowly. Seedling establishment and growth are much more dependent on site conditions and postfire weather. Snowbrush seedlings grow slowly until age 4 or 5, but then grow rapidly until about age 10, while sprouts of snowbrush may grow from 1 to 2 feet (0.3 to 0.6 meters) per year from the time growth is induced (Peterson 1989). Exceptions to this general rule do occur. Obligate seeders, plants that must regenerate from seed, can be adapted for making rapid growth on burned or disturbed sites (Parker 1984).

Greatly increased amounts of flowering and fruiting may occur, including a significantly enhanced output of grass seed and berries (Daubenmire 1975; Young 1986; Christensen and Mueller 1975b). Changes in production are caused by the same factors that increase vegetative productivity: warmer soil temperatures, improved nutrient availability, and removal of senescent, woody material that requires a lot of energy to maintain. For a given species, flower and fruiting generally occur sooner on sprouts than on plants that develop from seed. For some species, flower buds are formed on the previous year's growth, so it takes two growing seasons for flowers and fruits to appear. Increased levels of fruit or seed production may only persist for a few years of burning. Improvements in forage amount and availability, and increases in flowering and fruiting are key reasons for wildlife and livestock attraction to newly burned areas.

C. Resource Management Considerations

Fire effects on plants cannot be understood unless their survival and reproductive strategies with respect to fire are understood. Some plants resist fire by characteristics such as thick bark or buds that can withstand scorching temperatures. A site can be repeatedly burned, and many of these plants survive. Plants may have their surface parts completely consumed, but endure the fire because belowground reproductive structures typically survive. Some plants are almost always killed by fire, and their seedlings cannot tolerate immediate postfire conditions. It can be said that these species avoid fire, because they are only found on sites that are fire-free for long periods of time (Rowe 1983).

Plants can be divided into four basic groups with respect to postfire revegetation of a site (Stickney 1986), as defined by their source and time of establishment. Survivors are species with established plants on the site that can regenerate after a fire. Colonizers are species that establish on the site from seed. Residual or onsite colonizers originate from seed that is present on the site at the time of the fire. Off-site colonizers develop from seed that is carried from off the site. Secondary off-site colonizers develop from off-site seed, but not until site conditions are mitigated by the plants that established first. Initial establishment of a plant is only the first step, because its long-term survival and productivity is affected by competition with other plants and by weather.

The following management considerations summarize key elements to consider with respect to predicting, observing, and interpreting the effects of fire on plants. They are derived from information explained in greater detail in the text of this chapter, as well as in Chapter II. Fire Behavior and Characteristics, and Chapter III. Fire Effects on Fuels.

1. Plant Mortality.

a. Relationship to fire behavior, fire characteristics, and fuels.

(1) Flame length relates to the amount of crown scorch and canopy consumption.

(2) Dry concentrations of down, dead woody fuels can ignite and provide a long-term heat source that can damage a tree crown, tree stem, roots, or buried reproductive structures.

(3) The amount of heating that results from combustion in the flaming front of a prescribed fire can be regulated. Ignition methods and techniques must be selected with consideration for fuel conditions, weather, and slope steepness and concavity.

(a) The width of the flaming zone can be manipulated by controlling the number of lines of strip headfires that are ignited at once (Norum 1987), and the spacing between them.

(b) Regulating the interval between lines of strip headfires controls flame length, because the shorter the interval between lines, the shorter the flames (ibid.)

(c) Use of rapid ignition techniques can greatly increase the rate of heat release and decrease the duration.

b. Crown scorch height.

(1) The height to which tree crowns are being scorched is often not obvious during ignition of a prescribed fire.

(2) Scorch height can be estimated from current weather, and observed flame lengths, using the graphs in Albini (1976, pages 63 to 66).

(3) If scorch height is too high, then ignition can be altered to lower flame lengths, or the fire may be curtailed until more moderate burning conditions occur.

(4) Too high a scorch height can indicate that the fire prescription may require modification to reduce scorch heights, such as by prescribing increased fuel moistures, or lower air temperatures when the fire is ignited.

c. Mortality of crowns.

(1) Dormant buds have varying degrees of sensitivity to fire heat. Sensitivity relates to size, the presence of protective bud scales or needles, and whether they are physiologically active or dormant.

(2) Foliage flammability and sensitivity to scorching temperatures varies seasonally, especially because of changes in foliar moisture content.

(3) Foliage flammability varies by species according to branch density, the presence of lichens, presence of flammable compounds, retention of ephemeral or evergreen leaves or needles, and the proximity of the crown base to the surface of the ground.

d. Mortality of tree stems and cambium.

(1) Thick barked species are more resistant to fire heat than thin barked species.

(2) Duration of heating is generally more important than peak temperature in determining damage to thick barked trees and shrubs.

e. Mortality of roots and other buried reproductive plant parts.

(1) Potential for heating to lethal temperatures relates to the plant part and its location.

(a) Depth of roots or reproductive structures below the surface.

(b) Whether plant parts are located in litter, soil organic layers, or mineral soil.

(2) The potential for heating relates most closely to the duration of heat released during the consumption of accumulations of dead woody fuels or deep litter and duff layers. Duff reduction relates to its moisture content (Norum 1977; Brown et al. 1985). See Chapter III.B.3.a. for moisture content guidelines for consumption of organic soil layers.

(3) Moist soil retards the penetration of heat and protects buried plant parts.

2. Postfire Sprouting.

a. Process. The physiological processes that control postfire sprouting are essentially the same for trees, shrubs, forbs, and grasses.

b. Species specific characteristics. The type of plant part on which dormant buds are located, the subsurface distribution of reproductive structures, and the depth below the surface from which new shoots can develop are species specific characteristics.

c. Relationship to burn severity. Sprouting is closely related to burn severity because the number of postfire sprouts relates to the number of reproductive buds or bud primordia that survived the fire. A species may be enhanced or harmed depending on how deeply lethal temperatures penetrated below the surface, and the characteristic depth of its reproductive structures.

d. Spread from adjacent areas. On sites where all reproductive structures were killed, sprouts may develop from rhizomes or roots that colonize the area from adjacent, less severely burned areas.

e. Bunchgrasses. Bunchgrass species also have reproductive buds located at characteristic depths below the surface, and with respect to accumulations of dead basal material.

(1) Moisture contents of basal litter, dead centers of plants, and soil are critical for determining the amount of consumption of a bunchgrass plant.

(2) There is a potential for additional heating of bunchgrasses from burning of adjacent shrubs, with the amount of heat related to shrub species, density, and flammability.

(3) The amount of consumption of a bunchgrass plant of a particular species can be related to its potential for postfire sprouting, because it relates to the amount of physical damage to growing points and dormant buds.

3. Postfire Reproduction by Seed.

a. Seed ecology. The likelihood that a species will reestablish from seed depends upon its seed ecology.

(1) Germination and establishment requirements.

(2) Whether its seed is sensitive to heating or is stimulated by heat or chemicals leached from charred materials.

(3) Length of period of seed viability.

b. Seed source.

(1) Distance from living, seed producing plants.

(2) How much seed in organic and soil layers survived the fire.

c. Timing of fire.

(1) Production of current year's crop of seeds.

(2) Age of plants on or near the site, whether they were old enough to produce seed.

d. Soil seedbank. Some species of plants may establish from duff or soil stored seed and produce a significant amount of biomass.

(1) The length of time that a species persists depends on its habitat requirements and how the site conditions change as plant succession proceeds.

(2) Different plant communities have characteristically different species and numbers of seeds in their seed bank, that also vary in longevity.

e. Relationship to burn severity.

(1) The amount of bare mineral seedbed created.

(2) The amount of heat stimulation or mortality of specific species.

4. Carbohydrates.

a. Plant phenology. Plant growth stage is related to the level of stored carbohydrates that provide energy for initial postfire vegetative regrowth.

(1) The amount and timing of high and low levels, and rates of recovery, of stored carbohydrates varies by species, and with conditions in a particular growing season.

(2) Recovery of a plant may be most affected if a plant is burned during a low point in its carbohydrate cycle, or when there is not enough time for the plant to rebuild stored carbohydrate levels before the next period of high demand.

b. Animal use. Prefire and postfire use of a site by livestock and/or wildlife must be evaluated and managed, particularly important if heavy utilization has occurred.

5. Postfire Plant Productivity.

a. Tree growth. Postfire productivity of surviving trees relates to the amount of injury to crowns, stems, and roots.

b. Sprouting woody plants. Rapid recovery of perennials may occur by postfire sprouting if reproductive structures were not killed.

c. Seed and fruit production. Seed and fruit production generally increase much more quickly from plants that regenerate vegetatively, than from plants that must establish from seed.

6. Direct Seeding and Planting.

a. Postfire rehabilitation considerations.

(1) The requirement for seeding is determined by the specific situation on the burned area and the management objectives for the area. Factors such as erosion control, native species restoration, limiting establishment of annual exotics, and meeting wildlife habitat requirements are major considerations in the decision whether or not to do postfire rehabilitation.

(2) The likelihood of survival of native species should be assessed before artificial reseeding is planned. The percentage mortality of individual plants should be estimated, and likely methods of recovery determined, such as vegetative regeneration or plant establishment from stored seeds. (See B., this chapter.) Reseeding is not necessary where recovery of native plants will occur.

(3) Prefire species composition may be determined by inspection of adjacent unburned areas. A seed mixture of species adapted to the site results in the highest likelihood of establishment, as well as the greatest long-term diversity and productivity. Grass, forb, and shrub mixes have been successfully seeded on some Federally managed rangelands.

(4) Seeded grasses may compete with other desirable species.

i. Seeded grasses can interfere with the establishment of native plants, and limit the future seed bank of those species.

ii. Seeded grasses can provide significant competition to planted trees and shrubs.

iii. Where postfire erosion is a significant threat, seeding annual or short-lived perennial grasses may allow greater recruitment of native plants than seeding long-lived perennial species.

b. Need for rapid replanting. It is often necessary to plant tree seedlings on productive sites as soon as possible after fire because of potential competition from naturally regenerating shrubs, grasses, and forbs. Rapid reseeding of rangeland sites is required if an objective is to establish perennial species on a site dominated by annual exotics.

c. Prescribed fire considerations.

(1) Residual logs and duff can enhance site productivity by providing sites for mycorrhizal infection, and nitrogen fixation, both of which are beneficial to establishment and growth of tree seedlings. (See V.B.c.(4) and (5), this Guide.)

(2) Residual downed logs and shade from standing dead trees provide shade that can aid establishment of planted seedlings or natural regeneration on dry forest habitat types.

7. Effect of Postfire Weather. Postfire weather has a significant effect on the rate and amount of postfire vegetative recovery.

8. Need for More than One Treatment.

a. Dual treatment. A site may require burning after mechanical, chemical, or manual treatment to kill residual target species or seedlings developed from residual seed.

b. Maintenance burning. Repeated burning at regular intervals may be necessary to prevent reinvasion of the site by seedlings of undesired species. The desired burning interval is related to the natural regime that fire used to play in the vegetation community on the site.

D. Methods to Monitor Fire Effects

A variety of monitoring methods have been employed to study vegetative attributes and their changes over time. Those methods most appropriate for postburn studies will be reviewed here. Monitoring schemes chosen to evaluate the effects of fire on both individual plants and plant communities must be sensitive to the responses observed from the perturbation of burning. If the fire has been planned, methods selected by the observer to evaluate changes in the vegetative component must necessarily follow the objectives of the fire so that the vegetative responses can be properly evaluated. Preburn measurements are critical, and thoughtful establishment of almost any preburn study will provide valuable information.

Specific attributes of vegetation or plant communities affected by fire may be expressed in the generally accepted terms of cover, density, frequency of occurrence, weight, species composition, number, height, vigor, growth stages, age classes, and phenology. Plant mortality, injury to trees, and burn severity, all a direct function of burning, also merit consideration because they directly or indirectly relate to postfire effects. Definitions of each of these attributes will be given as monitoring methods appropriate for each are discussed.

In addition to selection of the most appropriate methods of study, two other considerations are vital for a successful monitoring program: control plots must be established outside the area of the fire so that universal factors that may be influencing results, such as climate or insect infestations, can be separated from effects of the fire itself; and, timing of studies must be planned so that plants have reached maximum growth, and repeat studies should be taken as near to the same time as possible as the initial studies were conducted. For planned burns, control plots must be in similar vegetative communities as the area to be burned in order to make valid conclusions regarding fire effects.

Standard references discussing both the philosophy and methodology of vegetation sampling include Cook and Stubbendieck (1986), Greig-Smith (1983), Mueller-Dombois and Ellenberg (1974), Pieper (1973), and Brown (1954). A rangeland monitoring guide describes in detail the more commonly used techniques for monitoring range trend, some of which may be valuable in monitoring fire effects (USDI-BLM 1985a). Additional guidance for prefire and postfire vegetation monitoring is found in USDI-NPS (1992).

The matrix in Table VI-1 relates the specific effects of fire on vegetation to measurable vegetation and site attributes, so that appropriate methods of study can be most efficiently chosen for the effects to be measured. In designing any sampling scheme, the community type being sampled must be considered in determining which methodology to be employed, as well as size and shape of plots to be used. Chambers and Brown (1983) outline appropriate quadrat sizes and shapes for specific methodologies in a variety of vegetation types. It is important to work with qualified personnel to design valid sampling schemes and methods of analysis. (See Chapter XI, this Guide, for a discussion of sampling and statistical analysis.)

1. Cover. Cover refers to the area on the ground covered by the combined aerial parts of plants expressed as a percent of the total area. Specifically measured are either basal cover, which is the vertical projection of the root crown on to the ground, or foliar cover, which includes the projection of all plant parts vertically on to the ground. Cover of litter, rocks, or any other physical parameter on the ground may be determined using cover measurements.

Points and point frames are also used to measure cover (Chambers and Brown 1983; Floyd and Anderson 1983), and are particularly suited to dense or rhizomatous vegetation where intensive sampling is desired. A disadvantage of using points is that an extremely large number of points must be collected to obtain a representative sample of the population. Specific methods include vertical and inclined point frames, points along line transects, and pace transects. First hit only or all hits through the various canopies may be recorded. Usually, aerial canopy is used for trees, shrubs and broadleaf perennial forbs, and basal crown is used for grasses and single-stemmed forbs. Where vegetation is identified by layer, cover may exceed 100 percent. Cover using quadrat frames has been employed by Daubenmire (1959). The method uses canopy coverage classes for each species within a given frame.

Table VI-1: Vegetation and Site Attributes Useful for Evaluating Selected Fire Effects.

FIRE EFFECTS

ATTRIBUTES	Mortality	Reproduction		Productivity	Structure
		Sprouts	Seedlings		
Cover	I*			I	D
Density	D**	D	D		
Frequency	I	I	I		
Weight	I			D	
Species Composition	D		D		I
Number	D				D
Height				I	D
Crown scorch	D/I***	I***		I	
Crown consumption	D***	I***		I	D/I
Stem char	D/I***	I***			
Burn severity	D/I***	D/I***	I	I	D/I

* I = Indirect Relationship
** D = Direct Relationship
*** = Depends upon species

2. Density. Density is the number of plants or parts of plants per unit area, although older literature may use the term to refer to the attribute of cover. Density is highly useful and frequently used for evaluating effects of fire on mortality and reproduction. It is generally straightforward, easily measured and readily understood. Density is not particularly useful in describing community structure and the relationship of species importance to one another, but can be highly valuable in tracking response of individual species to fire. For example, the methodology may measure the number of seedlings, shrubs, or trees per unit area. Response of rhizomatous or suckering plants, such as Western wheatgrass or aspen, may be measured in terms of stems or ramets per unit area with this methodology also. Sprouting shrubs are often tracked using density measurements before and after controlled burning.

Quadrats used to sample density may be small frames or large plots, depending on size and abundance of the species studied. Species to be monitored must initially be defined; size of plots will follow so that the physical sampling does not become cumbersome. Belt transects to measure density of shrubs before and after burning are frequently used in rangeland situations.

3. Frequency of Occurrence. A quantitative expression of the presence or absence of individuals of a species in a population is termed frequency of occurrence, or simply frequency. It is the ratio between the number of sample units that contain a species and the total number of sample units. Its sensitivity in accurately reflecting the population parameters is a direct function of the size of the quadrat used for sampling.

Because this method does not measure any plant or plant community attribute directly, its usefulness in fire management has been somewhat limited. Frequency is an integrator that encompasses plant size and shape, density, distributional patterns, number, and a host of other physical attributes. Because of the often severe nature of fire's effects on a plant community, wide swings in frequency values may present problems in both sampling and interpretation of results.

Quadrat sizes used to sample frequency will vary based on vegetative characteristics and the size and distribution of the species being sampled. Frequency values between 20 and 80 percent are considered necessary to both describe the plant's occurrence and detect change over time. Smith and others (1986) describe a nested frequency configuration to sample more than one species in a specific series of transects. If a single frame is used, it is critical that the quadrat size used to collect the initial set of frequency data be used on all subsequent data collections so frequency values are comparable. Statistical analysis cannot be conducted if quadrat sizes have been changed during the course of monitoring.

4. Weight. A measure of the mass of some aspect of an ecosystem may be defined as weight. As used in both ecological and fire literature, the term needs considerable redefining to be understood and thus useful. The term biomass refers to the total weight of living plants and animals above and below ground in a given area at a given time. Because total biomass is obviously beyond normal capabilities to measure, aboveground plant biomass becomes a standard reference in describing a weight aspect of plant communities. It is the total amount of living plants above the ground in a given area at a given time. A virtually synonymous term, standing crop, may be used as both a time and weight indicator of biomass, and refers to the total amount of living plant material in aboveground parts per unit of space at a given time, with particular emphasis on the specified date. Vegetation samplers often seek to measure peak standing crop, that being the maximum amount of living tissue when accumulation is greatest. Aboveground phytomass, which includes dead attached parts, is a standard expression for all organic plant parts in a specified area.

Aboveground phytomass data are useful for fire managers particularly for writing prescriptions and understanding fire behavior. The fuel load, or aboveground phytomass, carries the fire; knowing the precise fuel load prior to burning not only contributes to designing a successful fire, but permits evaluation of observed fire behavior and results of the prescription. In addition, an objective of many prescribed burns is to increase the yield of specific species, or groups of species such as grasses, on a site. Weight data must be collected in order to evaluate success in meeting the objective.

Methods employed to sample weight include clipping of quadrats, estimates, double sampling, use of height-weight curves, and use of capacitance meters. Dense, uniform vegetation requires fewer quadrats for clipping studies. The vegetation is clipped to a specific height in a specified size quadrat, air or oven-dried, and weighed. For total aboveground plant phytomass, everything but unattached litter is clipped. Litter also may be added if total fuel loading is desired. For aboveground plant biomass, also referred to as current year's production or current annual growth, all dead material must be removed from the material clipped. Weights may be estimated in the quadrats, or a double sampling scheme may be employed whereby some plots are clipped and some are estimated, and the actual weights from the clipped plots used to adjust estimated weights in the nonclipped plots. For shrubs, regressions of crown volume, stem lengths, or stem diameters have been used to estimate current annual production. Height-weight curves have been developed by researchers, particularly for individual grass species, based on the relationship of plant height to weight in the various segmented portions. Capacitance meters, which require recalibration for each site and sampling date, rest over vegetation to be sampled and, using the difference between the dielectric constant of herbage and air, estimate weight of underlying vegetation.

Actual clipping or sampling yields good information that can provide more than weight data alone. Fuel moisture content can be calculated; species can be sampled individually or lumped into categories; and botanical composition by weight can be obtained. The attribute is useful not only in determining changes in productivity on an area, but may provide information on kinds and amounts of wild and domestic animal use that may be expected in a given area.

5. Species Composition. Species composition is a term relating the relative abundance of one plant species to another using a common measurement. It is defined as the proportion (percentage) of various species in relation to the total on a given area. It may indicate the relative importance or influence of one species to another in a specific physical setting and is a reflection of structure and hence wildlife habitat. Composition can be determined by weight, cover, number, or other basic variables, and should be reported as such, e.g., percent composition by weight. Generally, it is an attribute arrived at indirectly. The attribute sampled may have been cover, but in order to understand the relationship of species to one another, the relative percents by species are calculated based on cover measurements. In a burn situation, data may be somewhat misleading if caution is not exercised in interpretation. For instance, the entire shrub or tree component may be eliminated, resulting in a dramatic increase in the herbaceous component on a percent composition basis, although no real increase in number of plants or volume of plant material produced may have been realized.

6. Number. Number is the total population of a species or classification category in a delineated unit and is a measure of its abundance. The attribute is most valuable when dealing with small numbers or particulars. In fire situations, actual counts may be important to know for a scarce resource that may be affected by the fire. Threatened or endangered species may be counted in their entirety, or numbers of snags before and after prescribed burns may be noted. Because the attribute does not involve a sample but rather the entire population, no sampling techniques except sheer counting can be described.

7. Height. Height is the vertical measurement of vegetation from the top of the crown to ground level. In herbaceous vegetation, it may be an indirect indication of productivity. (See 4. Weight) Changes in height and hence changes in structure are some of the most important vegetation characteristics used in determining suitability of areas for various kinds of wildlife. Methods used for measuring height include the Biltmore stick, clinometer, Abney level, and Relaskop.

8. Vigor. Vigor relates to the relative robustness of a plant in comparison to other individuals of the same species and may vary with site, climatic conditions and age. It can be a subjective assessment of the health of individual plants in similar site and growing conditions based on general observations, or it can be more completely defined with some kind of "measurement" of vigor, e.g., references to seed stalk production per plant or unit area, number of tillers produced per plant or unit area, number of leaves or stems, and so forth. Vigor also can be reflected by the size of a plant and its parts in relation to its age and the environment in which it is growing. To be a useful attribute to measure for fire effects, definition of what is to be measured must be made prior to the fire, so that the term maintains a modicum of objectivity. The phenological phase of the species under observation must be the same during each evaluation in order to accurately assess and compare vigor. No matter how carefully measurements are standardized, vigor is considered subjective and is based generally on indirect measurements which may or may not relate to the actual vigor of the plant.

9. Growth Stages and Age Classes. Growth stages are the relative ages of individuals of a species usually expressed in categories. Examples of such categories are seedlings, juvenile (young), mature, and decadent plants. Age classes define in more discrete units the ages of individuals, such as 0 to 5 years, or 6 to 20 years. Age classes may be difficult to determine in herbaceous vegetation, succulents, and any vegetation that does not produce definable growth rings. Both density and frequency measurements outlined above may be made within the parameters of growth stages or age classes, so that the observer may catalogue postburn changes in reproductive capabilities of a site or in effects of the fire on the diversity reflected in different age structures.

10. Phenology. Phenology refers to the timing of various growth and reproductive phases of vegetation. It is based on yearly growth patterns of individual species. A wide variety of phases may be described and then traced for individual species as the growing season progresses (West and Wein 1971). For example, recording the time of initiation of spring growth may be valuable to assess the effects of fire on early growth before and after burning. Other phenological phases frequently recorded include time of blooming, time of seed set, initiation of new terminal bud (signalling the end of seasonal stem or leader growth) and time of dormancy. Mechanics of tracking phenology simply involve delineating the growth phases one is most interested in and then charting them as the season progresses.

11. Injury to Trees. As described earlier in this chapter (B.1.a.), percent crown scorch and percent crown consumption can be good predictors of mortality for many tree species. These can be assessed by estimating or measuring (as with an Abney level) the total length of the tree crown and the length of crown scorched or consumed. Monitoring of damage to tree stems may be needed to better understand the cause of tree death. Height of stem char is measured on all sides of the tree. Depth of char might also be a useful measure of injury on thick barked trees. If bark was consumed or is sloughing off, this should also be noted.

12. Plant Mortality. The cataclysmic effects of fire frequently result in mortality of vegetation. Conversely, in many situations it is of great value to know if plant mortality has been slight following fire.

a. Tagged individuals. A quick and easy way to assess mortality is to tag individuals prior to the fire. Pieces of tin, numbered metal tags, metal stakes, and other nonflammable materials should be used adjacent to the individuals to be checked postburn. A mapped layout of the plot will permit rapid relocation following the fire. It may be necessary to monitor mortality for several years because it may take that long for injured plants to die. Mortality of aboveground portions of shrubs, grasses, forbs, and some species of trees can be visually determined. For many nonsprouting species, death of the main stem, such as of a big sagebrush, is readily apparent, and indicates that the entire plant is dead.

Some species on the burned area are capable of producing vegetative regrowth from buried plant parts. A plant that appears to be dead immediately after the fire may sprout the following growing season. In some cases, new growth must be excavated to determine if a plant has vegetatively reproduced or if seedlings have established.

b. Chemical tests. Chemical tests can be performed to assess the death or survival of individuals of important species.

(1) Tetrazolium. Tetrazolium tests were developed to determine the degree of seed viability, but have been a standard mortality test for range situations. This chemical tests for hydrogen (dehydrogenase) that is released by plant tissues during respiration. Strong, healthy tissues develop a red stain; dead tissues remain their original color. Detailed procedure for testing grass tissue and grass seeds are given in Stanton (1975). The basic procedure is to soak the tissue of interest in a one percent tetrazolium solution, and place it in the dark. Results show up in 5 to 6 hours or overnight. Although this test has long been used, there are associated problems. Procedures for seeds vary by species, and are best performed by experienced analysts. Any sample being tested must be put in a closed container in the dark, because bright sun can affect tetrazolium and cause the same color change as occurs in the presence of dehydrogenase. Results take several hours to appear. On dark tissue, such as Idaho fescue meristems, the color change may not be visible. The interpretation of results can be a problem, because red stain may indicate something other than active metabolism.

(2) Orthotolodiene-peroxide. The chemicals orthotolodiene and peroxide are used sequentially to test for the enzyme peroxidase, found in most living plant cells. This test has been successfully used on trees, and should work well on shrubs. While no documentation of its use on grasses has been found, peroxidase should be present. However, it is not known if peroxidase is present in sufficient quantities in dormant or quiescent grass tissues to stain blue. The basic procedure is described in Ryan (1983). For trees and shrubs, a piece of cambium is extracted with an increment borer (the preferred approach), or exposed by scraping away the bark. An eyedropper is used to cover the sample with a one percent orthotolodiene solution, and then peroxide is applied. Live tissue will turn bright blue within a few moments. A reddish purple color, followed by the appearance of a blue color, also indicates life. A greenish blue color probably means dead tissue. After using this technique for a while, the colors that indicate dead or live cambium become readily recognizable. This test is preferable to the tetrazolium test because it can be used in the field and provides almost immediate results. However, caution is necessary because orthotolodiene has been found to be carcinogenic in laboratory studies. Gloves should be worn as a precaution.

(3) General comments. Metabolic by-products being tested for may not break down until a few days after a fire, even though the plant is dead. The proper location on the plant must be tested to determine mortality. On coniferous trees with living foliage, the cambium should be checked, and also the roots, if much heating occurred at the base of the tree. Trees and shrubs sprout from different locations on stems, root crowns, and roots, and it is these sprouting sites which should be tested to indicate whether the shrub may sprout. Grass crowns should be tested where the buds and reproductive meristems are found.

More than one test may be necessary per plant, because plants can survive some amount of fire damage. Tree cambium requires a test on all sides, and a shrub at several sprouting sites. Unburned meristems and buds of bunchgrasses should be tested at both the center and edges of each plant, and at different depths below the surface if the buds occur below the ground surface.

13. Burn Severity. Burn severity (discussed in II B.6.e), while not an attribute of vegetation, is an exceptionally good predictor of fire effects on vegetation. It indirectly measures the heat pulse below the surface, and provides an indicator of fire impacts on buried plant parts. Burn severity classes can be developed that apply to the type of vegetation and soil organic layer characteristics on the site being investigated. The degree of burn severity can be assigned to one of five classes, including "unburned", "scorched", and "light", "moderate", and "high" severity. Definitions for the latter three classes can be based upon the information in section B.2.c. in this chapter. Burn severity can be described as a percentage of area on plots of a specific size, or related to specific inventory points. Although a qualitative measure, this descriptor can be related to plant mortality, and amount and mode of reproduction, such as by rhizome sprouting or seed germination.

Burn severity classes have been developed for bunchgrass plants. (See VI.B.2.d.(4)) Monitoring the relationship of these classes to postfire mortality or production of specific species can provide a valuable tool for predicting postfire grass response when considering emergency fire rehabilitation, or developing prescriptions for prescribed fire use.

14. Moisture Conditions. The heat regime of a fire depends on the amount and condition of the fuel on the site, how it burns, and the duration of burning. In order to build a database that can be used to predict plant response to fire, moisture conditions at the time of a fire must be documented, because moisture levels are a key regulator of heat release during a fire. See Chapter III.B. and III.D. for a more complete discussion of fuel moisture content and how it is measured.

15. Postfire Weather. Vegetation response to fire can be dramatically affected by postfire weather, particularly in regions with arid or semiarid climates. Knowledge of postfire weather, especially precipitation, can often explain much of the measured or observed variation in postfire effects.

E. Summary

Plant response to fire is a result of the interaction of the behavior and characteristics of a fire with the characteristics of a plant. Plant community response is a product of the responses of all plants on a burned area. The response of an individual species of plant, or plant community, can vary among fires or within different areas of one fire. This is because of variation in fuels, fuel moisture conditions, topography, windspeed, and structure of the plant community itself, causing the heat regime of a fire to vary significantly in time and space. The immediate effects of fire can be modified by postfire weather and animal use. Fire can cause dramatic and immediate changes in vegetation, eliminating some species or causing others to appear where they were not present before the fire. Monitoring techniques that are used to detect trend in vegetative communities are often not appropriate, either because they are not sensitive enough to detect the changes that have occurred, or provide statistically inadequate samples. Fire effects on plants, and plant response to fire treatments are predictable if the principles and processes governing plant response are understood. If burning conditions, the fire treatment, and vegetation response are properly monitored, the fire effects that are observed can be interpreted, and our ability to predict fire effects on plants will increase.

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CHAPTER VII - TERRESTRIAL WILDLIFE AND HABITAT

By Loren Anderson

A. Introduction

Fire effects on terrestrial wildlife and their habitat are addressed in this chapter. Too many variables are involved with fire, wildlife and wildlife habitat to allow a "cookbook" approach. The underlying ecological relationships of vegetation and wildlife are briefly described. A discussion on how fire may subsequently influence those relationships through effects on food, cover, water, and space follows. Considerations for managing and monitoring fire effects on wildlife habitat are also offered.

There is an increasing literature base available regarding fire-wildlife relationships. Four publications the reader may find of particular interest are: Effects of Fire on Birds and Mammals (Bendell 1974); Effects of Fire on Fauna (Lyon et al. 1978); Fire: Its Effects on Plant Succession and Wildlife in the Southwest (Wagle 1981) and Fire in North American Wetland Ecosystems and Fire-Wildlife Relations: an Annotated Bibliography (Kirby et al. 1988). This last document includes an extensive bibliography of all literature on fire-wildlife relations indexed in Wildlife Review 1935 to 1987.

The subject of wildlife, habitat and fire is burdened with generalizations and ambiguities. The definition of wildlife varies from a taxon of invertebrates to an entomologist, a Life Form (Thomas 1979) or Guild (Short 1982) to an ecologist, or a full curl bighorn ram *(Ovis canadensis)* to a hunter. Evaluation of the quality of habitat varies depending on the perspective. Fire is frequently given the anthropomorphic rating of "good" only because fire is considered a natural phenomenon. There is a segment of the public which confuses the fact of fire with the effect of fire and envisions only death, destruction, and loss. Cool burn, hot burn, spring burn, and fall burn are terms that have definitive meaning only to the person using them. Generalizations regarding fire effects on vegetation also can be misleading. Species such as bitterbrush *(Purshia tridentata)* are frequently credited with being so severely harmed by fire that they should be given complete protection. Ultimately, however, many of them are dependent on fire or some similar disturbance (Bunting et al. 1984). Diversity and mosaic are two other commonly used terms that frequently generalize to the point of being meaningless. The widely held assumption that increased edge is always beneficial is not uniformly accurate (Reese and Ratti 1988). As there are no averages in nature (Vogl 1978), there are no generalizations that can stand alone. Terms must be clearly defined and qualified appropriately.

Oversimplification of fire effects commonly occurs when data, knowledge, time or initiative are lacking. Conversely, there is the attitude that if it is not complicated and difficult to understand, it is invalid (Szaro 1986, Vogl 1978). Providing for (as with prescribed fire) and assessing fire impacts on wildlife habitat consistent with general ecological concepts can assist in addressing many complex relationships in a more simplified manner while still retaining a level of validity (Vogl 1978).

B. Principles and Processes of Fire Effects

Adhering to ecological principles and processes is recognized as essential in preserving functional systems (Dubos 1972, Wilson 1985). More accurate effect prediction and assessment, increased assurance of success with prescribed fire, overall cost, and production efficiency are a few of the other benefits derived from thinking and acting as "ecologically" as current knowledge allows (Allen 1987, Chase 1988, Graul and Miller 1984, Savory 1988, Yoakum 1979).

Implicit is the caveat to keep all the pieces (Allen 1987, Chase 1988, Lyon and Marzluff 1984). What we may initially deem insignificant (e.g., mycorrhizal fungi) could be of ultimate importance in maintaining the stability of the ecosystem (Watt 1972, Wilson 1985). How important may lichens *(Rhizoplaca spp.)* be to the nutritional health of species such as the pronghorn *(Antilocapra americana)*? What does the insidious loss of forb diversity and abundance portend? Our imperfect knowledge of ecosystem dynamics and the ramifications of our actions make it imperative we retain the pieces and therefore, in many cases, options. Disruption and loss of indigenous ecosystems have occurred over extensive areas of the west through a combination of inadequate management, fire, and highly competitive exotics such as cheatgrass brome *(Bromus tectorum)* (Wright and Bailey 1982).

1. Floral Response.

a. Ecological basis. Much of the literature regarding fire effects, wildlife and wildlife habitat revolves around successional theory, thus, it is important to understand the concept. Floral succession - that somewhat orderly progression of occupancy by successively higher ecological order plant communities - is one of the primary descriptors of the natural environment. The progression, however, from a "pioneer" stage through various seral stages to that mostly esoteric end point called "climax," is more easily addressed in theory than fact. Although the successional trajectory is often portrayed as following a predictable path and timeframe, there are many who question that view (Bendell 1974, Dubos 1972, Leopold and Darling 1953, MacMahon 1980, Watt 1972). The observation that some species such as gambel oak *(Quercus gambelii)* are successional in one environment and climax in another further complicates the picture (Harper et al. 1985, Whittaker 1975). The "orderliness" of succession we like to envision is commonly disrupted and altered by stochastic events we can neither anticipate nor control (Rosentreter 1989). The apparent controversy does not invalidate successional theory, but it does point out the limitations of our knowledge and the need for being inquisitive and prudent.

b. Structural development. Habitat structure follows successional trends in most plant communities. Short fire intervals tend to maintain or promote early successional conditions typified primarily by herbaceous species and comparatively limited structural diversity. Long fire intervals favor community development along the successional trajectory. This normally results in increased woody species development and greater horizontal and/or vertical structural diversity.

c. Postburn plant community.

(1) For the most part, preburn plant composition and the individual plant species response to fire determine membership of the initial postburn floral community. Understanding plant survival mechanisms (see VI.B., this Guide) is essential for assessing wildfire effects on habitat and in providing for desired prescribed fire effects.

(2) Plants stressed through drought, disease, insect infestations, overgrazing, old age or a combination of these factors are likely to be negatively impacted by burning regardless of how they would respond if healthy (Bunting 1984, DeByle 1988b, Wright and Britton 1982). However, trees that die as a result of fire can provide an important habitat component for certain species.

(3) Herbaceous production increases occur most often on range sites in high Fair or better ecological condition (Bunting 1984, West and Hassan 1985).

(4) Various animal species disseminate seed and can influence subsequent floristic makeup of an area. Pinyon jays *(Gymnorhinus cynanocephalus)* have been credited with the ability to

transport upwards of 30,000 pinyon *(Pinus spp.)* seeds per day up to 6 miles (9.7 kilometers). Both birds and small mammals are considered instrumental in the expansion of pinyon-juniper woodland (Evans 1988). Small mammals, such as chipmunks *(Tamias spp.)*, disperse spores of mycorrhizal fungi into burned areas, an essential component for the establishment and survival of many plant species. (See V.B.c.(4).)

(5) Increases in plant nutrient density, palatability and earlier "greenup" are not unusual occurrences (Bendell 1974, Daubenmire 1968a, Leege and Hickey 1971, Wagle and Kitchen 1972). Earlier greenup of burned areas is largely a function of heat absorption by the dark ash and resultant increases in soil temperature. Reduced soil shading is also a factor. Plants surviving a fire take advantage of higher nitrogen levels provided by the ash and remain greener, more nutritious and more palatable for a longer period of time (Brown 1989). However, this phenomenon is normally shortlived. Commonly, available nitrogen returns to normal levels within two to three growing seasons. Personal observation (Anderson 1983) indicated elevated crude protein levels for 7 years following burning on a bighorn sheep winter/spring range. The extended period of increased protein levels was believed due to subsequent utilization made by bighorns rather than from burning, however.

2. Faunal Response.

a. Ecological basis. Faunal succession follows floral succession, i. e., a given set of vegetational conditions provides habitat for a more or less distinct collection of wildlife species (Bendell 1974, Burger 1979, Dasmann 1978, Evans 1988, Huff et al. 1984, Smith et al. 1984, Wolf and Chapman 1987). Maser et al. (1984), however, pointed out that ecological distinctions between plant communities do not uniformly correlate with differences in animal communities. That apparent inconsistency is explained by the observation that wildlife species most often select habitat on the basis of structure rather than plant species composition. Thus, most of the literature discusses faunal response in terms of general vegetational structure and successional stage.

Fires which set succession back to a grass/forb stage primarily benefit herbivores (vertebrates and invertebrates) and those species for which herbaceous vegetation is desirable for cover. Various vertebrate and invertebrate predators of herbivores also may benefit (Beck and Vogl 1972, Bendell 1974, Hansen 1986, Huff et al. 1984, Lyon and Marzluff 1984, Lyon et al. 1978, McGee 1982). Red foxes *(Vulpes fulva)*, gray foxes *(Urocyon cinereoargenteus)*, and weasels *(Mustela spp.)* are associated with early to mid-successional stages and the ecotones between these stages and climax vegetation communities (Allen 1987). Whitetail deer *(Odocoileus virginianus)*, bobwhite quail *(Colinus virginianus)* and cottontails *(Sylvilagus spp.)* are common to early-mid stages (Dasmann 1978). Fagen (1988) notes a dependency on old growth timber, especially during years of heavy snowfall, by Sitka black-tailed deer *(Odocoileus hemionus sitkensis)*. Muskrats *(Ondatra zibethicus)* are favored by early successional conditions (Allen 1987). The spotted owl *(Strix occidentalis)* is primarily an inhabitant of old growth forests (USDI-Fish and Wildlife Service 1989). As broad as the preceding descriptions may be, they do provide a relative perspective of floral/ faunal relationships. Habitat manipulation almost invariably involves efforts to either set back, retard or accelerate plant succession (Burger 1979, Huff et al. 1984, Wolf and Chapman 1987). Most animal species are more cosmopolitan in their use of various successional stages and structural conditions for feeding than for cover, escape or reproduction (Dealy et al. 1981, Maser et al. 1984).

b. Structure.

(1) The consistency with which the value of structure is referred to in the literature (e.g., Allen 1987, Geier and Best 1980, Harris and Marion 1981, McAdoo et al. 1989, McGee 1982, Smith et al. 1984) gives credence to the assumption that structure is possibly the single most important habitat clue to which wildlife responds. Structure may indicate a feeding site for one animal. For another, that same structure may be sought as nesting cover. The perceptual environment differs from species to species and a structural "clue" for one may mean something entirely different to another species (Dubos 1972). Although specific plant species are frequently insignificant (Johnsgard and Rickard 1957, McAdoo et al. 1989), vegetational complexity associated with developing structural diversity is significant, particularly when faunal species richness is the objective (Campbell 1979, Germano and Lawhead 1986, Johnsgard and Rickard 1957, Short 1983, Willson 1974). A variety of "clues" accommodates interspecies variance and automatically denotes a variety of potential habitat niches. Addressing Great Basin habitats in southwestern Utah, Germano and Lawhead (1986) found postbreeding bird diversity significantly correlated with vertical habitat layering and that diversity of both rodents and lizards correlated with horizontal habitat heterogeneity. Birds make more efficient use of habitat volume or vertical space than other classes of wildlife. Although structure is not height limited, Hall (1985) equated herbaceous stubble of 1 to 2 inches (2.5 to 5.1 centimeters) to bare ground for many species that nest and feed on the ground.

(2) The addition of a single structural element to a plant community can greatly enhance faunal species diversity (Germano and Lawhead 1986, Willson 1974). Maser and Gashwiler (1978) reported that the presence of pinyon and juniper trees provided habitat for four additional Life Forms that would otherwise not be present. Conversely, the loss or lack of a single structural component can eliminate some species and be just as lethal as a direct mortality factor (Knopf et al. 1988, Lyon and Marzluff 1984, Wecker 1964).

(3) Habitat and community structure can include dead as well as living components. Large diameter logs provide habitat in the form of travel routes, as well as feeding, nesting, and reproduction (Bartels et al. 1985). Snags are critical nesting and feeding habitat for many species of birds, as well as mammals and amphibians (Neitro et al. 1985). Insectivorous birds that inhabit snags not only harvest insects in recently burned areas, but help regulate populations of insects in adjacent unburned areas, and in the newly developing forest (Wiens 1975 in Neitro et al. 1985).

(4) The interplay between only one or two structural components and subsequent wildlife use is illustrated in the following examples. In a sage *(Artemisia spp.)* shrubsteppe, horned larks *(Eremophila alpestris)* and meadow larks *(Sturnella neglecta)* are favored primarily by a grass stage. Sage *(Amphispiza belli)* and Brewer's sparrows *(Spizella breweri)* are favored by a shrub stage. All four species can exist in nearly a 1:1 ratio in a mixed grass/shrub type. Lark sparrows *(Chondestes grammacus)* appear to benefit more from the mixture than either the grass or shrub stage alone (McAdoo et al. 1989, Rotenberry and Wiens 1978). Rotenberry and Wiens (1978) noted that horned larks replaced sage sparrows as dominant following a burn that eliminated sagebrush. Pronghorn have a somewhat similar potential response to the lark sparrow's. They, too, are benefitted most by a combination of herbaceous and shrub components. Their habitat quality drops rapidly if either component is depauperate or, in the case of sagebrush, too tall or dense (Yoakum 1980).

(5) The Life Form (Thomas 1979, Maser et al. 1984) and Habitat Guild (Short 1982) concepts are organized around the relationship between plant succession and resultant structural conditions, and wildlife. The basic premise is that there are groups of animals with similar ecological requirements that are met by similar successional stages of the plant community. Not unlike successional theory, there are some who question aspects of that approach (Block et al. 1987, Szaro 1986). The Life Form approach to assessing and predicting effects (see Maser et al. 1984) can be of considerable value, however, when large scale fires are addressed. It is important to recognize that within a given Life Form, a full range of species adaptability and species-specific niche requirements may be encountered. The habitat needs of individual species in a given Life Form may have to be scrutinized to assure adequate consideration is given sensitive animals.

c. Species adaptability. Animals that are broadly adaptable behaviorally and in their habitat preferences can accommodate change more efficiently -- they have more options (Dubos 1972, Knopf et al. 1988, Vogl 1978, Watt 1972, Wecker 1964). These species are frequently termed generalists, species of high versatility

(Maser et al. 1984) or eurytopic (Knopf 1988). Deer mice *(Peromyscus maniculatus)* and the ubiquitous coyote *(Canis latrans)* are two common generalists. At the opposite end are species that have a narrow range of environmental conditions under which they can survive and flourish. At the extreme are the species that appear on "sensitive" or threatened and endangered species lists. Species of specialized adaptability are commonly termed specialists, of low versatility (Maser et al. 1984), obligates (Kindschy 1986) of a particular habitat component, or stenotopic (Knopf et al. 1988). Hammond's flycatcher *(Empidonax hammondii)* has very narrow food and cover requirements (Maser et al. 1984). The sage grouse *(Centrocercus europhasianus)* and pinyon jay are considered obligates of sagebrush and pinyon-juniper woodland respectively (Kindschy 1986, Hardy 1945). Allen (1987) notes that many furbearers of forested and wetland cover types have specific habitat requirements and are less resilient in adapting to habitat modifications. Specialists commonly can be eliminated by loss of a single habitat component. Species of intermediate adaptability such as robins *(Turdus migratorius)* and red-wing blackbirds *(Agelaius phoeniceus)* are referred to as mesotopic (Knopf et al. 1988). Knopf et al. (1988) separated riparian avifauna into eurytopic, mesotopic, and stenotopic guilds to accommodate variations in habitat sensitivity.

d. Food and cover. The two most visually obvious determinants of habitat suitability are food and cover.

(1) Dense timber travel lanes are frequently preferred by elk *(Cervus elaphus)*. Sagebrush can reach heights and densities that inhibit or prevent pronghorn movement. Voles *(Microtus montanus; Clethrionomys gapperi)* require certain litter layer or woody debris habitat components. Birds require various structural conditions for nest sites, hunting and song perches. Some species (e.g., the white-tail deer) select for denser woody vegetation. Species such as bighorn sheep or pronghorn normally select against it (Lyon et al. 1978, McGee 1982, Yoakum 1980).

(2) One species may consume primarily grass and forbs (e. g., grasshoppers or elk), another mostly forbs and shrubs (e.g., sage grouse or pronghorn) and yet another, such as turkey *(Meleagris gallopavo)*, may make heavy use of mast. Hobbs (1989) provides a strong case that the habitat mule deer *(Odocoileus hemionus)* need for thermal cover correlates well with the nutritional plane of the animal. Hobbs and others have noted the inherent value of forage diversity and availability. Hobbs and Spowart (1984) found substantially improved winter diet quality for both deer and bighorn sheep as a result of burning although there were only relatively small changes in the quality of individual forages. They attributed the diet quality increase to improved availability of forage items and enhanced forage selection opportunities. It is commonly assumed that increased herbaceous production automatically occurs after burning.

There is sufficient documentation, however, indicating production increases are not a foregone conclusion (Peek et al. 1979, Yeo 1981 and others). Certainly, some highly valued food items can be eliminated if burning is too frequent. For example, McCulloch et al. (1965), determined that Gambel oak produce very few acorns before reaching 2 inches dbh (diameter at breast height) (5.1 centimeters) and that maximum production of mast probably does not occur until healthy stems are 12 to 14 inches (30 to 36 cm) in diameter. Management of Gambel oak for both mast production and deer winter browse may not be possible on a given site.

(3) The differential effect fire has on wildlife is typically noted in a realignment of species as some species become favored over others as a result of changes in abundance of food and cover. For some classes of wildlife (e.g., birds and small mammals), stability of total numbers has beennoted, even though species composition changed (Lyon and Marzluff 1984, Lyon et al. 1978, McGee 1982). Bendell (1974) explained changes in the kind and frequency of parasitic infections following burning as likely a result of alteration of habitat structure and cover favored by intermediate hosts. He noted a trend towards more species of parasites in greater frequency of infection with longer time after burning. He stressed, however, that there is a broad response range and that any blanket statement regarding fire effects on parasites must be qualified.

(4) Various efforts have been made to "codify" vegetational requirements for a few species. Yoakum (1980) outlines some fairly specific vegetational conditions that constitute quality pronghorn range in shrub-grasslands. Autenrieth et al. (1982) and others have developed similar recommendations for sage grouse. Allen (1987) and Parker et al. (1983) note vegetational criteria for pine marten *(Martes americana)* and lynx *(Lynx canadensis)* respectively. A growing number of plant community/wildlife association listings are available. Most are built around the Life Form (Thomas 1979) or Habitat Guild (Short 1983) concepts that relate wildlife use to structural conditions. Maser et al. (1978) address wildlife species of the western juniper type; Maser et al. (1984), fauna of the Northern Great Basin; Allen (1987), furbearers; Harper et al. (1985), wildlife of the oak brush type, and Thomas (1979) and Brown (1985) address coniferous forest wildlife. Brown (1985) is somewhat unique in the level with which fish and amphibians are addressed.

e. Influence of time.

(1) Each wildlife species has a unique reaction to fire and the subsequent ecological changes caused by fire. Some species exhibit an almost immediate reaction. For others, behavioral time lags and site tenacity may extend the response time nearly indefinitely (Wiens et al. 1986). Eurytopic or generalist species can likely accommodate the change more efficiently than stenotopic or obligate species (Lyon et al. 1978).

(2) Immediate postburn effect assessments can be a poor reflection of long-term animal use. For example, McGee (1982) noted that mountain voles *(Microtus montanus)* could not sustain populations on severe fall burns. Repopulation was contingent on the subsequent development of an adequate herbaceous mulch layer. Red-back voles *(Clethrionomys gapperi)* require woody cover and moisture conditions (Getz 1968) that may be eliminated by fire. Four years following a fire, however, red-back voles may be the most common mammal present (Moore 1989). A decadent stand of bitterbrush under a pinyon/juniper overstory may be providing valuable deer forage. Burning that habitat may be the only hope for assuring <u>any</u> bitterbrush is available for some future generation of deer (Bunting et al. 1984). Huff et al. (1985) found that the highest diversity of birds occurred in a 19-year-old forest in the Olympic Mountains of Washington. Moore (1989) stated that burned forest 5 to 10-years-old becomes prime habitat for chipmunks, possibly even better than the original forest. He associated improved chipmunk habitat with development of complex shrub layers.

Bunting et al. (1984) observed managers must not be so concerned with the short-term effects that they lose sight of the future needs of species. A fire-damaged tree, for example, may not die for several years, but then provides important habitat for cavity nesting birds for a long time. The species that use the snag change over time as the snag decomposes. In many more years the snag falls, becoming a forest floor log that is habitat for many other species.

f. Extrinsic/intrinsic influences. Both extrinsic and intrinsic factors direct individual species response to fire effects. Extrinsic factors include such items as food, cover, water, predators, and other elements of the external environment. A noticeable population increase, decrease, or shift in use patterns would indicate burning had modified some extrinsic factor(s), creating or removing a limiting element, or creating a more desirable (not necessarily required) condition. Physiological, behavioral andgenetic characteristics are intrinsic factors that play a large role in determining how a species responds to a burned area. When no particular response occurs it may be assumed the impact of fire was inconsequential or that there were overriding intrinsic factors that inhibited or prevented a response (Bendell 1974, Moen 1979, Wolf and Chapman 1987). The presence or absence of one species can influence the presence, absence or habitat utilization pattern of another (Bendell 1974, Peek et al. 1984). Extrinsic and intrinsic factors are not mutually exclusive and the seemingly endless combinations of the two can easily make an absolute determination of fire effects virtually impossible in many cases. Peek et al. (1984) found positive results from fire on seven different bighorn sheep ranges. They indicated however, that in each case, definite proof was lacking because they were unable to isolate the effects of fire from other potential factors. Wiens et al. (1986) also noted confounding elements associated with trying to evaluate the effects of small-scale burning on shrubsteppe avifauna.

3. Burn Characteristics: Influence on Potential Faunal Response.

a. Size of burned area. A number of small burns produces more edge than a single large burn. More edge is commonly assumed to provide more benefit to more species of wildlife (Odum 1966, Thomas et al. 1979, and others). When particular species are considered, however, the picture is not that clear. A number of 5 to 10-acre (2 to 4-hectare) burns in a pinyon-juniper/ sagebrush-bunchgrass type might be relished by mule deer but be of little or no value to pronghorn. Some species, such as the western flycatcher *(Empidonax difficilis)* and brown creeper *(Certhia americana)*, are seldom found associated with edge and actually may be harmed if edge is increased at the expense of adequate forest interior (Rosenberg and Raphael 1986).

The creation of fragmented habitat for some species is a potential concern, especially with large scale fires. Burned areas are a considerable attraction for many herbivores. Larger species such as elk, moose *(Alces alces)*, bighorn sheep, domestic cattle *(Bos taurus)*, and wild horses *(Equus caballus)* are capable of overutilizing burns of insufficient size to accommodate their demand.

b. Burned area configuration.

(1) Patchy or irregular burns can enhance habitat diversity, particularly in an area with only one or a few communities all in the same structural condition. Increased diversity and resultant increases in edge effect makes more niches available for partitioning. Edge length, width, configuration, contrast, and stand size largely determine the degree of benefits. It must be recognized that diversity and edge cannot be increased indefinitely. Beyond some threshold, the pieces become sufficiently small and mixed that they assume a sameness or homogeneity (Thomas et al. 1979). Also, increased fragmentation of habitat components caused by maximizing edge can eliminate those species requiring larger tracts or that inhabit stand interiors (Reese and Ratti 1988). The amount and type of diversity sought with prescribed fire is determined by the management goals and objectives. Maximum diversity provides for species richness but is incompatible with an objective to maximize a particular species. The reader is referred to "Edges" by Thomas et al. (1979) for one of the more concise and understandable treatments of diversity and edge. "Edge Effect: a Concept Under Scrutiny" (Reese and Ratti 1988) is a good companion treatise offering qualifying considerations of the edge concept.

(2) Areal extent, composition, and orientation of habitat components (food, cover, water, space) determines habitat suitability for individual species and/or groups of species. Juxtaposition, interspersion, complexity, diversity, and mosaic are terms commonly used to reflect the physical mix and patterning of edges, structural components, plant communities, and seral stages. These somewhat generic terms give a relative idea of the variety and positioning of resources within a given area. Nearly mystical qualities have been attached to these terms and they are frequently (and improperly) used without qualification. The ideal mosaic for a soil-surface invertebrate obviously sayslittle about the optimum mosaic for sage grouse. A sage grouse habitat mosaic has no relationship to a mosaic promoting coniferous forest avifauna species richness. A "good" mosaic is meaningful only within the context of a specific management goal or objective (Thomas et al. 1979).

(3) The scale of the postburn configuration or mosaic is a major consideration. Whether the components (structure, cover, openings) are measured in square inches, acres or miles can dictate which species benefit. Thomas et al. (1979) suggest that wildlife species richness should be approaching maximum in rangeland settings where "average" habitat size is approximately 200 acres (81 hectares). It is recognized that habitat requirements of individual species determine the relative potential benefit of a particular size burn where species richness is not the primary objective.

A seldom discussed aspect of habitat quality is that of habitat fragmentation (Reese and Ratti 1988, Rosentreter 1989). Small isolated islands of shrubs and trees following prescribed or wildfire are examples of fragmented habitat. Many wildlife species exhibit high extinction rates in fragmented habitat (Wilcox 1980). Fragmented habitat fails to provide areal extent and linkages between and among components that are implied with "quality" mosaic, juxtaposition, interspersion and diversity for a given species or collection of species. Adequate linkage of habitat components (e.g., a stringer of cover connecting larger areas of escape cover) is a determining factor for many species. As with other wildlife/habitat considerations, some species are favored over others by a particular mosaic or juxtaposition of elements and a few species may be eliminated entirely.

c. Burned area location. The location of a burn relative to animal use patterns can have a major influence on subsequent use. The proximity of propagules or potential inhabitants has an influence on what species may occur on a burn site. Species mobility also plays a part. A young bighorn ram may travel miles, a shrew *(Sorex spp.)*, hardly any. Whether potential inhabitants can see, smell or be expected to wander across a burned area may dictate the presence or absence of a particular species. An otherwise "excellent" burn (prescribed or wild) that is too distant from traditional use areas (e.g., bighorn) may not be utilized in any reasonable timeframe. Proximity of the burn to a critical habitat component such as water or cover also determines use. Sage grouse exhibit a reluctance to use water sources devoid of adequate surrounding cover. In contrast, pronghorn generally avoid water sources screened with tall dense vegetation. Loss of a critical habitat component and how soon - if ever - that element is replaced may be of paramount importance. Burn location can strongly influence ultimate vegetational establishment. A small stand of Douglas-fir *(Pseudotsuga menziesii)* on a steep south exposure may - from a practical standpoint - never regenerate whereas a similar stand on a more moist north exposure may be restocked in comparatively few years. Slope, aspect, and elevation affect snow deposition, snow crusting, thermal patterns, and wind conditions on burned areas. All of these factors have a bearing on habitat quality for a given species.

d. Completeness of burn. A fire of low burn severity and low fireline intensity, which consumes comparatively little of the existing plant community, may have no perceptible impact on wildlife. However, the high severity, high intensity fire can significantly alter habitat makeup, sometimes for an extended period of time. The first example may have influenced plant community succession very little. The second could result in a major adjustment of seral position potentially resulting in significant changes in structure, cover and the forage base. It is common to see both examples and many variations of the two on a single fire.

e. Timing of burn. Timing of a fire relative to plant phenology is a primary factor dictating the postburn plant community makeup. Perennial herbaceous species, for example, are most resistant if burned when completely dormant (Britton 1984, Bunting 1984). The size and phenological stage of coniferous tree buds influences their resistance to fire. Large buds such as on ponderosa pine *(Pinus ponderosa)* that have scaled out are more resistant than small and/or scaleless buds (Ryan 1988). (SeeVI.B.1.a., this Guide.) Negative impacts may occur if a vital habitat element for a species is burned at the "wrong" time. For example, a fall burn that consumes bighorn sheep winter range could be disastrous, at least in the short term. If that fire occurred early enough in the spring for regrowth, it may be beneficial (Peek et al. 1984). The effect of fire on birds nesting in residual herbaceous vegetation can vary markedly depending on whether the fire occurred before, during, or after nesting activities were completed.

4. Direct Mortality. Fire related mortality is popularly considered insignificant and generally ignored. That generalization can be very misleading - at least on a site specific basis. There is no reason to believe various wildlife species have some superior capability to predict fire behavior or to locate safety zones through dense superheated smoke. Animals do die, apparently, most often through suffocation (Lawrence 1966). At times, the number may be high. Quinn (1979) reported that an intense burn eliminated all small mammal species but the kangaroo rat *(Dipodomys heermanni)*. Nelson (1973, p. 139) relates a very graphic eyewitness account of large numbers of dead and dying buffalo *(Bison bison)* that were caught in a prairie fire in the early 1800's. There are indications that severe burning can cause potentially long-term reductions in some insects and other invertebrates of the soil surface layer (Lyon et al. 1978). A long-term loss of these invertebrates could be of particular significance in the altered and frequently truncated ecosystems affected by man. Highly mobile species and species that can escape underground or into rock crevices are least subject to direct mortality (Beck and Vogl 1972, Lawrence 1966, McGee 1982, Starkey 1985). Direct mortality is unlikely to have much effect on many species if the entire population or range of those species are considered. In a particular geographic setting, however, the potential significance of that loss should at least be considered.

5. Miscellaneous Considerations.

a. Noxious weeds and exotic plant species. Noxious weeds and exotic plant species are an increasing concern. Any wild or prescribed fire occurring or planned in areas subject to noxious plant invasion should be evaluated from that standpoint.

b. Human effects on subsequent use. Fences, roads, human activity and other similar factors, either on or off-site, can significantly influence subsequent wildlife use.

c. Livestock use. Burns are an attraction to many animals and livestock are no exception. Fires occurring on slopes less than about 35 to 40 percent may be subjected to heavy use by all classes of livestock. Horses may make excessive use of burns regardless of location. Livestock can easily influence potential wildlife values of a burned area by altering plan responses, reducing herbaceous habitat structure, removing forage, and merely by their presence. Control and management of livestock is essential.

d. Snow crusting. Wind crusting of snow is a common problem on some deer winter ranges. Carpenter (1976) documented that a sagebrush canopy disrupts wind crusting in addition to providing frequently melted out areas around larger plants. Sagebrush stands approaching 20 inches (51 centimeters) in height have been found to collect up to 1 inch (2.5 centimeters) more water in the form of snow than open grassland (Hutchison 1965). Haupt (1979) noted that small burns in climax coniferous forests accumulate more snow than unburned forest. He found a similar result on larger burns if there was residual tree cover. However, if burn size exceeded four times the height of surrounding tree cover, snow accumulation could be reduced through wind scour.

e. Indirect effects. The possibility of remote or very indirect wildlife-fire effect relationships should be considered. For example, there is little question the current concern and management efforts directed toward aspen *(Populus tremuloides)* stand rejuvenation are valid. Robb (1987) however, found that 85 to 90 percent of all gastropods infected with bighorn sheep lungworm *(Protostrongylus spp.)* larvae in her study area, resided in aspen stands and aspen edges. Could fire in an aspen type in one area have potential implications for bighorn monitored in another? As difficult as it may be, effort must be extended to look at the whole system; to think and act within an ecological perspective (Savory 1988).

f. Stochastic events. Climatic and weather related events such as drought, abnormally high precipitation, shifts in precipitation regimen, and unusually hot or cold temperatures can have a marked effect on the interpretation of fire effects. Large populations of insects such as the Mormon cricket *(Anabrus simplex)* can consume remarkable amounts of vegetation in a relatively short time thus clouding fire effects evaluations.

C. Resource Management Considerations

Understanding existing management goals and objectives for an area is essential. It is recognized that site specific objectives may not be in place to adequately address every wildfire situation. Some objectives may even be mutually exclusive. It is recommended that a familiarity with fire terminology be developed to facilitate communication on wildfires and in planning for prescribed fire. The Fire Effects Information System (F.E.I.S.) contains a wealth of information and is an invaluable aid in predicting and assessing fire effects. (See XII. D.4., this Guide.)

Every fire is a "wildlife" burn. Only through careful consideration, accommodation and management of factors influencing the results of fire can wildlife goals and objectives hope to be met.

1. Define Terrestrial Wildlife Habitat Goals and Objectives.

2. Standard Considerations for Fire Suppression.

a. Protection of habitat improvement projects. Protect habitat improvement projects such as guzzlers, nest structures, browse plantations, fences, and recent prescribed burns.

b. Water. Water quality and flow considerations are of vital importance to many species of wildlife. Efforts to protect water include, but are not limited to, the following:

(1) Prohibiting the washing or rinsing of any container or equipment containing potentially harmful substances in or near any spring, stream, pond or lake. Containers would include such items as helicopter buckets, retardant tanks, engine tanks, backpack pumps, and other such items. Potentially harmful substances include, but are not limited to, wet water, foaming agents, and petrochemicals in any form.

(2) Avoid the dropping or spraying of retardant, wet water, or foaming agents directly on, or immediate to, wetlands, springs, streams, ponds or lakes.

(3) Avoid alteration or damming of stream courses.

c. Control of vehicle and heavy equipment use.

(1) Restrict travel to existing roads to the extent possible.

(2) Avoid any travel in or across streams or wet meadows, or through unique or limited habitats.

(3) Physically close and rehabilitate all firelines that potentially offer

ORV access.

d. Control of aircraft use.

(1) Establish low-level flight routes that avoid important habitat areas such as bighorn sheep summer range, raptor nest sites, and waterfowl nesting areas.

(2) Avoid harassment of big game or other species of wildlife.

e. Wildlife barrier management.

(1) Bulldozer-line windrows through timber or heavy brush should be broken up, lopped and scattered. At a minimum, they should be breached at all drainage crossings and at intervals between drainages to facilitate movement of big game.

(2) Where trees have been slashed around ponds or other bodies of water used to facilitate bucket drops, the slash should be reduced to a depth of no more than 18 inches (46 centimeters) and/or travel lanes cut through for wildlife access to the water.

3. Species Habitat Requirements.

a. Structure. Species structural requirements for feeding, hiding cover, reproductive cover, thermal cover and ease of movement should be a primary consideration. It is important to keep in mind that structure per se is not defined by height (i.e., a short-grass meadow is just as much a structural component as an impressive stand of grand fir). A number of species-specific habitat management guides are available which address structural requirements. Life Form, Habitat Guild, and other similar listings also can be of assistance.

(1) How do current structural conditions compare with the perceived optimum for a featured species or management for species richness? The areal extent, shape, height, age, density, and orientation of structural components, and the necessary linkages between and among those components should be addressed. If structural conditions of vegetation are at or near the perceived optimum and in a healthy condition, fire would not be of benefit. It is important to remember the value of nonliving structural components such as snags and downed logs. Fire may have a positive effect on these features, such as when fire creates snags, or a negative effect when a severe fire consumes most downed woody debris.

(2) How adequate are structural conditions adjacent to the proposed burn or wildfire? A number of species (e.g., elk, mule deer, and others) more readily use burned areas if their cover requirements are met in close proximity to the burned area. In some vegetation types (e.g., sagebrush-grass), the "best" habitat frequently burns because it has the highest fine fuel loading.

(3) What structural conditions and orientation are desired within the fire area? For example, some species may require certain cover characteristics along drainage courses, from drainage courses to ridge lines and/or along ridgelines to make efficient use of burned areas.

(4) What postburn timelags for structural development are tolerable? If no timelag is acceptable, that structural condition should be afforded protection from fire. Threatened or Endangered species, species classed as "sensitive," and species that are obligates of late seral conditions are species likely intolerant of any habitat loss duration if that loss is of sufficient size. The opportunity for accepting short-term structural losses for long-term gain should be explored, however.

Factors influencing plant response time include:

(a) Plant survival mechanism;

(b) Plant health;

(c) Phenological stage;

(d) Preburn and postburn management;

(e) Stochastic events such as drought, torrential rains, insect or disease outbreaks and other unpredictable and largely uncontrollable occurrences.

b. Behavior. Behavioral attributes may influence species response.

Nominal home range size, territory, interspecific compatibility, sensitivity to human disturbance, site fidelity, preference for open vistas (e.g., antelope, bighorn sheep), preference for denser cover (e.g., white-tail deer, ruffed grouse), and other aspects of behavior can have a profound effect.

c. Food habits. Food habits must be considered. An animal that depends on a comparatively few select food items is more sensitive to fire effects than a species with more cosmopolitan dietary requirements. The following is oriented toward herbivorous species with the understanding that predators and scavengers are indirectly affected through their prey base.

(1) What shift in available food items may occur as a result of burning? Fire of sufficient fireline intensity and/or burn severity could benefit grazers at the expense of browsers. Browsers could benefit from a fire in a habitat type such as oak brush but species dependent on mast produced by that oakbrush may be negatively impacted for many years.

(2) Will food items be available when the species requires them? For example, a fall burn could eliminate critically needed forage for wintering herbivores. A fire on that same site early enough in the spring to promote substantial regrowth, could be beneficial.

(3) Is fire-sensitive vegetation involved in the food base? Long-term negative impacts can be incurred if an animal is dependent on a fire-sensitive species that burns. The opportunity, however, for accepting short-term forage loss for long-term enhancement of the food base should be considered.

d. Water availability. Free water availability dictates the presence or absence of many species following a fire.

(1) Is water present on or close to the burned area? Some species will travel miles for water. Others, however, need it immediately available.

(2) Is the water present yearlong or on a seasonal basis?

(3) What cover characteristics are present immediate to the water?

Some species (e.g., sage grouse, white-tail deer) show a reluctance to use a water source deficient of adjacent cover. Other species, such as antelope, prefer good visibility.

(4) The potential adverse effects of fire on water quality -- both onsite and off-site -- should be addressed. Water quality can have a major influence on food chain relationships.

4. Miscellaneous Considerations.

a. Size of burned area. Is the burn of sufficient size to accommodate the forage demand of large herbivores? Deer, elk, bighorn sheep, livestock, and a number of other species are capable of making excessive use of burned areas that are of insufficient size. Many of these species exhibit a strong affinity for burned areas. Options to consider include:

(1) Burn additional similar size areas;

(2) Increase the size of the prescribed fire unit;

(3) Protect burned areas with fencing or by herding (as with domestic sheep);

(4) Reduce numbers of animals generating the demand;

(5) Unless otherwise accommodated by management, conduct prescribed burns for wildlife on cattle allotments on areas not readily accessible to livestock, such as steep slopes.

b. Noxious weeds and exotic plants. Potential for noxious weed and/or exotic plant invasion should be addressed and management adjusted as necessary.

c. Potential changes in human access. Is the burned area in or near zones of human activity? Human activity associated with roads, campgrounds, ORV use, and other sources can strongly influence the presence, absence or habitat use efficiency of many species. Bulldozed firelines may create undesirable access. Burned areas may attract recreational use by snowmachiners, skiers and others. Closures to protect wildlife may be necessary.

d. Snow. Will the habitat quality of some species be altered by changes in snow deposition and crusting factors as a result of burning?

e. Snags.

(1) Adequate snag protection should be incorporated into prescribed fire plans. The opportunity to protect snags under certain wildfire situations may also be present. Damage to snags from fire can be limited by such measures as hand pulling or machine piling fuel away from their base, and applying fire retardant foams around the bottom and along the bottom part of important snags. Leave some living trees with broken tops that will eventually become snags, and provide raptor nesting habitat in the interim.

(2) When conducting postfire salvage logging, leave some dead or dying trees to become future wildlife trees.

f. Downed logs. When prescribed burning, ensure that a certain number of logs of a minimum specified diameter are left onsite. If broadcast burning, prescribe moisture contents high enough in the larger diameter material that it does not burn. If pile burning, leave logs out of the piles.

D. Methods to Monitor Fire Effects

This section views some considerations for monitoring fire effects rather than specific techniques.

1. Animal Population Changes. It is suggested that monitoring of animal population changes be avoided unless there are overriding reasons to do so. As noted previously, intrinsic factors and synergistic relationships between and among plants and animals can easily confound cause/effect assessment of fire effects on populations. The sophistication of study design and execution, time and cost of such studies is normally beyond field office capabilities. Contract studies or support of cooperating agencies, organizations or institutions should be investigated when such information is required.

2. Objectives.

a. Well-defined and measurable. Well-defined, measurable objectives that describe essential plant community characteristics greatly facilitate monitoring. For example, an objective to increase herbaceous production for elk forage would require much more monitoring effort if it were written to increase specific plant species rather than the total production of herbaceous plants elk utilize. Yoakum (1980) indicates a variety of forbs is required on quality pronghorn range. Specific forbs are apparently of little importance. An objective to increase the variety of forbs is much simpler to monitor than one that requires the absolute determination of plant species. The same consideration holds for objectives relating to structure.

b. Expressed in absolute terms. Objectives expressed as percent composition are essentially meaningless unless accompanied by an element addressing ground cover, pounds production, or some other absolute. For example, 50 percent grass and 50 percent sagebrush on a rangeland could mean anything from one grass plant and one sagebrush plant to 500 pounds (227 kilograms) production of grass and 500 pounds of sagebrush.

3. Monitoring Level. The level of monitoring required needs to be defined. There is a temptation to set up monitoring procedures of detail or sophistication that are unwarranted for management purposes. Monitoring procedures should match the issue sensitivity. For example, if only an index of bighorn sheep preference for a burned area is needed, a simple grazed-ungrazed plant transect inside and outside of the burn may suffice. An effort that addressed factors such as comparative production by plant species, chemical analysis of forage, and pounds of various plant species utilized by bighorns inside and outside the burn would be "overkill." The latter approach might be appropriate, however, if bighorn sheep use of a burn was a controversial issue or some detailed information regarding their ecology was needed.

4. Consistency of Technique. Maintaining consistency of technique is essential. The plot that is estimated one year, measured the next, and perhaps photographed the next, does not allow for any meaningful comparisons among years.

5. Observations. The value of observational information should not be overlooked. Frequently, this subjective information provides the critical links with more formal data to clarify what actually transpired due to fire or whether the apparent effects were due to another reason. Anyone who has had an occasion to be on the site, either during or following the fire, is a potential source of information. Observations should be properly documented and filed. Subjective information alone seldom provides the confidence needed to make politically sensitive management decisions.

6. Overall Effect. Addressing overall effect of fire on wildlife for a given area that has burned is most easily approached by going from the general to the specific.

a. What was the original successional stage and structural condition?

b. What Life Forms or Guilds were associated with those preburn conditions?

c. What will the new successional stage and structural makeup be?

d. What Life Forms or Guilds will be favored by the new conditions?

e. How were species of management or public interest affected?

f. How may any obligate or otherwise sensitive species have been affected?

7. Sources. An increasing number of sources for assistance in developing monitoring programs are available. Only a few of the more readily available are listed here. Inventory and Monitoring of Wildlife Habitat (Cooperrider et al. 1986) contains a wealth of information. Species specific habitat guidelines have been developed for pronghorn (Yoakum 1980), sage grouse (Autenrieth et al. 1982) and a number of other animals. Thomas et al. (1979) outlines simple procedures for measuring and evaluating edge diversity. Estimating Wildlife Habitat Variables (Hays et al. 1981) is an excellent field-oriented guide that not only addresses procedures but offers estimates of time and cost involved with various techniques. Chapters VI and X of this Guide should be referred to for further considerations and direction on monitoring and evaluation.

E. Summary

Fire is a shock - frequently, nearly instantaneous - to the ecological setting involved (Huff et al. 1984, Lyon et al. 1978). Some wildlife species are able to adapt to the rapid change in environment and some cannot (Lyon and Marzluff 1984, Parker et al. 1983, Rotenberry and Wiens 1978, Wecker 1964). The habitat for some species is greatly improved, while for others it may be degraded if not eliminated, and there will be endless variation in between (Beck and Vogl 1972, Bendell 1974, Evans 1988, McGee 1982, Wolf and Chapman 1987). No fire - either wild or prescribed - is uniformly "good" or "bad." Effects are differentially imposed.

A righteous attempt at providing for desired fire effects through prescribed burning or evaluating wildfire effects on wildlife and its habitat requires an integrated effort of disciplines. An appreciation of the historical perspective can be invaluable. Contributions by plant or fire ecologists are essential - individuals may have the talent but not the title. Input from those with a thorough knowledge of fire is certainly important. Postburn management is absolutely critical. Obtaining good management necessarily requires close coordination with and commitment from specialists in range, forestry, recreation, and others. Without adequate monitoring and evaluation, little knowledge can be gained and even less, shared.

CHAPTER VIII - CULTURAL RESOURCES

By Dr. Richard C. Hanes

A. Introduction

Cultural resources include a range of different resource types. These resources include locations containing archaeological and architectural remains resulting from human activity in the prehistoric and historic periods; and locations of continued traditional use activities, primarily associated with areas of religious or traditional subsistence concern to Native Americans.

Prehistoric archaeological sites include artifact scatters at locations where tools were made, a series of depressions in the soil surface representing a pithouse village, pueblo ruins, and rock art panels where figures were carved or painted centuries ago. Historic period sites pertain to more recent activities. Examples include old cabins, early homesteads, trails, battlegrounds, early mining remains, and logging camps. The second category of cultural resources noted above includes traditional areas where soil or plants are collected, or ceremonies conducted for secular or religious purposes. In some cases, these areas coincide with locations where archaeological remains are found, but they are just as likely to be a spring, mountain, or other geographic feature not containing tangible reminders of past activities.

B. Principles and Processes of Fire Effects

Particularly important information concerning fire effects on cultural resource values has been developed by Peter Pilles (1982) of the U. S. Forest Service and by National Park Service programs (Kelly and Mayberry 1980). Much of the following information draws from those sources as well as others noted.

It is difficult to accurately assess the effects of prescribed fires or wildfires on cultural resources. One important factor is the widely varying responses of vegetation and soils to fire within the same burn area, or under the same prescription in different burn areas. At most cultural resource sites on public lands, artifacts are distributed on the soil surface, or buried within the soil, even when historic or prehistoric structures are also present. The amount of surface and subsurface heating depends upon the peak temperatures reached and the duration of all phases of combustion. The amount of subsurface heating is a function of a number of variables, including soil moisture content and coarseness, amount and distribution of woody fuels, occurrence of duff layer or other accumulations of organic litter, weather conditions, and fuel and duff moisture content. (See Chapter III.B.6., this Guide for a more detailed discussion of burn severity.) Fire behavior studies have shown that no clear relationship is currently known between surface temperatures attained in a fire and temperatures conducted below the soil surface. It appears that only a small percentage of surface heat penetrates the soil deposits, because soil temperature during a fire can decrease dramatically in just a few inches of depth. Smoldering and glowing combustion of both surface and subsurface fuels can be important contributors to heating of buried artifacts.

Few formal studies of the effects of fire on archaeological sites have been performed. Studies in the 1970's involved the Radio Fire in the Coconino National Forest near Flagstaff, Arizona (Pilles 1982),the La Mesa Fire near Bandelier National Monument, New Mexico (Armistead 1981; Traylor 1981), the Moccasin Mesa Fire at Mesa Verde National Park, Colorado (Switzer 1974), and the Dutton Point Fire at Grand Canyon National Park (Jones and Euler 1986). These were all wildfires, not prescribed fires. A handful of studies and recorded observations have been conducted in the 1980's, including experimentation with prescribed fires in the Cleveland National Forest in California (Pidanick 1982; Welch and Gonzalez 1982). The literature addressing the effects of fire and heat on archaeological materials is still very meager in quantity and largely unpublished. However, enough information exists to indicate that the effects are variable, depending upon the material that is heated and the level of heating attained.

Arguments are made that many of the prehistoric cultural resource sites have been exposed to fires, perhaps repeatedly, in the past. So why the concern over fires today except in the more obvious cases where perishable structures are involved? In addition to the rebuttal that we are likely dealing with cumulative information loss from repeated impacts, other important factors must be considered, including relative burn severity between historic and prehistoric fires, recent surface exposure of some ancient sites, and cumulative changes in erosion patterns.

A growing body of information, based on early historic accounts, ethnographic studies, and field fire history studies suggest fire was much more prevalent prior to implementation of fire suppression policies earlier this century. The higher frequency of fires earlier in time is at least partly attributed to aboriginal burning practices (Lewis 1973, 1985; Barrett and Arno 1982; Arno 1985; Gruell 1985). In areas where fires occurred frequently, the exclusion of fire has often led to levels of fuels higher than would have "naturally" occurred. Fires which occur now potentially have greater impacts on cultural resources because of the increased amounts of heat that can be released during burning.

Archaeological sites often contain a variety of cultural-related materials, including stone, bone, shell, ceramics, metal, glass, wood, leather, and other substances. The resultant combination depends on the technologies of the inhabitants, the specific activities being performed at that location, and the preservational characteristics of the setting.

1. Potential for Physical Damage to Materials. The effects of fire on these various materials, whether buried or on the surface, can vary significantly because of different inherent properties and locations where materials occur.

a. Stone. A commonly observed result of intense, high temperature fires is the occurrence of heat damaged stone artifacts. An example of such damage was presented by a very hot prescribed fire in California's chamise chaparral that resulted in temperatures over 700 F (371 C) at one location where archaeological materials had been placed to assess the effects (Pidanick 1982). Some chert chipped stone implements had shattered; other artifacts including obsidian items and grinding stones were heavily smudged. Artifacts placed at other locations where temperatures never reached 400 F (204 C) were unbroken and only lightly smudged. Laboratory experiments have demonstrated that the crystalline structure of many forms of silica-rich stone changes when heated above 700 F (371 C) (Purdy and Brooks 1971; Mandeville 1973). Beyond that temperature, stone will spall, crack, shatter, oxidize, or simply break from direct exposure to heat. Extensive heat spalling of lithic artifacts was observed in hot "spots" of the 1974 Day Burn in the Apache-Sitgreaves National Forest.

Many masonry pueblos in the Southwest are constructed with dressed sandstone blocks. Exposure to intense heat can lead to color changes through oxidation, severe cracking, spalling, and even crumbling as a result of burning away vegetation that has aided in stabilizing the remains through time (USDD-COE 1989; Traylor 1981).

Rock art sites, including those where designs are painted on stone (pictographs) and others that are pecked into stone (petroglyphs), are especially susceptible to damage by fire. When exposed to intense heat, painted designs can be soot blackened, scorched or completely burned away while petroglyphs on friable stone, such as sandstone or limestone, can exfoliate (Pilles 1982; Noxon and Marcus 1983).

b. Ceramics. Pottery is another class of artifact that may be seriously affected by fire (Burgh 1960). Pottery is made by subjecting fabricated clay vessels to intense heat where sintering and other physical and chemical changes give it clastic properties. However, fire of long duration or high intensity may refire prehistoric or historic ceramics, which can recombine the constituents, oxidize certain elements, burn out carbon paints and cause increased brittleness. Smudging or the deposition of surface carbon residue also may make it difficult to identify and date ceramics.

In the Apache-Sitgreaves fire, ceramics became highly vitrified and appeared as hard black sponges. Similarly, after the 1972 Mesa Verde National Park wildfire, spalling and discoloration of ceramics was noted. The primary impact observed at the Dutton Point Fire was smudging of shards that may disappear naturally after years of weathering. In summary, fire can burn pot shards, affect their chemical composition, change their colors, and alter their decorative paints and glazes, making identification of styles and manufacturing techniques difficult in some cases. (See also Pilles 1982, p. 6.) The more substantial changes begin to occur with temperatures of 925 F (496 C), a threshold higher than for stone.

c. Organics. Objects made or manipulated by a site's occupants are not the only materials used to reconstruct a scenario of activities that were performed at a given location. Many sites contain shell and bone, giving evidence about the nature of prehistoric diets. When exposed to a high level of heat, shell will become calcined and very friable. The effects of fire on bone have yet to be thoroughly investigated, but at Custer's Battlefield, old bovine bone fared very poorly compared to stone and metal objects (Scott 1987). Pollen grains, used for paleoenvironmental as well as dietary studies, are destroyed at temperatures above 600 F (316 C) (Traylor 1981). Artifacts made of organic materials such as woven baskets, wooden digging sticks, rawhide cordage, and fur clothing are usually very fragile in the archaeological record and are highly susceptible to charring and consumption at very low temperatures (Seabloom, Sayler, and Ahler 1991).

d. Metal and glass. Not much is known about the effect of wildland fire on inorganic materials largely associated with historic period sites in the West, such as metal implements and glass bottles or beads. A recent North Dakota prairie fire study found that small lead and glass items became fused or melted when subjected to ground surface heating (Seabloom, Sayler, and Ahler 1991).

2. Effects on Dating Techniques. The archaeologist today has several techniques available for deriving absolute dates of site occupation (Michels 1973). In addition to the impacts to artifacts and material types noted above, materials used for several dating techniques also may be affected by fires (Traylor 1981, Pilles 1982).

a. Tree rings. Tree ring records preserved in wooden beams or other construction materials used in dendrochronologic studies are highly susceptible to fire.

b. Radiocarbon. Charcoal samples used for radiocarbon dating can become contaminated from ash and charcoal produced by a fire, and could yield a date more recent than the true date of the sample.

c. Thermoluminescence. Pottery fragments, when subjected to thermoluminescent dating techniques, could provide significantly younger dates than expected after being exposed to high heating episodes.

d. Obsidian hydration. Obsidian hydration is a dating technique that measures the amount of moisture present in the external surface of an obsidian artifact. Moisture is absorbed from the atmosphere by freshly flaked obsidian surfaces at a constant rate. Heat from a fire (apparently at only high levels of heating) can alter the moisture content, thus yielding an inaccurate date or erase the record altogether.

e. Archaeo-Magnetic. Archaeo-magnetic dating measures the orientation of electrons in stones from prehistoric hearths and compares this data to changes in the earth's magnetic field over the past several thousand years. If these features are subjected to temperatures above 975 F (524 C), they can give erroneous information by releasing electrons to realign with the current magnetic fields of the earth.

f. Cation-Ratio. Cation-ratio dating is a new technique for dating rock art through chemical analysis of surface varnish. It is possible that smoke from a fire could alter the ion structure of these features, thereby preventing accurate dating.

3. Impacts of Burn Area Preparation and Mechanical Suppression. The most dramatic and predictable effects of fire activities on cultural resources result from the use of equipment in burn area preparation, fire suppression, or burn area rehabilitation work. Impacts from these activities are also the most preventable. Pilles (1982, p. 6) has noted that:

Studies of the La Mesa Fire at Bandelier National Monument and the 1977 fire on the Coconino National Forest found that heavy equipment used during suppression activities and mop-up operations had a greater effect to archaeological sites than did the actual fire itself. Artifacts are broken and displaced and small sites can be completely destroyed by one pass of a bulldozer blade. Depending on the depth of a blade cut and the proximity of site features to the surface of the ground, buried features, such as caches, burials, and firepits, can also be destroyed by bulldozer work. During both the Radio and La Mesa forest fires, about 15 percent of the archaeological sites in the area were damaged by heavy equipment. In the La Mesa Fire, however, most sites were damaged during mop-up and restoration activities after being initially avoided by fire suppression activities. Both instances point out the importance of timely planning and continued coordination with archaeologists for projects involving the use of heavy equipment.

Obviously, burn area preparation could cause damage to cultural resources if mechanical equipment is used. Additionally, construction of heliports, vehicular traffic, and hand construction of firelines can impact cultural values. Postfire erosion control measures such as mechanical seedings, contour trenching and furrowing, and construction of sediment traps are restoration activities that pose significant threats to archaeological sites.

4. Erosion and Looting. Loss of ground cover normally leads to greatly enhanced visibility. In many regions of the West, wildfires have long been noted for their propensity to expose sites previously difficult to find; consequently large numbers of people can be found cleaning the surface of diagnostic tools and excavating sites where archaeologically rich deposits are discovered following fires. Similar behavior has been noted of fire crews who had not previously been advised of the significance of such activities (Traylor 1981). This is of increasing concern, as the illegal collection and excavation of archaeological materials has escalated during the past 30 years. The water holding capabilities of litter, duff and surface soils are also reduced by fire, which sometimes generates erosion hazards.

C. Resource Management Considerations

The preceding sections briefly describe a diverse array of impacts that fire and associated fire management activities pose for cultural resource values. However, many of the heating effects only occur at significantly high temperatures and many associated on-the-ground activities can be planned ahead of time. Consequently, the fire process can be managed to minimize harmful effects and serve as a useful tool in managing cultural resources.

1. Fire Planning. The most effective means of addressing fire effects is through development of a management plan that takes the above concerns into account. (See Anderson 1985.) Various facets of the land management planning process may be used. The cultural information may be provided in a prescribed fire plan, a wilderness management plan, a general resource management plan, or, for areas that are of particularly high cultural resource values, a cultural resource management plan. All agency cultural resource management plans should include a section on the effects of fire suppression. Regardless of the type of plan employed, it should provide information about the number, type and distribution of cultural resources, known or predicted to occur, in a proposed project area (Pilles 1982, p. 8.) and how susceptible these resources are to impacts from fire. Are there abundant cultural resources in the area? Are there historic settler's cabins or sawmills present that could be destroyed by fire? Has the area ever been examined by a professionally qualified archaeologist? Are there any Native American concerns that might be affected by a prescribed burn? Are there any areas considered highly religious? Would burning at a particular time of the year disrupt traditional religious pilgrimages, plant collecting, or hunting practices in the area?

Prior to prescribed fires or the next wildfire season, baseline cultural resource information should be gained minimally through an updated synthesis of existing information, contacts with the appropriate Indian tribes, coordination with the State Historic Preservation Office, and inclusion of information from other knowledgeable sources. Further information may be gathered through field reconnaissances, sample field surveys, or detailed individual site assessments. From the information gathered, areas of unusual sensitivity or highly significant sites may be identified on maps and their vulnerability to fire effects assessed. Management direction regarding fire activities may then be established and the resulting information provided to those in charge of planning and directing field activities. The management direction for wildfire suppression and prescribed fire projects should be coordinated with the State Historic Preservation Office, again, to streamline any required Section 106 consultation needs that may arise when fire activities are imminent. The plans should include procedures for training fire crews about the illegality of artifact collecting and the associated stiff penalties, and for educating crews to identify sites so that damage to these resources can be avoided during fire suppression activity.

2. Maintaining Historic Plant Communities. Constructive use of fire also can be identified in terms of reestablishing the historic environmental context of important cultural resources and maintaining certain Native American traditional practices (Larson and Larson 1988). Examples of the former case includes restoration of grassland from recent pinyon-juniper invasion at a historic fort site and removal of brush thickets from historic trails, thus opening them to recreational use (Pilles 1982).

In the case of Native American needs, burning can be used to promote the growth of certain plants used for food, medicine, or craft manufacture. An outstanding case is presented in California where prescribed burning by the U.S. Forest Service allows growth of new plant shoots. This new growth has the proper strength and resiliency for the Yurok tribe to use in weaving baskets and hats for tribal ceremonies and as traditional apparel (Pilles 1982). Such activity is helping revitalize certain areas of traditional Indian culture.

3. Use of Prescribed Fire to Minimize Potential Damage from Wildfire. As noted above, the heating effects of low temperature prescribed fires appear to be substantially less than the effects of much hotter wildfires. Archaeologists can learn much from fire history studies and effects on soil properties. Knowledge of the frequency of prehistoric fires would likely indicate the possible cumulative effects on cultural resources, with high fire frequencies likely associated with "cool" fires and minimal impacts on resources.

a. Subsurface resources. During prescribed fires, effects of heating are usually not severe. Most artifacts are insulated from the heat of a fire by an earth cover and ideal temperatures for most prescribed fires are less than those that critically affect artifacts. If a condition is present of low fuel loads or a fire occurs with higher duff or soil moisture content, there is less potential for heating. However, if fire burns with high heat per unit area, then damage to surface artifacts is likely. Also, if a fire is of long duration, damage to buried artifacts is more likely.

In some areas fire suppression policies of the past century have led to "artificially" high fuel loads, thus increasing the potential for damaging cultural resources through severe heating when fires occur. Additionally, encroachment of shrubs and/or trees allows deep litter layers to accumulate and increases the potential for longer duration fires. In some situations, an agency may need to use prescribed burning or some other fuel load reduction strategy to attain its mandated mission for protecting cultural resources.

b. Aboveground structures. Historic period and prehistoric architectural sites pose special concerns. The historic period sites were created either during, or just before, the period of enforcing strict fire suppression policies without the augmentation of prescribed burns. Consequently, the sites have not been subjected to any form of fire, and preservation in many cases may be very good. Old buildings and ruins constructed of wood are obviously susceptible to destruction by fire. Burn prescriptions will need to be designed to avoid impacts on these types of cultural resources yet reduce the fuel load buildup around them. Possible prescriptions might be to put a fire line around sites with wooden structures so they are not burned; modify project boundaries to avoid rock outcrops where rock art is located; remove combustible materials from the surface of a site so the fire will either burn around it or burn with "cool" temperatures above it; shift the location of a control line, staging area, or utilized water source to avoid a site; change the dates of the burn so it does not impact Native American use of the area; or simply have the archaeologist monitor the burn while it is in progress.

It can be concluded that by burning under favorable conditions where burn severity may be controlled and monitored, management of vegetative communities through fire can be pursued while enhancing the agency's ability to protect cultural resources.

D. Methods to Monitor Fire Effects

The above discussion briefly addresses a number of complex issues for which few objective data are available. Most information thus far has been collected in association with major wildfires occurring in areas of heavy fuel buildup. Very little quantification of the effects of fire on archaeological sites has been documented, and little has been reported of prefire site conditions. There is a great need for experimentation, particularly utilizing prescribed fire conditions. In addition to recording artifactual and site preburn and postburn information, detailed documentation of fuel load, fuel and soil moisture, weather, fire rate of spread, temperature at and below the soil surface during combustion, duration of heating, and other fire factors needs to be accomplished. In anticipation of a fire, half of a site could be excavated prior to the fire, and the remainder excavated afterwards. By employing such procedures, the effects of the burn on various aspects of the archaeological record could be evaluated, and correlated with the behavior and severity of the fire.

More study is needed to determine the full range of effects to cultural resources by wildfire and, especially, controlled burning projects. In order to accomplish this, a variety of experiments in different environmental settings with different kinds of cultural resources needs to be done. Only by observing fire effects in a variety of conditions can we know for certain that there is no significant or irreplaceable loss to cultural resources as a result of prescribed fire programs or the degree of damage posed by wildfire. To accomplish this goal, land management plans can commit specific cultural resource sites to "management use" for fire effects experimentation.

In addition, furnace tests on archaeological materials are needed to establish controls for comparison of field test results. Furnace tests can assess the effects of different temperature levels and heating periods on specimens of ceramics, metal, glass, bone, shell, and stone. Such information can aid in documenting actual fire effects on artifact friability, weight, and visible characteristics (e.g., color, form, decorative patterns, and trademarks).

Experiments, such as those described above, would provide an ideal opportunity for interagency cooperation and could assess the relative success of the fire management procedures and philosophies of different agencies. The value of such cooperation has already been demonstrated by studies of the Radio Fire and the La Mesa Fire, conducted by the Coconino National Forest and the Southwestern Regional Office of the National Park Service. These two studies are the main data sources available for assessing the impacts of fire and fire management activities on cultural resources. An interagency clearinghouse for assembling data and reports pertaining to fire effects on cultural resources could greatly assist the otherwise disjointed approach taken by the various organizations.

As acknowledged above, visibility of cultural resources is greatly enhanced by burning away the ground cover. A 1977 tundra fire in Alaska removed shrub growth, revealing prehistoric stone-lined pits where none were previously visible (Racine and Racine 1979). Wildfires in the early 1980's in pinyon-juniper woodland areas near Las Vegas and Carson City similarly resulted in the discovery of prehistoric rock ring features where none were previously known. The Las Vegas rings were likely associated with past pinyon nut caches; the Carson City features are possibly remains of habitation structures. In Mesa Verde National Park, prehistoric farming terraces were revealed when fires burned away the dense underbrush. Before this, archaeologists were not aware of the abundant existence of such features in the Mesa Verde area. Consequently, the coordination of prescribed fires with postfire archaeological surveys would be beneficial to the agencies in achieving goals for two programs. The benefits to the cultural resources program are obvious in the greater efficiency achieved in conducting inventory efforts. Also, patterns identified in heat damage to artifacts by the above furnace and field studies have promise to aid in the interpretation of heat damage sustained by artifacts in early historic and prehistoric times (Seabloom, Sayler, and Ahler 1991).

E. Summary

Damage to cultural resources posed by wildfires and prescribed fires can be severe, ranging from chemical alteration of cultural materials to exfoliation of building materials and rock art panels. However, almost all impacts can be avoided through advanced planning. Protective measures can include removal of high fuel loads by hand or prescribed fire, careful use of fire breaks for avoiding fire effects on wooden structures and other highly susceptible resource values, and use of archaeological monitors on wildfires in sensitive areas to avoid fire suppression damage.

The experiments and observations thus far conducted indicate that cultural materials below the surface, unless directly exposed to a burning duff layer or burning underground roots, normally do not sustain significant damage, if any at all (Traylor 1981). Though the Cleveland National Forest found that many surface artifacts were damaged by a prescribed fire in chamise chaparral, no subsurface artifacts were affected (Pidanick 1982). Measurements taken at the prescribed fire documented temperatures in excess of 800 F (427 C) at the ground surface, but only 100 F (38 C) at 5 centimeters (2 inches) below the surface. Obviously, the magnitude of fire effects on the soil and its contents is proportional to heat penetration. In conifer forests, temperatures of 200 F (93 C) have been recorded one/half inch (1.3 centimeters) deep in the soil, with duff layers considerably above that figure. Obviously, such heating depends on the thickness of the duff layer, duff moisture content, amount and moisture content of large diameter dead woody fuels, and soil type and its moisture content. Given current knowledge of fire effects on cultural resources, it is apparent that fires involving larger fuel loads, longer duration burns, and large total heat release pose significantly greater hazards to cultural resources, than fires with short duration "cool" combustion temperatures.

CHAPTER IX - PREFIRE AND POSTFIRE GRAZING MANAGEMENT

By Ken Stinson

A. Introduction

The impacts of grazing management before and after a fire have a dramatic effect on the response of vegetation to the fire, and what one can expect in the long term. The history of management on burned areas has included such things as:

1. Seeding introduced species for increased livestock or wildlife forage that resulted in additional management conflicts.

2. Short-term rest from livestock grazing to allow seedling establishment.

3. Some followup long-term grazing management but with heavy to severe utilization rates.

4. Conducting prescribed fires to temporarily increase production on an allotment to avoid adjustment in grazing use.

5. Temporarily increasing utilization by improving palatability of rank plant species such as Tobosa grass *(Hilaria mutica)*, sacaton *(Sporobolus spp.)*, and sprouting browse species.

6. Grazing use in an area during a prefire rest period required to accumulate adequate fuel to carry a fire, resulting in a subsequent prescribed fire that could not meet objectives.

The need for increased intensity of grazing management on burned areas can be understood by realizing the potential change in the plant community and associated animal response that can result from a burn. If one is not willing to commit to long-term grazing management, prescribed fire should not be considered or approved.

B. Principles of Prefire and Postfire Grazing Management

1. General Need for Improved Management. "Prescribed fire should not be a substitute for good range management. A problem rooted in inappropriate range management practices may not be corrected by vegetation treatment. In these instances management should be altered prior to application of prescribed fire. If livestock have premature access to the burn, the full benefits of the prescribed fire may not be realized and negative impacts may occur unless management of the livestock is included in the plan" (Bunting et al. 1987). "Followup management is the most important aspect of a controlled burn and must be provided for in the overall management plan" (Smith 1981). "Grazing management following burning may significantly affect the degree of change in forage species productivity and possibly the composition of the postburn vegetation" (Smith et al. 1985). The need for management of livestock use on a burned area is most critical the first growing season after fire, particularly in plant communities of arid and semiarid regions (Trlica 1977). Livestock use must be managed on the sites of both prescribed fires and wildfires.

Fire results in changes of animal behavior including grazing pattern, preferences, utilization rates, forage consumption, and frequency of grazing use. Wild and domestic animals are attracted to recently burned areas resulting in greater utilization of the burned area than surrounding vegetation (Pase and Granfelt 1971; Bunting et al. 1987). Cattle, horses, and sheep usually have the greatest impact. Grazing animals frequently concentrate on a burn because the herbage or browse is more accessible, palatable, and nutritious (Wright and Bailey 1982). Plant growing points may also be exposed, increasing the likelihood of damage from a foraging animal. Carbohydrate reserves of sprouting plants are usually depleted because of energy required to regenerate after a fire. Repeated use of these plants can cause considerably reduced vigor, and sometimes death of key forage or browse species. (See VI.B.4.b. (1) and (2), this Guide, for a more detailed discussion of carbohydrate reserves.)

Grazing in forested areas can help forest regeneration if competing plant species are grazed, or hinder regeneration if tree seedlings or sprouts are eaten or trampled. Extensive damage to young conifers from trampling has occurred in clearcut areas that were seeded to grasses (McLean and Clark in Urness 1985), and has been observed in burned clearcuts where postfire growth of grasses and sedges attracted livestock (Zimmerman 1990). The presence of larger diameter logging slash can discourage livestock and big game use.

2. Rest and Deferment.

a. Prefire. Prefire rest from grazing is required on many range sites to allow the accumulation of enough fine fuel to carry the fire. This is important in shrub/grass and pinyon-juniper types as well as in forested areas, particularly aspen ecosystems where grass and shrub litter may be the main carrier fuels (Jones and DeByle 1985). Allowing grazing, sometimes even for a short period of time during the year before the fire, can remove enough fuel to limit fire spread. A patchy fire may occur, or the fire may not be able to carry at all, and in both cases fire treatment objectives are not met. Prefire rest may also be required to restore levels of plant carbohydrate reserves on heavily grazed sites, shrub dominated sites, or where shrubs are very old and in poor condition. More than one year of prefire rest from grazing may be required to obtain adequate fuel to carry the fire, or to achieve the desired postfire response, especially in areas with severely depleted understories.

b. Postfire. The amount of nonuse necessary after a fire varies considerably with the vegetal composition, site conditions, and objectives of the burn (Bunting et al. 1987). The initial concern following burning is the restoration of plant vigor and seed production. Generally, at least two growing seasons rest are recommended (Pase et al. 1977; Wright et al. 1979; Blaisdell et al. 1982), both to allow reestablishment of preferred species and to deter reinvasion of shrubs. Bunting (1984) usually recommends rest for one year and deferment of grazing until after seeds have ripened the second year, if the range is otherwise in fairly good condition. Some species of sprouting shrubs take much longer than two years to recover, such as bitterbrush, and rest for a longer time period is necessary if reestablishment of browse species is an objective.

"Anticipated results from the best prescriptions for a burn may be seriously modified if destructive grazing practices are allowed afterwards. Only a small amount of forage is produced the first year, and grazing may cause serious damage to soil and desirable perennials. Despite the apparent abundance of green herbage, most plants are low in vigor and will be further weakened or destroyed by grazing. Furthermore, grazing will disturb the inadequately protected soil and allow increased water and wind erosion. Protection through the second growing season will allow restoration of vigor and the typical heavy seed production of perennial grasses and forbs. However, after seed dissemination, light grazing may serve a useful purpose in helping to plant the seed" (Blaisdell et al. 1982). Early establishment of a good grass cover, and subsequent conservative management, virtually assures soil stability and low sediment yields on moderate slopes (Pase et al. 1977).

Grazing in the early growing seasons immediately following burning may accelerate sagebrush reestablishment. This is particularly true when areas with dense sagebrush and low production of grasses are burned (Laycock 1979; Smith et al. 1985). This may be desirable if sagebrush is an important habitat component for wildlife species. Grazing systems that provide for periodic rest during the growing season will extend the useful lifetime of the project (Britton and Ralphs 1979; Smith et al. 1985).

Evans (1988) gives a general rule that newly seeded areas should not be grazed for at least two years following seeding. Low potential sites and those seeded with slow developing and slow growing species may require as many as four seasons of nonuse to develop into productive stands. Below average amounts of postfire rainfall also can retard the recovery of a site.

3. Proper Followup Grazing Management. "Improvement of an overgrazed range--that is, improvement in range condition--starts with a decision to stock the pasture at a rate to permit improvement" (Dyksterhuis 1958). Burning an area that is in poor condition because of overgrazing can temporarily increase production of desired species. However, the improvement will be short-lived if grazing practices remain unchanged. "Various combinations of rotation land deferment. . . have all proven to be successful where such factors as range condition, kind of livestock, stocking rate, season, and intensity were given proper consideration. Rate of stocking--balancing numbers and time of grazing animals with forage resources--is the most important part of good grazing management ... Seemingly there has been over-optimism in judging grazing capacity and allowable use, which has been an important factor in range deterioration . . . It has become increasingly apparent that former utilization standards are often several times more than can be tolerated continuously, and that reduction in livestock numbers is often necessary to correct unsatisfactory conditions" (Blaisdell et al. 1982).

Holechek (1988) researched and published utilization guides by precipitation zone for different range types in the USA. The recommended average degree of use of the key species varies from 20 to 50 percent with the upper levels only on good condition ranges or for dormant season grazing. Heavy grazing invariably leads to a gradual loss in forage productivity and vigor, high death losses, and higher costs for supplemental feed in drought years. Pechanec, Stewart, and Blaisdell (1954) found in the sagebrush-grass type that proper followup management, i.e., protection from livestock use the first year, and light grazing the second year with proper stocking thereafter, resulted in increased grazing capacity 9 years later. Capacity on this area was increased by 83 to 106 percent, but there was only a 4 percent increase without this management. The area with proper management had five sagebrush plants per 100 square feet (9.3 square meters), compared to 55 plants per 100 square feet on the area without the above management.

On desert grasslands postfire rest must occur, and careful, conservative management followed until the weakened grass cover has completely recovered (Pase et al. 1977). Postfire recovery of browse species in these arid areas may take much longer than on more mesic sites (ibid.) A common goal for all grazing systems should be reduction of damage from grazing while promoting beneficial effects, and many systems appear equally effective (Blaisdell et al. 1982). Many combinations have proven to be successful where such factors as range condition, kind of livestock, stocking rate, season, and intensity were given proper consideration.

4. Economic Considerations. One of the primary reasons for the interest in using prescribed fire and limited control of wildfire is the perception that fire is a cheap brush control treatment. Smith (1981) states that prescribed burning provides an inexpensive brush control method, but labor will greatly increase the cost of prescribed burning, so the planning process should emphasize practices (such as fuel breaks) that will reduce labor needs to a minimum. He also lists one disadvantage as the risk of fire escaping and consuming valuable forage, ensuing property damage and danger to lives, resulting in expensive suppression costs and civil suits.

Bunting et al. (1987) suggest that selection of area to be burned will dictate many of the economic variables such as fire prescription and characteristics and whether it achieves its objectives . . . the higher potential sites produce the highest benefit. He also states that burning during the spring with snow lines and increased fuel moisture on varying aspects adjacent to the proposed treatment area may aid in fire control and reduce overall cost. The limited burn size, however, may increase the amount of time and personnel required for ignition resulting in higher average costs per acre or not achieving the planned objectives. Bunting says that economics is also a factor in determining the size of fires. The costliest portion of conducting prescribed fires is establishing and burning out the fire lines. The smaller the size, the greater the perimeter per unit area. Without natural fuel breaks, an extensive system of fire lines may have to be established to restrict the fires to the desired size. This often makes the prescribed burns economically unfeasible.

From an economic standpoint, spring burning is cheaper as it can be accomplished with fewer individuals and without firebreaks in some situations (Blaisdell et al. 1982). West and Hassan (1985) state that the highest potential for prescribed burns is on sites in good condition. Haslem (1983) provides several guidelines to maximize returns from burning including realistic prescriptions, treating manageable units, using livestock use for controlling escapes, use of natural control barriers, and use of test burns. Smith (1981) states that followup management is essential in extending the fire's useful lifetime.

Young and Evans (1978) state a general rule that one must be able to step from one bunch grass plant to another to have a reasonable chance of enhancing the site by recovery of existing plants. Bunting (1984) also notes the bluebunch wheatgrass response is from existing plants for the first 3 or 4 years after a fire. Dramatic increases in numbers of plants of exotic annual species can occur after fire, particularly if the existing bunchgrass community was in poor condition or many of the plants were killed by the fire. This potential for site invasion must be considered along with the above guidelines when deciding if a site can recover without artificial seeding.

5. Examples of Different Intensities of Grazing Management. Many different grazing management strategies have been implemented after burns, however, few have been intensively monitored to determine their impacts on fire effects. Two prescribed burns in northwest Wyoming, which escaped into adjoining grazing allotments, were monitored during 1987 to provide data on effects of postfire grazing management on vegetative response.

a. Blue Creek Coordinated Resource Management Plan (CRMP). In 1984, the operators agreed to a CRMP with the Wyoming Game and Fish Department and the Bureau of Land Management. The area is located south of Meeteetse, Wyoming, in the 15 to 19 inch (38 to 48 centimeters) precipitation zone at the 7,800 foot (2,377 meters) elevation. The vegetation type is composed of limber pine *(Pinus flexilis)* and mountain big sagebrush *(Artemisia tridentata vaseyana)* on a shallow loamy range site. Key graminoid species include Idaho fescue *(Festuca idahoensis)*, green needlegrass *(Stipa viridula)*, and rhizomatous wheatgrasses. The growing season in this area is from mid-May until about September 1. The adjoining allotment received heavy livestock use from the first of July until snowfall each year. The unburned site had a mountain big sagebrush canopy cover of 60 percent and produced an estimated 700 pounds per acre (785 kilograms per hectare) of annual sagebrush growth.

The planned actions started in 1981, including nonuse of livestock grazing, conducting prescribed burns, and fencing for grazing strategy implementation. In the year of the prescribed fire, snow left the area earlier than normal. The prescribed burn was conducted on April 3, 1985. The fire escaped across the allotment boundary fence into the adjoining allotment, burning about 20 acres (9 hectares) of mountain sage type. About 15 acres (7 hectares) of the escaped fire area were deferred from grazing for two growing seasons by a temporary electric fence, that is, no grazing occurred during the growing season. The original intent was to exclude animal use entirely but elk tore down the electric fence in September both years.

Herbaceous production data was collected during July 1987 in four adjoining sites. Weight estimates were made on ten plots, and two plots were clipped to obtain a correction factor. The study included one transect in the Blue Creek allotment that received no grazing for 4 years before the prescribed fire, and no use in the 27 months after the prescribed fire when the production data was collected. There were three areas studied in the adjoining allotment, all of which were grazed in the years before the prescribed fire. One area was unburned; the second received season long grazing in 1985 and 1986; and the third site was the fenced area where grazing was deferred throughout two growing seasons. Table IX-1 details the site and species production data that was collected.

Table IX-1: Herbaceous Production (pounds/acre dry weight) - Blue Creek.

Species	Unburned	No Rest	Deferred	Nonuse
Idaho Fescue	280	74	568	1,056
Rhizomatous wheatgrasses	19	447	210	762
Green needlegrass	24	51	182	103
Other Grasses and Forbs	590	920	828	713
Forbs	NA	579	1140	859
TOTAL	913	2071	2828	3493

All burned areas had higher grass production than the unburned area. However, the areas with deferred grazing and nonuse had much higher production of Idaho fescue, the preferred species. The nonuse area had twice the fescue production of the area that was grazed the year before the fire and deferred for two seasons afterwards. The unrested burned area had one-quarter of the Idaho fescue as the unburned area. Higher postfire palatability of this preferred species likely resulted in higher utilization rates by livestock, causing it to all but disappear from the site.

b. Orchard-Woods allotments. The second study area is located south of Ten Sleep, Wyoming, in the upper 10 to 14 inch (25 to 36 centimeters) precipitation zone at the 6,800 foot (2,073 meters) elevation. Vegetation was dominated by mountain big sagebrush, bluebunch wheatgrass *(Pseudoroegneria spicata)*, green needlegrass, and Idaho fescue. The permittee for the Orchard Ranch was conducting a prescribed burn on September 14, 1983, and the fire escaped into the adjoining Woods Allotment. The Orchard pasture had received light to moderate grazing with a deferred rotation strategy for two years prior to the fire and was rested for two growing seasons afterwards. The adjacent Woods pasture received heavy season-long grazing prior to the fire, and was deferred until seed ripe the first two seasons after the burn. Herbaceous production data was collected on July 30, 1987, from both sides of the division fence by clipping ten plots (Table IX-2).

Table IX-2: Herbaceous Production (pounds/acre dry weight) - Orchard-Woods.

Key Species	Woods (Deferred)	Orchard (Rested)
Green needlegrass, Bluebunch wheatgrass, Idaho fescue	131	447
Other Grasses and Forbs	1,648	864
TOTAL	1,779	1,311

Total production on the deferred Woods allotment was higher than on the Orchard area. However, much of this production was weedy grasses and forbs. Production of the three preferred grass species on the Woods allotment was only one third of that on the Orchard allotment which had been rested after the prescribed fire.

c. Management implications. The primary implication of the preceding examples is that in order to increase production of late successional species, there must be a commitment to rest after the burn and proper grazing management in the long-term. The two growing-season rest after a burn greatly speeds the recovery and improvement of the key species. If a burned area is not rested, the extra moisture available after the sagebrush or other shrub and tree species are eliminated is used by rhizomatous grasses, or early successional grasses and forbs, depending upon what species are present before burning. If there are sprouting shrubs present that are not used by livestock such as rabbitbrush, they can become dominant in the community. Lupine, which is a legume, will take up the extra moisture in the mountain sage type for the first two seasons if the late successional grass species are damaged or lacking in the understory. The lack of sagebrush invasion into the burn sites on Blue Creek shows the importance of maintaining the maximum vegetative ground cover and vigor to help slow the recovery of sagebrush seedlings on the site. It can be expected that forage would continue to increase on these sites because peak production on a sage site generally does not occur until the third to fifth year after a burn. An additional implication for prescribed fire is that increased production of herbaceous species does not necessarily mean that the site is enhanced, if, as on the Woods pasture, much of the production is composed of annual weeds and rhizomatous grasses.

C. Resource Management Considerations

1. Fire Effects. The effects of fire on plants and their response characteristics are described in detail in Chapter VI, this Guide. The following impacts and changes must be considered in planning proper site management to obtain the desired fire effects.

a. Damage to key forage and browse species by repeated heavy utilization by animals or burning is very similar; therefore, many areas are impacted by fire and then again by grazing and/or browsing animals.

b. Increased palatability and accessibility of grasses, forbs, and shrubs, influenced by the green period, nutrient content, growth form, and removal of dead material, occurs during the first few growing seasons after a burn.

c. Carbohydrate reserves of burned plants are lowered the first few seasons after a burn.

d. Fire effects result in changes of animal behavior including distribution, utilization rates, forage consumption, and frequency of use.

e. Prefire and postfire grazing management largely determines the benefit/cost ratio because of its considerable influence on the life of the beneficial aspects of the burn.

2. Plant Maintenance Factors. Little research has been conducted to determine the best long-term management practices for burned areas. However, the findings from plant ecology studies conducted over the past 60 years can be applied. The following factors should be considered to determine grazing management requirements:

a. Plant community health (carbohydrate reserves for plant vigor and recovery potential).

b. Composition of plant species that occupy the site and their successional position.

c. Recovery period required by species after burning for vegetative, root, and reproductive growth.

d. Utilization limits for species and season of grazing. A key factor in range deterioration has been overly optimistic estimates about the amount of allowable use that an area can sustain. The research literature gives a range of 20 to 40 percent utilization of annual growth during the critical growth period and 40 to 60 percent during the plant dormant period depending upon species and management objective. Use at higher levels can cause deterioration of the plant community. **e.** Site potential, which considers the range site or habitat type description.

f. Plant species morphology and reproductive mechanism.

g. The type of grazing and browsing animals that use the site, both wild and domestic, and rodent or insect use.

3. Length of Postfire Rest Period. The length of the period of postfire rest from livestock use depends on these factors:

a. Ecosystem type and ecological condition before burning.

b. Vigor of vegetation prior to fire.

c. Season of fire.

d. Growing season conditions, including temperature and precipitation, prior to and following burning.

e. Whether establishment of new plants is by seed or sprouting. Seedlings require a longer rest period to become resistent to grazing damage. Browse species often require second year growth before producing seeds.

f. The management objectives for the area. For example, the length of postfire rest may vary significantly for the same area depending upon whether the area is being managed primarily for range, wildlife, forestry, or recreation, or a mix of these activities.

4. Summary Recommendation for Rest. Postfire rest from grazing is required on both prescribed fires and wildfires, on seeded areas and unseeded areas. The length of the period of rest from grazing is dependent upon accomplishment of measured objectives for the area. General recommendations are:

a. Prefire.

(1) At least one growing season of rest before a prescribed burn is needed on many sites to increase both root reserves and fine fuels needed to carry fire.

(2) Severely depleted sites may require several years of rest before burning in order for key plants to regain vigor and reproductive capabilities.

b. Postfire.

(1) Burned areas should be rested until a good ground cover and a litter layer are present to provide soil and watershed protection.

(2) One growing season of rest may be adequate on some highly productive or high condition sites after a low severity fire. A minimum of two growing seasons rest is recommended for most burned areas.

(3) Areas under intensive grazing management can be grazed immediately after a fall-winter burn to harvest some unburned vegetation within the unit. This short use period prior to regrowth could assist in nutrient cycling, roughing of the soil surface, and breaking of any sealed ash layers. Because this use can also result in physical damage to the plant roots and crowns, it should be closely monitored and occur during a short time period. Time control grazing may be used to help accomplish postfire objectives if proper consideration is given to animal impacts and plant community recovery periods.

(4) Sites that are burned to increase utilization of unpalatable species should be grazed immediately after the fire while the undesirable plants are young and actively growing.

(5) Heavy utilization grazing of an area by wildlife or wild horses will require further rest from permitted livestock if their numbers cannot be controlled. Wild horses are difficult to move from their normal territories but any water close to the burn area can be regulated, especially during the first few growing seasons. Wildlife numbers can be controlled by harvesting excess animals, although this is only a feasible management strategy in the event of an extremely large wildfire.

(6) Below normal precipitation may delay vegetative recovery. A burned area should be inspected to determine if it is ready for grazing. It cannot be assumed that vegetation is ready for grazing just because the prescribed period of rest has occurred. The degree of accomplishment of measured objectives should be the most important criteria in determining the length of the postfire rest period.

(7) If recovery of wildlife browse is a key objective, the length of the postfire rest period may need to be much longer, and permitted levels of utilization by livestock may be much lower, than if target species for an area are grasses and forbs to be used by livestock.

c. After postfire rehabilitation. If postfire rehabilitation has been conducted, livestock should not be allowed back onto the burned area without evaluating whether rehabilitation objectives have been met. Postfire rehabilitation considerations are discussed in Chapter VI.C.6.a., this Guide.

5. Effects of Management Strategy. The commitment to long-term grazing management on burned areas is vital for real long-term improvement in plant productivity and composition. Determination of desired plant community objectives is necessary before the grazing strategy can be decided. Many sites proposed for burning are in poor condition or have mature stands of trees with little understory vegetation. These sites require long periods of time to progress through successional changes to meet objectives. If introduced plant species are seeded on the burned area, a grazing strategy must be designed to meet their survival needs. Seeded sites may have to be fenced separately from native rangeland due to phenology and palatability differences.

Effects of fire and grazing management cannot be easily separated; therefore, fire effects on vegetation should be monitored and evaluated both in the short term (prior to start of grazing or at the end of second growing season) and the long term (after two cycles of the grazing strategy or 8 to 10 years). The short-term evaluation assesses achievement of fire treatment objectives, while the long-term evaluation considers the attainment of desired plant community objectives.

Specific grazing strategies must be designed to meet key species requirements and land use planning objectives. These general principles should be kept in mind in post fire management of burned areas.

a. Type of grass. Bunchgrasses require lighter utilization rates and longer rest periods than do rhizomatous or annual plant species.

b. Palatable shrubs.

(1) Highly palatable sprouting shrubs often require long rest periods after fire to allow restoration of carbohydrate reserves, to produce seeds, and permit seedling establishment.

(2) Upland shrubs such as sagebrush require bare soil surface and minimal herbaceous competition to enhance reestablishment. Therefore on many of the drier and lower snowfall sites heavy spring grazing could promote sagebrush establishment, if that is the management objective.

c. Riparian communities. Riparian communities with shrubs and trees require long-term rest to recover and light utilization of key shrubs to maintain a healthy community. It may be necessary to fence riparian areas for several years to allow initial recovery.

d. Forb-dominated communities. In order to maintain a forb-dominated plant community, the grasses must receive heavy grazing pressure or be burned more frequently.

6. Economic Factors. The following general guidelines can be used when analyzing fire effects that have an influence on economics.

a. Site selection criteria. The first step is to consider the site potential and set objectives accordingly. These selection criteria can be used for analysis of fire effects on either prescribed burns or wildfire rehabilitation.

(1) Ecological condition. Sites in high-fair or better condition should be selected for prescribed burning if increased herbaceous production of desirable species is a short-term objective and reseeding is not planned.

(2) Presence of desirable species. If improvement of native species is the objective, it must be determined if there are enough desirable remnant plants to make the burn worth conducting. Seeding is very costly and the native species are more adapted to the sites.

(3) Invader species. Are undesirable species or noxious weeds present on the site that might be favored by fire? Species such as cheatgrass, rabbitbrush, and horsebrush are common problems on arid and semiarid rangelands. Any reseeding must be completed before the first growing season to avoid dominance by introduced annual species such as cheatgrass. Noxious weeds may require treatment if there is a significant number present.

(4) Burn size. Is the burn acreage within the management unit large enough to avoid livestock and wildlife concentrations, thus negating the positive fire effects? Refer to Chapter VII.B.3.a. and b., this Guide, for a discussion of the impacts of burn size and configuration on wildlife habitat.

b. Factors to consider in analyzing benefit/cost. The following points are given to consider in planning prescribed burns to improve native herbaceous vegetation. If the objective is to prepare a site for seeding or removing undesirable species, then other principles could be involved.

(1) Conduct burns during the spring period or other seasons that require minimum fire control efforts. The three major costs that can be reduced are equipment, personnel, and fuel break construction. Offsetting factors include ignition problems and objective accomplishment because fuel or soil moisture or weather limit the likelihood of a successful fire.

(2) Burn the largest acreage possible within the constraints of the objectives for the burn. The impact on animal species and other resources will determine the maximum size.

(3) Sites with higher ecological condition and plant vigor respond more quickly and favorably to burning. Greater production increases, a quicker recovery, and better chance for seeding establishment occur when a given ecological site in the mid to upper precipitation zone is burned and less damage to desirable species can be expected.

(4) Extending the life of the fire effects through long-term grazing management can improve the long-term cost effectiveness of a burn project.

E. Summary

Proper site management based on specific objectives and plant species is essential in the management of fire effects. Improper grazing management can easily nullify efforts put into prescription burning or wildfire rehabilitation, as well as impede natural vegetative recovery after wildfire. Impacts of long-term grazing management before and after a fire can be easily overlooked; therefore, proper grazing management including the appropriate kind of livestock, the stocking rate, the season and the intensity of utilization, and the length and frequency of use are most important.

The period of nonuse by livestock necessary after a fire varies considerably with the vegetative composition, site conditions, resource conflicts, and objectives of the burn. Grazing closures apply to prescribed fires and wildfires, whether they are artificially reseeded or recovery is by natural means. In some situations, the only way to ensure nonuse of critical areas after a fire is to construct fences.

Proper grazing management before and after a fire has a major impact on fire effects, vegetation changes, economics, and rehabilitation success. In analyzing fire effects, several site selection criteria should be considered including the site potential, the ecological condition, the presence of desirable and invader plant species, the acreage of burn within the management unit, and the livestock management. The consideration and implementation of these factors determines the benefit/cost ratio and the success of a burn project or postfire rehabilitation effort.

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CHAPTER X - EVALUATION

By Ken Stinson and Melanie Miller

A. Introduction

Documentation is the collection, organization, and storage of all information pertinent to a specific project, in order to maintain a long-term record, and to facilitate project evaluation. Evaluation is both an objective and intuitive process of examining and assessing data and observations to determine if planned objectives were met. Fire effects documentation and evaluation are important in order to replicate positive fire effects and avoid duplication of negative fire effects in future prescribed fires; to assess postfire management of land uses on both wild and prescribed fires; to assess the effectiveness of postfire rehabilitation in preserving site quality; to provide rationale for fire use to the public; to meet legal requirements and liability; to permit evaluation of objectives; and to provide a basis for improvements in project planning, implementation, and management. Fire effects monitoring and evaluation should be included in area monitoring and evaluation plans.

1. Documentation. All documents shall be labeled by project name and number, date, and legal description. A detailed list of types of data that can document a wildland fire are listed in C.3.a., this chapter, pages 3 to 5. The following are general classes of information used to evaluate fire effects, and should be included in project records.

a. A complete description or reference shall be documented for the method and technique used to collect the monitoring data. Monitoring studies appropriate to evaluate land-use objectives should be used.

b. Photographs properly labeled, dated, and filed, including compass direction of photo.

c. Observations before, during, and after a prescribed fire or wildfire.

d. Schedules and responsibility of evaluation and documentation.

2. Organization and Maintenance of Documents. Because fire effects information requires long evaluation periods and the data accumulates over time, it is important that fire monitoring and evaluation records are placed in a permanent file. Records may be needed many years after the original incident to study the site, or for comparison with more recent events on similar sites. The data should be stored in the appropriate permanent project file, such as allotment/ management unit files, or timber sale file. Records should be kept indefinitely or archived and labelled as "Permanent File - Do Not Destroy."

B. Considerations for Fire Effects Evaluation

Evaluation is both an objective and intuitive process of examining and assessing data and observations to determine whether planned objectives were met. There are two aspects of postfire evaluation, evaluation of fire effects, and an evaluation of the effectiveness of postfire management actions. A "cookbook" approach to evaluating fire effects should not and can not be applied in all situations (Pellant 1989).

1. Prescribed Fire versus Wildfire Evaluations.

a. Fire effects. This evaluation provides the decision maker with the necessary information to make sound decisions regarding postfire rehabilitation and management actions.

(1) Prescribed fire. For a prescribed fire, fire effects are evaluated and compared to the fire treatment objectives. The fire treatment is assessed to determine whether it indeed enhanced resource management objectives for the site. Because the event occurs under pre-planned conditions, site-specific prefire and postfire monitoring can occur. If desired effects are not attained, then an evaluation must determine why they were not. If postfire rehabilitation is planned, an assessment must be made whether the fire treatment suitably prepared the site for seeding or planting. A decision is made whether postfire site management objectives that were developed before the prescribed fire are still suitable.

(2) Wildfire. The area in which a wildfire occurs may have established resource objectives, and fire treatment objectives may have been prepared in the Escaped Fire Analysis. However, because wildfires are random events, any prefire monitoring with the specific intent of documenting the effects of that fire can rarely be done. Some monitoring data may be available that was performed for other resource management programs or projects, and some of these data may be suitable for postfire comparisons.

After a wildfire, an assessment is made of the degree to which fire may have affected the ability of the land to meet any resource management objectives that may have been established for the area. In particular, the expected response of the vegetation on the site, and the potential for site erosion, must be evaluated. A plan to take actions paid by Emergency Fire Rehabilitation funds may be written if action is required to mitigate the effects of the wildfire.[(1)] The decision to use EFR funds is very important; therefore, appropriate personnel should be utilized and the evaluation process should be initiated as soon as possible. Fire effects evaluation can begin long before the fire is declared out. Recommendations are made whether a continuation of present site management practices is acceptable, or if changes are needed, such as in grazing management or use by all terrain vehicles.

b. Effectiveness of postfire actions. An evaluation should be conducted to determine whether postfire site rehabilitation treatments limited negative effects of fire, to assess the impacts of postfire activities such as salvage logging, and to establish the effectiveness of postfire site management actions, such as grazing restrictions, in preserving or improving site quality.

c. Effect of fire and postfire actions on attainment of site objectives. Depending on whether a wildfire or prescribed fire is being evaluated, and the level of land use goals and objectives that existed for the site before the fire occurred, an assessment must be made of whether resource management, fire treatment, and/or rehabilitation objectives were met.

2. Degree of Evaluation. The degree of evaluation that is required depends on:

a. The complexity of the project; several resources may have been monitored and documented.

b. Whether the resource and/or treatment objectives were tied to ecosystem effects or individual species responses.

c. The potential for controversy, involving such factors as designated Wilderness, critical wildlife or watershed values, Areas of Critical Environmental Concern, or political considerations.

d. Experience with or understanding of site specific fire effects, or rehabilitating or managing similar areas.

e. Time and funding availabilities.

f. Availability of existing data bases. Other disciplines may have extensive records, such

as streamflow, weather data, or soils inventories, that can be incorporated into the evaluation.

3. Steps in the Evaluation Process. Existing agency policies and procedures may require certain steps to occur in specific order. The following steps are suggested for postfire evaluation.

a. Identify parties responsible for conducting the evaluation process.

b. Review objectives.

c. Assemble data.

d. Interpret data/observations.

e. Determine if and to what degree objectives were met.

f. Prepare evaluation report, which includes recommendations, for decision maker.

g. Disseminate new findings to colleagues.

h. Observe long-term changes.

C. Evaluation Procedure

1. Identify Parties Responsible for Conducting the Evaluation. An interdisciplinary team approach is used to evaluate both prescribed fires and wildfires. Managers designate both a team and a team leader. All resource specialists involved in planning a prescribed fire or who had the lead in conducting it (Burn Boss or Project Coordinator), should be involved with a prescribed fire evaluation. Any resource specialist involved in the suppression of a wildfire, particularly the Resource Advisor or Environmental Specialist, should be included on the team that assesses the effects of a wildfire. It is very important that individuals with fire effects experience, particularly in similar vegetation types, be involved in the evaluation.

2. Review Objectives. Review any general or specific objectives developed for the site being evaluated. These can include land use decisions, fire planning objectives, resource management objectives, prescribed fire objectives, fire treatment objectives, and rehabilitation objectives. Rehabilitation objectives referred to here are those objectives established as goals for the rehabilitation treatment, such as reducing soil loss, or preventing invasion by exotic plant species. Other objectives that are standard operating procedures are also evaluated, such as keeping a prescribed fire within the prescribed fire target area, meeting safety concerns, protecting cultural resources, and staying within the cost target for the project.

3. Assemble Data.

a. Data sources.

(1) Project file.

(2) Project plan such as Allotment Management Plan, or Timber Sale Plan.

(3) Site specific plan such as Prescribed Burn Plan or Rehabilitation Plan.

(4) Records of any onsite evaluations conducted by Interdisciplinary teams, such as preparation for a prescribed fire, or observations made during or shortly after a wildfire.

(5) Any reports associated with the occurrence of a wildfire being evaluated, such as the Escaped Fire Situation Analysis, Burned Area Report, or reports by the Fire Behavior Analyst, Incident Commander, or Resource Advisor.

(6) Fire effects data or evaluations from similar projects, such as other prescribed fire or wildfire evaluations.

(7) Climatological data.

(a) National Oceanographic and Atmospheric Administration (NOAA), e.g., monthly summaries.

(b) Remote Automated Weather Stations (RAWS), including archived

data.

(c) Local manual weather stations.

(d) State climatologist.

(e) Soil Conservation Service (SCS), e.g., snow surveys and soil moisture indices.

(8) Weather, fuel, or soil moisture data collected at the time of the fire.

(9) Air quality permits, smoke observations, or data collected at the time of the fire.

(10) Any site specific monitoring information, such as preburn and postburn fuel, soil, vegetation, or fuels data. For a wildfire, some information on prefire vegetation composition may be obtained from any resource management or activity plan for the area, or from rangeland inventory, trend, and utilization studies.

(11) Aerial photographs.

(12) Resource maps, such as vegetation, soil, timber, or cultural site locations.

(13) Records that document uses of the area.

(a) Timber sales, regeneration surveys, and records of post-logging treatment, such as slashburning, pile burning, scarification, or no treatment.

(b) Actual use and utilization, and season of use by licensed livestock or wild horses; utilization levels on key species; unauthorized use records (trespass file).

(c) "On-the-ground" observations, such as extensive amounts of wildlife use during a particular period of time.

(d) Use by other public land users, such as sportsmen or conservation groups, fish and game agencies.

(e) Observations on extreme weather events, anomalous climatic trends, grasshopper or rodent infestations, wildlife use, and ORV impacts.

b. Data adequacy. Compare the amount of monitoring data collected with the amount planned for collection. If data collection was inadequate, determine the reasons why planned monitoring was not carried out.

c. Statistical analysis. Determine if the appropriate statistical analyses have been completed, or if inadequate data were collected to conduct the analysis. (See Data Analysis.) If data were collected in such a fashion that statistical analysis is not possible, or is inadequate, note should be taken so future data are properly gathered.

4. Interpretation of Data/Observations.

a. Uncertainty and reliability. Fiscal and time constraints do not allow for collecting enough data for managers to make risk-free decisions, and some uncertainty will remain, even if a statistical analysis is conducted. Decide what risk level to accept, and whether any data inadequacy is the result of uncontrollable factors such as acts of nature (floods, hailstorms), vandalism, or equipment failures. If poor study design prevents proper data analysis, document this fact. Be sure the decision maker is informed of the reliability of data; i.e., distinguish between use of complete and properly collected data (hard data) and assumptions made where data gaps exist (soft data).

b. Results of data analysis. Explain data analysis results in terms that non-statisticians can understand. Integrate any quantitative or qualitative, onsite data with observations and results from other studies. Be wary of interpreting data mechanically without considering the possibilities of undocumented causes for change. If necessary, use expertise from other offices to decipher complex interrelationships. Prepare a summary report of the findings. **5. Determine If and To What Degree Objectives Were Accomplished.**

a. Indicate whether each planned objective was met and to what degree it was accomplished.

b. If objectives were not met, identify reasons why. Some general areas to consider are:

(1) Objectives were unattainable or mutually exclusive.

(2) Timeframes for objective accomplishment were unrealistic.

(3) Operational procedures used to implement the project were not appropriate, such as an ignition method or ignition pattern that caused a more severe treatment than needed to produce the desired fire effects.

(4) The operational plan and/or procedures outlined in the project plan were not followed.

(5) Followup site management was inadequate; e.g., postfire grazing occurred too quickly or at too high an intensity, or off road vehicle use occurred on a burned area before vegetative recovery could sustain ORV use.

(6) Monitoring techniques or sampling intensity were not adequate to detect change.

6. Prepare Evaluation Report with Summary and Recommendations.

a. Prescribed fire.

(1) Brief summary of actions taken and burning conditions.

(a) Date, time of day fire occurred, acreage burned, and ignition pattern and method.

(b) Weather, fuel, and soil moisture conditions during the fire.

(c) Observed fire behavior and characteristics.

(d) Observed smoke production and characteristics.

(e) Any differences between fire prescription and actual burning conditions.

(f) Map of the proposed fire area and the area that actually burned.

(2) List of objectives of prescribed fire.

(3) Summary of monitoring results and observations.

(4) Describe which and to what degree objectives were met (expected results versus actual results).

(5) If objectives were not met, briefly describe those factors that were responsible for the lack of achievement.

(6) Make recommendations to management.

(a) Immediate changes needed in management strategies.

(b) Changes in how future prescribed fires could be planned or implemented, including changes in prescription or ignition that would lead to better results.

(c) Changes in postfire site management.

(d) Changes in monitoring procedures.

(7) After management review and decision(s), evaluation report should be filed in the appropriate file(s) and required followup actions assigned and initiated. This report should be signed and dated by the preparer and the reviewing official.

(8) Followup on management decision(s) - repeat evaluation process.

b. Wildfire - fire effects evaluation.

(1) Brief summary of wildfire extent and effects.

(a) Date and acreage of public lands burned.

(b) Prefire vegetation.

(c) Map of the burned area including soil mapping units.

(d) Multiple-use objectives identified in land use plan, e.g., watershed value, wildlife habitat, livestock forage.

(e) Interdisciplinary team findings.

i. Estimated percent survival of key plant species.

ii. Potential for postfire erosion and sedimentation.

iii. Potential for invasion of site by exotic species.

(2) Recommendation for postfire actions.

(a) Postfire rehabilitation actions, e.g.,

i. Seeding, including recommended species and seeding rates.

ii. Contour falling of trees.

iii. Construction of instream structures to control channel erosion.

(b) Feasibility of conducting salvage logging.

i. Locations within burned area.

ii. Methods that will not cause negative impacts on soil.

(c) Changes in postfire land uses, e.g.,

i. Temporary restriction or exclusion of grazing to allow recovery of perennial plants or establishment of seeded or planted vegetation.

ii. Road or all terrain vehicle closures.

(d) Need for fence construction to exclude livestock and/or wildlife.

(3) Specific objectives for postfire management: specify desired condition, e.g.,

(a) Limit erosion to a specified amount.

(b) Restore site to a productive state by salvaging merchantable timber and replanting trees, and leaving a specified number of wildlife trees that do not pose a safety hazard.

(c) Obtain a specific level of plant cover or productivity.

c. Wildfire - rehabilitation and/or management evaluation.

(1) Prepare a brief summary of actions taken.

(a) List management objectives and planned actions.

(b) Describe actions taken and date.

(c) Include a map of treated or rested areas.

(2) Summary of monitoring results and observations.

(3) Describe which and to what degree objectives were met.

(4) If objectives were not met, briefly summarize what factors were the cause for lack of achievement.

(5) Make recommendations to management.

(a) Immediate changes required in management strategies.

(b) Recommendations for improvement in rehabilitation and postfire site management practices.

d. Post evaluation actions.

(1) After management review and decision(s), the evaluation report should be filed in the appropriate file(s) and the required followup actions assigned and initiated. This report should be signed and dated by the preparer and the reviewing official.

(2) Followup on management decision(s) - repeat evaluation process if appropriate.

(3) If no management action was taken (e.g., the burned area was grazed, or no erosion control efforts were made), document any adverse impacts that occurred and what future management actions need to be taken under similar conditions.

7. Disseminate New Findings To Other Interested Parties.

a. Fire Effects Information System.

b. Internal or interagency newsletters.

c. Professional meetings.

d. Local, state or regional workshops.

e. Agency technical publications.

f. "Expert Systems" or relational databases.

g. Office-to-office memos.

h. Professional journals.

i. Videos and other visual media.

j. Electronic bulletin boards.

8. Observe Long-Term Changes.

a. Within what timeframe did the original target species reestablish?

b. Are noxious weeds or unwanted species increasing in the postfire environment?

c. Have cyclic climatic events, such as drought or a series of wet years, affected postfire vegetative recovery? What effect have they had on plant community composition and characteristics?

d. Are postfire management actions still having the desired effects?

e. Is the level or type of postfire management adversely affecting desirable native vegetation or seeded species?

f. How have the different species that were originally seeded persisted?

g. Is cumulative acreage burned by wildfires large enough to affect whether future prescribed burns should be carried out?

D. Summary

Evaluation of both monitoring data and the impacts of postfire activities must be conducted in order to ensure that lands receive the best possible fire treatment, rehabilitation, and postfire management. Once we have monitored and evaluated enough projects and management actions on similar sites, and adjusted our actions based on these results, we can become more confident that the proper treatment is being implemented. The same degree of monitoring and evaluation need not be carried out on all subsequently treated areas if vegetation type, soil type, and treatment prescription are similar to that of other successful treatments. However, it is professionally unacceptable to conduct no prefire or postfire monitoring or site observation, to assume that an area is ready for grazing because the designated length of time has passed since the occurrence of a prescribed or wildfire, or to conduct no evaluation of the implementation or effectiveness of postfire site management in preserving or enhancing site quality. Without some check on the results of our activities, accumulated assumptions can lead to land treatments that do not meet resource management goals and objectives, and lead to deterioration, instead of enhancement, of site quality.

1. See BLM Manual Handbook H-1742-1 (USDI-BLM 1985b) for a discussion of EFR planning procedures on BLM land.

Fire Effects Guide

CHAPTER XI - DATA MANAGEMENT

By Dr. Robert Clark

A. Introduction

Managers can gain a number of benefits from the analysis of their data. The results of the analysis helps managers make informed decisions leading to favorable outcomes. Analyzing and manipulating the data gives the manager a special familiarity with the data and a feel for how precise and repeatable the sampling is likely to be. Describing and defending the credibility of the data is easier when it has been appropriately analyzed and described in standard statistical terms. Practice and familiarity with the most common statistical analyses provides a basis for better understanding, interpretation, and proper application of results presented in professional fire literature.

This chapter will acquaint fire managers with some elementary statistical methods that can be used to help make decisions. The methods are demonstrated by example. Managers interested in more detailed discussion or more sophisticated methods are referred to Freese (1962, 1967), Little and Hills (1978), and Eshelman et al. (1986). Managers are also encouraged to contact a statistician ***before*** data are collected to ensure the data will be usable and appropriate, and that assumptions of analysis are not violated.

Statistical terms used in this chapter are included in the Glossary of this Guide. Additional discussion is available in statistics texts.

B. Principles and Procedures of Data Analysis

1. Determination of Sample Size (Number of Observations). Samples (observations) cost money, but so do decisions based on inadequate data. Therefore, it is helpful to collect an appropriate number of observations. One useful method to determine the appropriate sample size for continuous data is (Freese 1967, p. 12):

$n = (t^2 s^2) / E^2$

where:

> n = the required number of observations.
> t = tabulated Student's t available in most statistics texts.
> s = sample standard deviation (and s^2 = sample variance). Note the unfortunate situation here, that some estimate of variance is required to calculate sample size, i.e., there is one equation with several unknown values. This is usually handled by collecting a preliminary sample from which to estimate a variance and a mean, which in turn are used to calculate the sample size.
> E = desired precision, expressed as a proportion of the sample mean.

Example: Suppose the manager needed to know the foliar moisture content of basin big sagebrush on a proposed prescribed fire area. Because fire behavior in sagebrush is closely related to foliage moisture content, the manager decided to sample such that the moisture content was estimated within 10 points of the true moisture content level at the 90 percent confidence level. This indicated that the manager wanted to know the moisture content on the site within plus or minus 10 points of the true average value (precision level), and wanted the estimate to be correct 9 out of 10 times (confidence level). 10 points of error was selected because fire behavior in sagebrush can begin to change quite significantly over a range of 20 percent foliar moisture content (plus or minus 10 percent).

The manager collected foliage from 12 different plants, dried and weighed the samples, calculated the moisture content, and recorded the following results. What sample size is required to meet the manager's needs? Was the preliminary sample adequate?

plant	x = moisture content (%)	x^2
1	70	4900
2	90	8100
3	80	6400

4	70	4900
5	60	3600
6	80	6400
7	90	8100
8	100	10000
9	90	8100
10	80	6400
11	70	4900
12	60	3600
n = 12	Êx = 940	Ê x^2 = 75,400

Note that the Ê symbol means summation.

a. Step 1. Look up t value from t table in most statistical texts (e.g., Freese 1967, p. 77). Degrees of freedom (df) are n - 1 (12 - 1 = 11). The appropriate t value at the 90 percent confidence level (or 10 percent error rate) is 1.796.

b. Step 2. Calculate the variance (s^2) of the preliminary, 12-observation sample according to [note that this calculation results in the sample variance (s^2) rather than the sample standard deviation (s)]:

s^2 = Êx^2 - ((Êx)^2/n) / n-1 = 75,400 - ((940)^2 / n) / 11 = 160.6

c. Step 3. Decide how much error can be tolerated. In this example, the manager wanted the estimate to be within 10 percentage points of the true mean moisture content. Therefore, E = 10.

d. Step 4. Calculate the appropriate sample size according to the formula described above:

$n = (t^2 s^2) / E^2 = (1.796)^2 (160.6) / (10)^2 = 5.18 = 6$ observations

e. Conclusion. The preliminary sample of 12 observations was adequate. If the preliminary sample of 12 observations had been inadequate, the manager had several options. First, more observations could have been taken. Second, the acceptable precision level could have been lowered. Third, a lower confidence level could have been accepted and some added risk incurred. Or fourth, the fire prescription might have been altered (e.g., faster windspeed or lower fuel moisture content) to compensate for the added uncertainty. The important point is that the manager had some quantitative information on which to base a decision.

f. Note. The size of the preliminary sample depends on the variable being measured, on the objective for measuring the variable, and on funds, time, and work force constraints. Inherent variability associated with most natural resource sampling indicates that 10 or more observations may usually be required to obtain a reasonable estimate of variance. One observation is **never** adequate because degrees of freedom would be zero and no analysis is possible.

2. t-Test for Paired Observations (Plots). This test is especially useful for comparing effects between two fire treatments, such as burned vs. unburned, or backing fires vs. heading fires. An assumption of the test is that pairs of plots are established prior to the treatment, each group has the same population variance, the population of observations follows the normal distribution, and that treatments are randomly assigned to each individual plot. It is possible, however, to establish plot pairs adjacent to firelines (one plot on either side) such that these assumptions are not violated. A similar test for unpaired plots (Freese 1967, p. 24) should be used where plots are not paired; that test, however, is slightly more time consuming and a slightly greater loss of sensitivity may occur. Only the t-test for paired plots is illustrated here.

Example: A fire manager suspected that fire residence time might be an important factor affecting postburn Idaho fescue *(Festuca idahoensis)* production. The manager designed an experiment to evaluate the suspicion. An area was selected where part of the burning would be done by a backing fire and part by a heading fire. A series of 10 plots were clipped, oven-dried, and weighed preburn to establish that the two areas were from the same population and had similar variances, and to determine preburn fuel loading. The heading and backing fires were then conducted on the same day under similar environmental conditions. Sufficient rate of spread and flame depth measurements were made during the fires to establish that residence time was significantly ($p = 0.05$) different between the two treatments. One year later the fire manager clipped, oven-dried, and weighed Idaho fescue standing crop to compare "production" on the two treatments. Based on the following results, and assuming that residence time (and its implications) was the only difference between the heading and backing fires, does residence time influence postburn production?

Quadrat	Heading	Backing	d = Heading - Backing	d^2
1	22	24	-2	4
2	15	13	+2	4
3	19	19	0	0
4	19	12	+7	49
5	21	17	+4	16
6	20	17	+3	9
7	18	19	19	1
8	20	12	12	64
9	21	15	15	36
10	14	14	14	0
n = 10	$\hat{E}_h$=189	$\hat{E}_b$=162	$\hat{E}_d$=27	$\hat{E}_d{}^2$=183

$x_h = 18.9$ $x_b = 16.2$

a. Step 1. Note that by inspection the two means appear to be different (18.9 appears greater than 16.2). The null hypothesis, H_o, is that the two means are equal, i.e., x_h is equal to x_b. The alternate hypothesis, H_a, is set up to allow rejection, i.e., x_h is not equal to x_b. This hypothesis will result in a "two-tailed" test; one-tailed tests also can be established by setting the means in the hypotheses "greater than" or "less than" rather than "not equal to." Note that one-tailed tests require different t values than two-tailed tests.

b. Step 2. Establish the confidence level for testing. By convention, testing in this example was set at the alpha = 0.05 level (this is the same as the 95 percent confidence level, or that the acceptable risk is to be wrong one chance in 20 due to chance alone). From the t table, with n-1 degrees of freedom and an error rate of 0.05, t = 2.262. This is the tabulated value below which the difference between sample means is likely to be due to chance alone. A calculated value larger than 2.262 would suggest that a real difference exists between the two means, and on the average, this conclusion would be correct 19 of 20 times.

c. Step 3. Calculate the variance of the difference between sample means according to:

$s_d^2 = \hat{E}d^2 - (\hat{E}(d)^2 / n^{) /}$ n - 1 = 183 - ((27)^2/10) / 9 = 12.2333

d. Step 4. Calculate t according to:

t = $(x_h - x_b)$ / §[s_d^2 / n] = (18.9 - 16.2) / §[12.2333 / 10] = 2.4412

§ = square root

e. Conclusion. The calculated value of 2.4412 is larger than the tabulated t value of 2.262. This suggests that a real difference exists between the two means. The fire manager may report to the supervisor that postburn Idaho fescue production was different (p = 0.05) between the heading fire and backing fire sites, and that more production occurred on the sites burned with a headfire. If it is certain that the **only** difference between treatments is residence time, it is also reasonable to assume that long residence time was more detrimental than short residence time. This conclusion is likely to be correct 19 out of 20 times. Note that this statistical significance does not necessarily imply biological significance. Also note that this "study" was not replicated, nor was a "control" treatment used; both are strongly encouraged. Also note that the method and level of testing, and the hypothesis, were established before any sampling or burning occurred.

3. Chi-Square Analysis of Counts. Chi-square is a nonparametric method that is useful for analyzing binary enumeration data that fall into two categories, such as scorched or not scorched, alive or dead, scarred or unscarred, or sprouted or not sprouted. These types of data are common in fire management. Although several procedures are available, the following example illustrates a useful method for many fire management data.

Example: One half of a plant community containing bitterbrush *(Purshia tridentata)* plants was burned in the fall and the other half was burned in the spring. The fire manager tagged 20 randomly located bitterbrush plants in each area, before burning, to estimate mortality. One year after burning, the fire manager found 11 tagged plants alive on the spring burned site and eight tagged plants alive on the fall burned site. At the 90 percent confidence level, was there a differential response between fall and spring burned plants?

a. Step 1. Set up a 2 x 2 contingency table (2 rows and 2 columns of observations):

	Spring	Fall	Total
Alive	11	8	19
Dead	9	12	21
Total	20	20	40

b. Step 2. Calculate chi-square. The general procedure, based on a 2 x 2 contingency table, is:

	I	II	Total
1	a	b	a+b
2	c	d	c+d
Total	a+c	b+d	a+b +c+d

chi-square = ([(| ad - bc |) - 1/2 n]^2 n) / (a + c) (b + d) (a + b) (c + d)

chi-square = [(|(11 x 12) - (9 x 8)| - 1/2 (40)]^2 (40)) / (20) (20) (19) (21) = 0.4010

Note that the vertical bar (|) indicates absolute value, so it is irrelevant which cross-multiplication product is subtracted from the other (i.e., 11 x 12 - 9 x 8, or 9 x 8 - 11 x 12). Use of the Yates Correction, [- 1/2 (n)] and [1/2(40)] found in the numerators of the above equations, decreases the chi-square value, and thus reduces the chance of declaring a significant difference when one does not exist.

c. Step 3. Look up the tabular value for chi-square in a chi-square table, such as Freese (1967, p. 82). Values in a chi-square table are different than those in a t-table, and a t-table should never be used to obtain values for a chi-square test. Degrees of freedom (df) for the 2 x 2 contingency table are calculated according to: [(rows - 1) x (columns - 1)]. In this example, df = (2-1)(2-1) = 1. Since the fire manager decided to test at the 90 percent confidence level (10 percent error level), the appropriate chi-square value to test this example is 2.71.

d. Conclusion. Since all values below 2.71 are below the 10 percent error threshold, the calculated value of 0.4010 is not significant. The manager concluded that, in this example, the sprouting of bitterbrush was not different between spring and fall fire treatments. Note that no cause and effect was implied. If a statistically significant difference had been observed, the difference could have been due to environmental factors or other unknown causes. This point is especially important for data gathered during different time periods.

4. Other Tests. Two additional statistical testing methods that are beyond the scope of this Guide but may be useful in routine fire management work include analysis of variance (often abbreviated AOV or ANOVA), and linear correlation and regression.

a. **Analysis of variance.** ANOVA is a method used to separate sources of variation *within* treatments and *among* treatments and may be used with several different experimental designs such as the completely randomized design or the randomized complete block design. ANOVA produces an "F" test of significance, and is often used with several mean separation tests, such as Duncan's New Multiple Range Test, or Orthogonal Comparisons. Although ANOVA has many potential applications in fire management, a statistician should be consulted before its use. Several texts, for example, Little and Hills (1978), provide excellent discussions of ANOVA.

b. Linear correlation and regression. Linear correlation and regression analysis are mathematical methods used to describe how independent variables relate to each other, and how dependent variables relate to independent variables. These approaches to describing and understanding relationships common in fire management work **do not** imply any cause and effect; they merely describe associations and relationships. Because the potential for misuse is so great, many statisticians discourage their use by apprentices. They are especially useful, however, when used with the aid of a reputable statistician.

5. Crunching Numbers. Development of microchip technology has made the manipulation of large data sets rapid and easy for fire managers. The three simple tests (sample size, t-test, and chi-square) that are described above can all be easily calculated on simple, 4-function, hand held calculators. Many small, hand held calculators are commercially available that have internal, preprogrammed statistical functions that quickly calculate the sample mean, variance, and sometimes, even complete linear regression. One caution is that the user should be aware whether the calculator in question uses n or n - 1 for degrees of freedom in the variance and standard deviation, and should understand the implications.

The Hewlett-Packard HP-71B hand held calculator, which is routinely used for fire behavior calculations, has several Custom Read Only Memory (CROM) modules available. One CROM (American Micro Products, Inc. 1984) contains many parametric and nonparametric tests and is powerful enough to handle relatively large data sets. Such devices make statistical analyses of fire management data routine.

Many statistical packages have been developed and are available for micro and mini-computers (e.g., StatSoft, Inc. 1987). Some packages include graphics capability, and many are available for several hundred dollars or less. Fire managers who anticipate the collection of large amounts of data for statistical manipulation are encouraged to investigate statistical packages that are available.

Mainframe statistical packages (Dixon 1985, SAS Institute Inc. 1985) are designed to handle very large data sets and complete an enormous number of statistical tests. These large machines are usually restricted to research institutions; however, fire managers should be aware that most colleges, universities, and experiment stations have access to mainframe computers. The use of such machines might be cost effective if used only when infrequent but large data sets must be manipulated.

C. Resource Management Considerations

1. It is essential to know what the questions are before sampling and data analysis can be designed to obtain answers. Sampling and data analysis must be objective driven. Further, objectives should be developed with sampling and data analysis in mind so that the objectives are reasonable, measurable, and lend themselves to analysis.

2. Sampling design and intensity (number of observations) should be determined **before** initiating any data collection to ensure sampling and analysis procedures are appropriate. The number of required observations depends on desired precision and confidence levels; for most management purposes it is usually adequate to sample within 20 percent of the mean at the 80 percent confidence level.

3. Experienced statisticians should be consulted **before** data are collected and **after** data are analyzed.

4. It is not necessary, nor feasible in most cases, to sample and analyze data from every community on every wild or prescribed fire. Usually it is better to do an adequate job on one community than an inadequate job on two or more communities. Further, it is often possible to design a series of prescribed fires with a sampling and data analysis scheme such that one fire or one stratum is emphasized and the remainder are spot checked. Biologically oriented statisticians can provide advice on how best to sample and analyze data when time and funding are constrained.

5. Inadequate sampling is often more expensive than excessive sampling; optimum sampling is usually the most cost effective.

6. Replicates are necessary to determine "sample error," and untreated "controls" are necessary to isolate fire effects from other effects.

7. After data are collected and analyzed, consider both statistical significance and biological significance; it is possible to establish statistical significance that has no biological significance.

8. Place measured trust in results of data analysis. An unexpected or undesired result is not a valid reason for discarding results and "massaging" the data. Data analysis should be used to enhance understanding as well as provide support.

9. It is tempting to draw inappropriate conclusions from analyzed data. Caution is advised.

D. Methods to Monitor Fire Effects

1. The appropriate sample size for each data set should be determined using the method described in B.1, or another statistically acceptable method. A more detailed description of this method to determine proper sample size is given in Norum and Miller (1984).

2. The t-test described in B.2 is especially useful for comparing the means of several treatments, such as burned vs. unburned, or fall burned vs. spring burned. Means that are helpful to compare include "production," cover, and density. The test assumes that identical treatments were applied; therefore, the comparison of spring burned vs. fall burned treatments should be approached with caution.

3. Chi-square is a nonparametric test that is especially useful for analyzing counts of binary data; such data fall into two convenient categories, such as alive or dead, or sprouted or not sprouted.

4. A statistician should be consulted for additional data analysis methods. Biometricians and statisticians who can provide assistance may be located at agency offices, national and regional service centers such as the BLM Service Center at Denver, experiment stations and universities.

E. Summary

Statistical analysis of data and interpretation of results are helpful for understanding fire effects and provide an essential tool for the decision making process. Calculation of the appropriate sample size is essential, and is based on desired precision and confidence levels.

The t-test for paired plots, and chi-square analysis of counts, are particularly useful for understanding fire effects. Other, more sophisticated techniques may require assistance of a statistician.

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CHAPTER XII - COMPUTER SOFTWARE

By Melanie Miller

A. Introduction

Many packaged computer programs have been developed that can provide information useful for managing or interpreting fire effects. Some programs are accessible on mainframe computers, while others are available on floppy disks that can be loaded onto personal computers. Additional information about programs described here can be obtained by reading the referenced publications, or contacting specific offices, where indicated.

B. Weather Analysis

Weather records can be used to manage fire effects by helping to establish seasons and parameters for appropriate fire prescriptions, and to document prefire weather trends and weather conditions at the time of the fire. Records of postfire weather can be used to make inferences about causes for observed fire effects. Long-term records are required to establish a statistical basis for occurrence of seasonal trends in elements such as temperature or rainfall, to detect deviations from seasonal trends, or to document the likelihood of occurrence of specific sets of weather conditions, such as combinations of temperature and relative humidity.

1. Computerized Databases. Sources for data on which computerized searches and analyses can be performed are the network of Remote Automated Weather Stations, and the National Interagency Fire Management Integrated Database.

a. Remote Automated Weather Stations (RAWS). The Remote Automated Weather Station (RAWS) System is a program that provides current remotely sensed weather data from stations established on Federally administered lands (German 1988). The

RAWS network contains about 350 weather stations on BLM lands in the lower 48 States, as well as about 250 weather stations established on other agency lands. There are approximately 40 RAWS stations in Alaska. Over the next 5 years, approximately 60 to 100 additional RAWS stations will be established.

The RAWS system uses self-contained meteorological collection platforms and a mini-computer controlled satellite receiving station located at the National Interagency Fire Center (NIFC). The weather stations collect weather data, summarize it on an hourly basis, and then transmit data on a one hour or three hour basis to NIFC through the GOES satellite system. A computer at NIFC immediately distributes the weather data to all users on the Initial Attack Management System (IAMS), to the Weather Information Management System (WIMS) (see item 1.b. below), and to the National Weather Service. BLM users access this "real-time" weather data through the IAMS computer located in most BLM District Fire Management offices. Other agency users acquire data through WIMS.

NIFC archives all weather data for permanent storage. A copy of this archived information is distributed quarterly and annually to the Desert Research Institute at the University of Nevada at Reno. Weather information can be obtained in a quarterly summary report for each station, and through specially requested reports and studies. BLM users request these reports and studies from BLM staff at NIFC, while other agency users obtain these data from the Desert Research Institute.

b. National Interagency Fire Management Integrated Database (NIFMID). The National Interagency Fire Management Integrated Database contains the historic fire weather information previously contained in the obsolete National Fire Weather Data Library. It is located at the National Computer Center - Kansas City (NCC-KC), managed by the U.S. Department of Agriculture. The library contains daily observations from all fire weather stations, collected at the time of peak burning conditions (1300 hours, local standard time) throughout the fire season. The Weather Information Management System database (WIMS), a replacement for AFFIRMS, stores the1300-hour observations from automated and manual fire weather stations, as well as 60 days of 24-hour observations from RAWS stations. The long-term historical weather database of NIFMID stores

1300-hour observations.

Access to NIFMID is available through computer software packages that reside in the computer library at the Kansas City Computer Center. In order to use these programs, users must establish an account. Once an account is opened, all access information is provided to the user. Telecom- munications packages on most computers can be used to communicate with this USDA computer. See item 2. Computer Programs, for descriptions of computer programs available through NCC-KC.

2. Computer Programs.

a. KCFAST. KCFAST is a program that facilitates use of data stored in NIFMID. KCFAST is a utility that assists the casual user of this database by removing the need to remember all of the commands required to extract and format weather data stored for a particular weather station. KCFAST itself does not perform analyses on data sets from the fire weather data library, but it makes it easy to transmit these data to a personal computer, where weather analysis can be performed. It facilitates operation of the other programs described in this section, as well as other software such as that used for fire planning. KCFAST is available in versions that operate on the U. S. Forest Service Data General system, as well as IBM compatible personal computers. To use the PC version, communication software is required that can transmit an ASCII file to a remote computer and log screen activity to a PC file (Bradshaw and Andrews 1990).

b. FIREFAMILY. Three different computer programs were consolidated into FIREFAMILY: FIRDAT, SEASON, and FIRINF. These programs use historic weather data to predict future fire management needs, and integrate fire management with other land management activities. The weather data used is that stored in the NIFMID (1.b., above), and FIREFAMILY software is on the USDA Kansas City computer. These programs are fully described in the publication by Main et al. (1988).

(1) FIRDAT. FIRDAT can combine up to 100 years of historical weather records with National Fire Danger Rating System (NFDRS) equations to produce frequency distributions and graphs of NFDRS indices and components. This can include the NFDRS calculated fuel moisture. FIRDAT can also produce lists of daily weather observations.

(2) SEASON. SEASON uses FIRDAT data to summarize variations in NFDRS inputs and fire danger severity during a fire season, and seasonal patterns of fire danger over many years. Fuel moisture values, fire danger indices, or fire behavior components can be presented in tabular and graphic form.

(3) FIRINF. FIRINF allows the analysis of the co-occurrence of any two NFDRS indices over 10-year periods.

c. PCFIRDAT. PCFIRDAT is a version of FIRDAT that has been rewritten for use on IBM compatible computers. Using the PC version of KCFAST, data are transferred from the NIFMID to a personal computer, and PCFIRDAT is then used to perform data analyses. PCFIRDAT, as well as PC versions of SEASON and FIRINF are in the final stages of development. Work is being performed by the California Department of Forestry.

d. PRESCRB. This program provides a climatological summary of specific fire weather occurrences. The program counts the occurrences of days on which all variables specified in a prescription are met, and gives the probable number of days in any year on which the prescribed conditions specified are likely to occur. The average number of days of occurrence of prescribed conditions during successive 10-day periods of the year is given. The average number of days in each burning period also can be obtained, giving the prescribed fire planner an idea of whether days meeting prescribed conditions are likely to occur singly, or in a series. Furman (1979) documents use of the PRESCRB program. An advantage of this program is that it can use weather data from other sources than NIFMID.

e. RXWTHR. RXWTHR (Prescribed Fire Weather) provides climatological summaries and co-occurrence frequencies of user selected fire weather and fire danger rating parameters (Bradshaw and Fischer 1981a, 1981b). The data base is the computerized fire weather records within NIFMD. Simultaneous occurrence of two or three of fifteen prescription parameters can be summarized, and shown in tables. For example, tables can include summaries of temperatures, two way co-occurrence tables for wind direction and wind speed, and three way co-occurrence tables for temperature, relative humidity, and wind speed. Once a user has obtained a feeling for the general pattern of occurrence of desired prescribed conditions, screening out those that have a low probability of occurring simultaneously, a more detailed analysis can be conducted using RXBURN. Please note that a sixteenth prescription parameter available for analysis in the program is duff moisture. This value is based upon a duff moisture model that was offered on an experimental basis in RXWTHR and RXBURN. This model does not provide accurate results, and the duff moisture output produced by these two programs should not be used.

f. RXBURN. RXBURN (Prescribed Fire Conditions) provides an analysis of the frequency of occurrence of a set of prescription conditions, also using the NIFMID as a database. Up to 15 parameters can be used in a single prescription. Users define a preferable range of prescribed conditions, and a broader range of conditions that is still acceptable. Output tables include a summary table of the percentage of weather conditions that are preferable, acceptable, and unacceptable; a table that shows frequency of occurrence of preferable, acceptable, and unacceptable conditions in each successive 10-day period, and by month; the number of successive days that prescribed conditions have occurred in each 10-day period and each month; and the probability of meeting the prescription 1, 2, and 3 days in the future for each month. As discussed under 2.d., RXWTHR, the duff moisture model that provides a basis for parameter 16 is inaccurate; this parameter should not be used.

There are two limitations to the use of RXWTHR and RXBURN. Weather observations are rarely recorded for more than the five months of the year that are the normal "fire season," and many prescribed fires are staged before and after this period. The single observation per day that must represent the entire day's weather is taken during average worst case conditions, 1300 hours (Standard Time), southwest aspect, midslope, and open canopy. This may poorly represent the weather at the time of the day when a prescribed fire would be implemented.

g. Other. An additional set of climatological software is described by Bradshaw and Fischer (1984). Eight computer programs for extensive climatic summaries of weather variables, temperature, relative humidity, wind, and precipitation, records are available. Five basic climatology programs analyze NIFMID records by 10-day periods and by month. Three averaging programs adjust results from the climatology programs to smooth variances caused either by short periods of record or incomplete station data.

C. Fire Behavior

1. BEHAVE. BEHAVE is a set of interactive, user friendly computer programs that are used for estimating behavior of wild and prescribed fires. BEHAVE is an integral part of the Fire Behavior Prediction System that is used by Fire Behavior Analysts to estimate fire potential under various fuels, weather, and topographic situations (Burgan and Rothermel 1984). BEHAVE predicts the behavior of a steady state fire advancing in surface fuels along a front. It cannot be used to estimate long-term fuel burnout, non-flaming combustion, or extreme fire behavior. The BEHAVE system consists of two subsystems: BURN and FUEL.

a. FUEL subsystem. The FUEL subsystem has two programs: NEWMDL and TSTMDL (Burgan and Rothermel 1984). NEWMDL ("NEW MODEL") is used to construct fuel models for specific application when the existing 13 stylized fuel models in the Fire Behavior Prediction System do not adequately describe fuels at a particular location. TSTMDL ("TEST MODEL") is used to test the fuel models developed in NEWMDL. The FUEL subsystem is rarely used except by trained Fire Behavior Analysts or for research purposes. Please note that these fuel models are not the same as those used in the National Fire Danger Rating System.

b. BURN subsystem. The BURN subsystem is frequently used on wild and prescribed fires. This subsystem has three components, FIRE 1, FIRE 2, and RXWINDOW (see section C.2.). FIRE 1 contains the wildland fire behavior prediction model developed by Rothermel (1972). It includes modules that allow prediction of fire behavior (DIRECT and SITE), fire growth (SIZE), containment requirements (CONTAIN), and spotting distance (SPOT). Fire effects on the tree overstory are predicted in SCORCH and MORTALITY, described in sections D.1.a., and D.1.b., this chapter. FIRE 2 allows calculation of fine dead fuel moisture (MOISTURE), the probability of ignition (IGNITE), and relative humidity (RH). Contents and operation of the BURN Subsystem are described in Andrews (1986) and Andrews and Chase (1989). Users require training for optimum application of this software to wildland fire situations.

2. RXWINDOW. RXWINDOW, a component of the BURN subsystem in BEHAVE, essentially runs DIRECT backwards, enabling prescribed fire planners to obtain detailed windows of required fuel moisture and wind conditions based upon desired fire behavior (Andrews and Bradshaw 1990). Desired fire behavior such as flame length or rate of fire spread are entered, and the program calculates which combinations of fuel and weather parameters would result in the fire behavior specified. The program uses one of the 13 standard fire behavior fuel models, or a custom model developed in the FUEL Subsystem. Other input values include slope of the burn area and exposure of fuels to the wind. The user can optionally set limits on 1-hour, 10-hour, 100-hour, live woody, and live herbaceous moisture content, and effective windspeed.

a. FIRE. The FIRE module generates tables that display combinations of effective windspeed and weighted fuel moisture that result in the desired fire behavior. It indicates those pairs of wind and dead fuel moisture that yield a fire within the fire behavior prescription. For those fuel models where live fuel moisture is a component, the program prints ranges of live fuel moisture for each appropriate wind and dead fuel moisture pair. **b. WIND.** The WIND module requires input of site description parameters, and whether the prescribed fire will be a headfire, backfire, or flanking fire. Based on a constant slope, the program prints a table of 20-foot windspeeds coming from different directions with respect to slope that will produce a range of effective windspeeds. WIND can use either effective windspeeds identified in the FIRE output table or windspeeds selected by the user.

c. MOISTURE. The MOISTURE module of RXWINDOW displays ranges of moisture contents for the 10-hour fuel size class that results in a specific weighted fuel moisture, for a given 1-hour fuel moisture. MOISTURE also produce a table that shows for a given herbaceous moisture content, the range of woody fuel moisture that results in a specific weighted live fuel moisture.

3. Availability. Contact agency fire management staff for information on obtaining access to FIRE 1, NEWMDL, and TSTMDL. A copy of the complete BEHAVE program (including FIRE 2 and RXWINDOW) that runs on an IBM compatible computer can be purchased through a government contract at a low cost. The program disks will become available through the Publications Management System at the National Interagency Fire Center.

D. Fire Effects

1. Models within BEHAVE. There are few fire effects that relate directly to fire behavior, the activity of the flaming front of the fire. However, two programs within the BEHAVE system predict two effects, crown scorch height, and tree mortality, that can be directly or indirectly related to fire behavior. Access to both of these programs is through the BEHAVE system, described in section C. of this chapter.

a. SCORCH. A module of the FIRE 1 program of BEHAVE, SCORCH predicts lethal crown scorch heights from flame length, ambient air temperature, and midflame windspeed. This model estimates the maximum height in the convection column at which the lethal temperature for live crown foliage is reached, assumed to be 140 F (60 C). Scorch heights can be estimated during a prescribed fire operation, based on observations of the flame length, and ignition can be adjusted accordingly if desired scorch heights are not being achieved. SCORCH can be run by linking it to outputs from DIRECT. A more detailed description of this model can be found in Andrews and Chase (1989).

The SCORCH model has several limitations. It was developed for flat ground, so should be used on slopes with care. The model may not be valid outside the range of conditions for which it was developed, with fireline intensities ranging from 19 to 363 Btu per foot per second, equivalent to flame lengths of 1.8 to 6.8 feet (0.5 to 2.1 meters). Air temperatures are 73 to 88 F (23 to 31 C), and midflame windspeeds are 1.5 to 3 miles per hour (3.4 to 4.8 kilometers per hour). Under these conditions, scorch heights ranged from 6.5 to 56 feet (2 to 17 meters). Also, this model considers the heat released by the flaming front of the fire, not from the long-term burnout of large fuels. If significant amounts of residual burnout of large diameter fuels is anticipated, expected or observed flame length resulting from this burnout can be entered directly, instead of using the flame length calculated by BEHAVE in DIRECT.

b. MORTALITY. Tree mortality is predicted by the MORTALITY module of BEHAVE, also located in the FIRE 1 program. The model was developed by Reinhardt and Ryan (1988b), and its use within the BEHAVE program is described in Andrews and Chase (1989). MORTALITY predicts the percentage of tree mortality from estimates of crown and bole damage for a specific species, as different species have varying abilities to survive a set amount of damage. Data on mortality was collected from the following species, which can be specified when running the model: western larch, Douglas-fir, western hemlock, Engelmann spruce, western red cedar, lodgepole pine, and subalpine fir. One can select one of these species to represent a species not listed if the bark thickness is similar. Inputs required to run this program are scorch height, tree height, crown ratio, and bark thickness, which is calculated from the species of tree and its diameter at breast height. Percentage of crown volume scorched is calculated from scorch height, tree height, and crown ratio. Bole damage is assumed to be proportional to bark thickness. The output is given in percent mortality. A 30 percent mortality means that 30 of 100 trees would be expected to die if subjected to the same fire, or that there is a 30 percent probability that any individual tree would die.

A linked run can be made from DIRECT to SCORCH to MORTALITY. Flame length can be calculated for a range of windspeeds in DIRECT. From these values, SCORCH will calculate a range of scorch height values, which provide one of the inputs to MORTALITY.

The model is limited by the assumption that the fire is of an average duration. Mortality may be under predicted if a fire of long duration occurs, caused by consumption of extremely dry duff or large diameter fuel. If fuel is very light or patchy, mortality may be over estimated.

2. First Order Fire Effects Model (FOFEM). The FOFEM program computes duff and woody fuel consumption, mineral soil exposure, fire-caused tree mortality, and smoke production for forest stands (Keane et al. 1990). A current version of the program is being tested by field users. Future versions will allow prediction of soil heating and successional changes. Default input values are derived from fuel models provided for natural and activity fuels by many forest cover types. For further information, contact the Fire Effects Research Work Unit at the Intermountain Fire Sciences Laboratory, Missoula, Montana.

3. CONSUME. CONSUME is a PC based software program that predicts the amount of fuel consumption on logged units based on weather data, the amount and moisture content of fuels, and other factors that describe a burn unit (Ottmar et al. 1993). The program allows a resource manager to determine when and where to conduct a prescribed fire to achieve desired objectives, while reducing impacts on other resources. CONSUME can be used for most broadcast and understory burns on forest lands where the dead woody fuels are relatively homogeneous. The program applies to western forests dominated by Douglas-fir, western hemlock, red alder, lodgepole pine, or mixed conifer species. Program disks and the users guide are available through the Publications Management System at NIFC.

4. Fire Effects Information System. The Fire Effects Information System (FEIS) is a computerized information storage and retrieval system that contains detailed information about the effects of fire on specific plants, plant communities, and wildlife species. Plant species information, for example, is organized into sub-categories of distribution and occurrence; value and use; botanical and ecological characteristics; fire ecology; and fire effects. Descriptions of the results of fire effects case studies are included if available. The FEIS is not a typical bibliographic data base that lists citations with key words and abstracts. The Fire Effects System provides information in a text format, providing reviews of the key facts in the literature, summarized into appropriate sub-categories. Numerical codes in the text refer to citations listed in a references section included in each species write-up. Where conflicting information about plant response has been found, interpretations are made if differences in season, burning conditions, or ecotype, for example, can explain why observed variations occurred. Information about wildlife species and ecosystems is handled in a similar fashion.

The system was developed by the U.S. Forest Service Intermountain Fire Sciences Laboratory in Missoula, Montana, and money for development of the prototype data base was provided by the BLM. Many plant species of ecosystems managed by the Bureau are presently in the system. Interagency funding is being used to expand the database to include species of the eastern U.S. and Alaska, as well as additional species of the western U.S.

The Citation Retrieval System (CRS) is an associated program that contains all of the references used in compiling species and plant community information for the FEIS. The CRS can be searched for a specific citation, author, or key word. It can prepare a bibliography from a list of citation index numbers selected by the user from a species write-up.

The FEIS and CRS are available on the Forest Service Intermountain Region computer in Ogden, Utah. Access is through the Forest Service Data General System, or by phone modem from any personal computer with software that allows communication with a Data General computer. There is no cost for PC users other than telephone line charges. Data can be saved to a temporary file on the main frame computer, and sent over phone lines to the user's computer. Department of Interior employees can contact their national fire management offices to obtain access information. U.S. Forest Service employees can obtain assistance from their regional FEIS coordinator. States provide information through their State FEIS coordinator.

E. Smoke Modeling.

1. SASEM. The Simple Approach Smoke Estimation Model (SASEM) is a tool for the analysis of smoke dispersion from prescribed fires (Sestak and Riebau 1988). It is a screening model, in that it uses simplified assumptions and tends to over predict impacts, yielding conservative results. If violations of air quality standards are not predicted by SASEM, it is unlikely that they will occur. Inputs to the model include basic descriptions of the fuels, such as type and loading, expected fireline intensity, and expected burn duration. Windspeed and direction, dispersion conditions, and average mixing height are considered, as well as distance and direction of the fire from sensitive receptors. The model calculates fuel consumption and particulate emission factors from fuel loading and expected fireline intensity. Model outputs include maximum particulate concentration and the distance from the fire at which it will occur, ranges of distances from the fire at which any primary or secondary particulate standards would be violated, and the reduction in visual range at selected receptors. Outputs are given in tabular fashion for a range of dispersion and windspeed conditions.

SASEM is extremely simple to use, and requires no data inputs that are not normally acquired as part of the prescribed fire planning process. The program is available on floppy disks for operation on IBM compatible machines. For further information, contact agency air resource or fire management specialists, or the air quality staff at the Environmental Science and Technology Center, National Biological Survey, Fort Collins, Colorado.

2. TSARS. The following discussion is taken from Sestak (et al. 1991). The Tiered Smoke/Air Resources System, TSARS, allows fire management field officers to test fire prescriptions for smoke management problems. Models with a high degree of rigor can be used to solve more complex problems, however, higher user proficiency is required.

a. Existing components. Models currently in the system include SASEM, explained in item E.1. above, EPM, and VALBOX.

(1) The Emission Production Model, EPM, is a more elaborate model of heat and particulate production than SASEM. Originally designed for forest fuels, particularly logging slash, data are presently being collected to broaden the model to other fuel types, particularly rangeland fuels.

(2) VALBOX models an airshed in complex terrain. Air in a mountain valley is divided into a series of connecting boxes, with dimensions calculated from topographic map data. This model best describes conditions when an inversion exists and air is stagnant.

b. Proposed components. BEHAVE, described in Section C. of this chapter, when added to the TSARS system, will expedite the running of EPM and SASEM because many of their input values are contained in the standard fire behavior fuel models used in BEHAVE. Use of these models together will allow consideration of smoke impacts when developing prescribed fire prescriptions.

TAPAS, the Topographic Air Pollution Analysis System, is a set of meteorological and pollution dispersion models suitable for use with multiple emission sources in complex terrain. Two models contained in TAPAS, WINDS and CITPUFF, will be specialized in the TSARS program for use in prescribed fire planning. WINDS is a two dimensional wind field model. A three dimensional wind model in TAPAS can be used by if elevation grid databases are created, information that is generally available in in Geographic Information Systems.

Wind fields created by the two or three dimensional models can be used with a final proposed component of TSARS. CITPUFF approximates the dispersion of a pollutant as it follows a path across a simulation area. The emission information required by this model would be provided by SASEM or EPM emission calculations.

It is intended that TSARS be available on the second generation IAMS system, and also on IBM compatible personal computers. For more information, contact air quality staff, Environmental Science and Technology Center, National Biological Survey, Fort Collins, Colorado.

F. Library Services

The literature search services maintained by Federal Libraries are valuable sources of computerized information helpful for managing fire effects. The Bureau of Land Management Library at the Denver Federal Center, for example, has the capability of making on-line searches of several hundred data bases that include periodicals, books, reports, and other publications. Some data bases provide abstracts along with full citations. The user works with a Library staff person by defining the kind of information desired, as well as specifying key words to be used in the search. Bibliographies can be requested by subject area, author, report number, or other category. The library can also provide copies of articles, and loan books in their collection and through inter-library loan. Any BLM employee can contact the Library at the BLM Service Center in Denver for assistance. The phone number is 303/236-6646.

The Alaska Resources Library provides a full range of library services to all Federal employees, particularly in the natural resources field. The Library is located in the Federal Building in Anchorage, where it is administered by the BLM. The phone number is 907/271-5025; FAX is 907/271-5965.

The Department of the Interior Natural Resources Library provides a full range of library services to USDI employees in response to telephone and written requests. They are located in the Main Interior Building, Washington, D.C.; their phone number is 202/208-5815.

National Park Service employees can contact the NPS Service Center at Harper's Ferry, Virginia or Denver for library assistance.

The phone number at Harper's Ferry is 304/535-6371; Denver is 303/969-2100.

U. S. Forest Service employees can obtain a full range of library services through FS INFO, available to them on the Data General System through the Information Center process. Both Forest Service Research and National Forest System Employees can seek assistance from the FS INFO center located in at the Forest and Range Experiment Station in their geographic region.

G. Summary

Computer technology and applications are developing so quickly that any list of software is incomplete as soon as it is published. Specialized computer programs, called expert systems, may be available in the next few years. Expert systems are being developed or planned that can assist in the development of fire prescriptions to meet specific resource objectives, and to achieve specific fire effects. Agency fire management and air quality specialists can be contacted for information about future computer software development.

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GLOSSARY OF TERMS

- A -

absolute value: the absolute value represents the distance that a positive or negative number is from zero, when numbers are arrayed on a line with negative numbers to the left of zero and positive numbers to the right of zero. The absolute value of a positive number is the number itself, whereas the absolute value of a negative number is the opposite (positive) number (Batchelet 1976).

accelerated erosion: erosion much more rapid than normal, natural, or geologic erosion, primarily as a result of the influence of the activities of humans, or, in some cases, of other animals or natural catastrophes that expose bare surfaces, for example, fires.

accuracy: the closeness of a measured or computed value to its true value. Accuracy cannot be determined from a sample, and usually remains unknown. (See precision.)

active crown fire: a fire in which a solid flame develops in the crowns of trees, but the surface and crown phases advance as a linked unit dependent on each other.

active layer: soil layer that overlies permafrost that thaws every summer (Viereck and Schandelmeier 1980).

activity fuels: fuels resulting from, or altered by, forestry practices such as timber harvest or thinning, as opposed to naturally created fuels. (See natural fuels.)

aeolian (eolian): movement of material, such as soil, through wind action.

aerial fuels: the layer of fuels that is above the surface fuels, including living tree and shrub crowns, mosses, lichens, vines, and dead branch material.

age class: classes that define the ages of individuals in discrete units, such as 0 to 5 years, or 6 to 20 years.

algal bloom: proliferation of living algae on the surface of lakes, streams, or ponds that is stimulated by nutrient, especially nitrogen or phosphate, enrichment.

alkaline soil: any soil with a pH value greater than 7.0. Often used interchangeably with "basic soil."

allelopathy: inhibition by a plant of the germination, establishment, and growth of seedlings.

ammonification: the biochemical process whereby ammoniacal nitrogen is released from nitrogen containing organic compounds.

analysis of covariance (ACOVA): test that combines regression with analysis of variance. In general, variation in *y* that is associated with *x* is removed from the error variance, which results in more precise estimates from more powerful tests. An example in fire management is the case where plants of different sizes are measured before burning; because plant size may affect postburn response, the effect of plant size is "controlled" so that differences due to burning will be apparent.

analysis of variance (ANOVA or **AOV):** test used when statistical inferences are to be made about more than two means. Test can "control" one or more sources of variation, depending on model and experimental design.

anion: negatively charged ion.

annual plant: a plant completing its life cycle in a year or less (Benson 1967).

Aridisol: soil with pedogenic horizons, low in organic matter, that are never moist as long as three consecutive months. They also have one or more of the following diagnostic horizons, including argillic, natric, cambic, calcic, petrocalcic, gypsic, or salic, and may have a duripan.

Aridisols are approximately equal to Desert, Reddish Desert, Sierozem, Solonchak, some Brown and Reddish Brown, and associated Solonetz soils of the pre-1966 classification scheme.

arithmetic mean: the mean (or average) of sample data; it provides an unbiased estimate of the parametric mean; designated by x. (NOTE: There are other kinds of means, such as harmonic, geometric, and parametric.)

arrangement: see fuel arrangement.

ASCII: American Standard Code for Information Interchange. A code for transmitting information asynchronously on local and long distance communication lines; representing a standard set of letters, numbers, and control characters.

attributes: those variables that cannot be measured, but must be expressed qualitatively. (See variable.)

available fuel: the portion of the total fuel on the site that would actually burn under a given set of environmental conditions.

avoidance: a smoke emission control strategy that considers meteorological conditions when scheduling prescribed fires in order to avoid incursions into smoke sensitive areas (Mathews et al. 1985).

axil: the upper side of the point where a leaf meets a stem, or a branch meets another branch or the main stem of a plant.

axillary bud: a bud in a leaf axil.

- B -

backing fire: a fire, or that part of a fire, spreading or set to spread into the wind, or down a slope.

basal cover: the vertical projection of the root crown onto the ground. (See cover and foliar cover.)

BEHAVE: a system of two interactive computer programs for modelling fuel and fire behavior.

bias: systematic distortion that may be due to measurement error, method of selecting the sample,

etc. An example is the use of an uncalibrated balance that consistently overestimates mass by 10 grams, or neglecting to subtract tare weight (weight of the container) from packaged samples.

biennial plant: a plant that completes its life cycle in two years. Biennial plants usually produce only

basal leaves above ground the first year and both basal leaves and flowering stems the second (Benson 1967).

broadcast burning: allowing a prescribed fire to burn over a designated area within well-defined boundaries for reduction of fuel hazard, as a resource management treatment, or both.

Btu: British thermal unit. The amount of heat needed to raise the temperature of one pound of water (one pint) one degree Fahrenheit.

bud: a vegetative growing structure at the tip of a stem or branch with the enclosing scale leaves or

immature leaves; a young flower bud that has not yet opened. A vegetative bud may also be located along the surface of roots or rhizomes, or buried in woody stem or root tissue (Benson 1967).

bud primordia: a cluster of plant cells with the physiological potential to develop into a bud or actively growing shoot.

bulb: an underground bud covered by fleshy scales, the coating formed from the bases of leaves (Benson 1967).

bulk density: weight per unit volume. For fuels, this is usually expressed as pounds per cubic foot; for soils, grams per cubic centimeter.

burl: a mass of woody tissue from which roots and stems originate, and which is often covered with dormant buds (James 1984).

burn severity: a qualitative assessment of the heat pulse directed toward the ground during a fire. Burn severity relates to soil heating, large fuel and duff consumption, consumption of the litter and organic layer beneath trees and isolated shrubs, and mortality of buried plant parts.

- C -

cambium: a layer of dividing plant cells which add during each growing season a layer of woody material (largely xylem) on their inner side toward the center of the stem or root and a layer of bark (phloem and associated tissues) on the outer side (Benson 1967).

carbohydrates: starches and sugars manufactured by a plant and used to provide energy for metabolism, and structural compounds for growth (Trlica 1977).

carrier fuels: the fuels that support the flaming front of the moving fire.

cation: positively charged ion. Common soil cations include calcium, magnesium, sodium, potassium, and hydrogen.

caudex: a largely underground stem base which persists from year to year and each season produces leaves and flowering stems (Benson 1967).

chain: unit of measure in land survey, equal to 66 feet (20 meters) (80 chains equal one mile). Commonly used to report fire perimeters and other fireline distances, chains can be easily converted to acreage (e.g., 10 square chains equal one acre).

Class 1 Area: geographic areas designated by the Clean Air Act where only a very small amount or increment of air quality deterioration is permissible. Class 1 Areas include specified National Parks, Wilderness Areas, and certain Indian reservations.

clastic: being able to readily break into small fragments or pieces.

climax: the highest ecological development of a plant community capable of perpetuation under the prevailing climatic and edaphic conditions (Range Term Glossary Committee 1974).

clone: a group of individuals propagated vegetatively from a single individual of seedling origin (Barnes 1966 in Jones 1985). Individuals in a clone are genetically the same plant.

colonizer: species that establish on a burned (or otherwise denuded) site from seed (Stickney 1986).

combustion: consumption of fuels by oxidation, evolving heat, flame, and/or incandescence.

combustion efficiency: the relative amount of time a fire burns in the flaming phase of combustion, as compared to smoldering combustion. A ratio of the amount of fuel that is consumed in flaming combustion compared to the amount of fuel consumed during the smoldering phase, in which more of the fuel material is emitted as smoke particles because it is not turned into carbon dioxide and water.

confidence level: the percentage confidence that a statement is true. If data are normally distributed about an average value, the statement 'within 10 percent of the mean at the 80 percent confidence level' would indicate that a sample is likely to be within 10 percent of the true average value of the population 80 percent of the time.

continuity: see fuel continuity.

continuous variables: those variables which, at least theoretically, can assume an infinite number of values between any two fixed points. An example is fuel load, which theoretically can be anywhere between zero and infinity. (See discrete variables.)

control strategy: a way of implementing a prescribed fire that manages smoke output. (See avoidance, dilution, and emission reduction.)

convection column: the thermally induced ascending column of gases, smoke, water vapor, and particulate matter produced by a fire.

cookbook approach: to follow a particular procedure without deviation.

coordinated resource management: a process that directly involves everyone concerned with resource management in a given planning area.

corm: a bulb-like structure formed by enlargement of the stem base, sometimes coated with one or more membranous layers (Benson 1967).

cover: the area on the ground covered by the combined aerial parts of plants expressed as a percent of the total area. (See basal cover and foliar cover.)

criteria pollutants: those air pollutants designated by the Environmental Protection Agency as poten- tially harmful and for which ambient air standards have been set to protect the public health and welfare. The criteria pollutants are carbon monoxide, particulate matter, sulfur dioxide, nitrogen dioxide, lead, and ozone.

crown consumption: combustion of the twigs, and needles or leaves of a tree during a fire.

crown fire: a fire that advances by moving among crowns of trees or shrubs.

crown ratio: the ratio of live crown to tree height.

crown scorch: causing the death of tree foliage by heating it to lethal temperature during a fire, although the foliage is not consumed by the fire. Crown scorch may not be apparent for several weeks after the fire.

crown scorch height: the height above the surface of the ground to which a tree canopy is scorched.

crowning potential: a probability that a crown fire may start, calculated from inputs of foliage moisture content and height of the lowest part of the tree crowns above the surface.

- D -

data: the facts collected during observations; used as a plural noun, i.e., "data are," or "data were." (See datum.)

datum: a single fact collected during observation; the singular of "data." (See data.)

dead fuels: naturally occurring fuels without living tissue, in which the moisture content is governed almost entirely by absorption or evaporation of atmospheric moisture (relative humidity and precipitation).

decreaser species: plant species of the original vegetation that decrease in relative amount under overuse by grazing or browsing animals. Commonly termed decreasers.

degrees of freedom: the quantity n or n-1, where n is the number of observations (population or sample size) upon which a variance has been based; degrees of freedom is usually designated by the abbreviation "*df*."

density: the number of plants or parts of plants per unit area.

designated area: those areas identified as principal population centers or other areas requiring protection under state or federal air quality laws or regulations.

desired plant community: a plant community which produces the kind, proportion, and amount of vegetation necessary for meeting or exceeding the land use plan goals and activity plan objectives established for the site.

diffusion: the net movement of gas molecules from areas with higher concentration of that gas to areas with lower concentration.

dilution: a control strategy used in managing smoke from prescribed fires in which smoke concentration is reduced by diluting it through a greater volume of air, either by scheduling during good dispersion conditions or burning at a slower rate (Mathews et al. 1985).

disclimax: (disturbance climax) a stable plant community which is not the climatic or edaphic climax and which is perpetuated by man or his domestic animals (Odum 1966).

discrete variables: those variables that have only certain fixed numerical values, with no intermediate values possible in between; also known as discontinuous or meristic variables. An example is the number of offspring per litter, where only integers (whole numbers) are possible. (See continuous variables.)

diversity: the relative degree of abundance of wildlife species, plant species, communities, habitats, or habitat features per unit of area (Thomas 1979).

duff: the partially decomposed organic material of the forest floor that lies beneath the freshly fallen twigs, needles and leaves. The fermentation and humus layers of the forest floor (Deeming et al. 1977).

- E -

ecological condition (range): the existing state of the vegetation on a site compared to the natural potential (climax) plant community for that site. This term is used interchangeably with "range condition" and describes the deviation from the climax condition according to four arbitrary condition classes. Not synonymous with "forage condition" which does not relate to site potential.

ecological niche: the role or function a particular organism plays in the environment (Hanson 1962).

ecological site: a distinctive geographic unit that differs from other kinds of geographic units in its ability to produce a characteristic natural plant community. An ecological site is the product of all the environmental factors responsible for its development. It is capable of supporting a native plant community typified by an association of species that differs from that of other ecologic sites in the kind or portion of species or in total production.

ecology: the study of the interrelationships of organisms with one another and with the environment (Hanson 1962).

ecosystem: an interacting natural system including all the component organisms together with the abiotic environment (Hanson 1962).

ecotone: the area influenced by the transition between plant communities or between successional stages or vegetative conditions within a plant community (Thomas 1979).

edge: the place where plant communities meet or where successional stages or vegetative conditions within plant communities come together (Thomas 1979).

edge effect: the increased richness of flora and fauna resulting from the mixing of two communities where they join (Thomas 1979).

effective windspeed: a value that combines the speed of the wind with the additive effect of slope when a fire is burning up or across a slope.

emission: a release into the outdoor atmosphere of air contaminants such as smoke.

emission factor: the mass (weight) of particulate matter produced per unit mass of fuel consumed (expressed as grams per kilogram or pounds per ton).

emission inventory: a listing by source of the amounts of air pollutants discharged into the atmosphere.

emission reduction: a strategy for controlling smoke from prescribed fires that minimizes the amount of smoke output per unit area treated.

equilibrium moisture content: the moisture content that a fuel particle will attain if exposed for an indefinite period in an environment of specified constant temperature and humidity. When a fuel particle has reached its EMC, the net exchange of moisture between it and its environment is zero (Deeming et al. 1977).

eurytopic: having a wide range of suitable ecological conditions (Pennak 1964).

eutrophication: the process whereby water becomes excessively rich in nutrients and correspondingly deficient, at least seasonally, in oxygen. Often accompanied or followed by algal blooms.

exfoliation: the separation of concentric layers of rock from the original rock mass.

experimental design: the process of planning an experiment or evaluation so that appropriate data will be collected, which may be analyzed by statistical methods resulting in valid and objective conclusions. Examples include Completely Random Design, Randomized Block Design, Latin Square, Factorial Experiment, Split-Plot Design, and Nested Design.

experimental error: a measure of the variation which exists among observations on experimental units that are treated alike; "natural" variation.

- F -

feeder roots: small diameter roots that collect most water and nutrients for a plant, usually located near the soil surface.

fine fuels: small diameter fuels such as grass, leaves, draped pine needles, and twigs, which when dry, ignite readily and are rapidly consumed.

fire behavior: the manner in which a fire burns in response to the variables of fuel, weather, and topography.

fire intensity: see fireline intensity.

Fire Behavior Prediction System: a system that uses a set of mathematical equations to predict certain aspects of fire behavior in wildland fuels when provided with data on fuel and environmental conditions (Rothermel 1983).

fire regime: periodicity and pattern of naturally occurring fires in a particular area or vegetative type, described in terms of frequency, biological severity, and areal extent (Tande 1980).

fire severity: see burn severity.

fire spread model: a set of physics and empirical equations that form a mathematical representation of the behavior of fire in uniform wildland fuels (Rothermel 1972).

fire treatment: the use of prescribed fire to accomplish a specified objectives.

fire whirl: a spinning, vortex column of ascending hot air and gases rising from a fire and carrying aloft smoke, debris, and flame. Fire whirls range from a foot or two in diameter to small tornadoes in size and intensity. They may involve the entire fire area or only a hot spot within the area.

fireline intensity: the heat released per unit of time for each unit length of the leading fire edge. The primary unit is Btu per lineal foot of fire front per second (Byram 1959 in Albini 1976).

firing pattern: see ignition pattern.

firing technique: see ignition pattern.

first order fire effects (FOFE): the direct and immediate effects of fire.

flame length: the average length of flames when the fire has reached its full, forward rate of spread, measured along the slant of the flame from the midpoint of its base to its tip.

flaming phase: the phase of combustion in which gases distilled from fuels rapidly combine with atmospheric oxygen, producing visible flames.

FLPMA: the Federal Land Policy and Management Act of 1976 (Public Law 94-579, 90 Stat. 2743, 43 USC 1701).

foliar cover: the projection of all plant parts vertically onto the ground. (See cover, and basal cover.)

forb: a plant with a soft, rather than permanent woody stem, that is not a grass or grasslike plant.

forward rate of spread: the speed with which a fire moves in a horizontal direction across the landscape, usually expressed in chains per hour or feet per minute.

frequency of occurrence: a quantitative expression of the presence or absence of individuals of a species in a population; the ratio between the number of sample units that contain a species and the total number of sample units.

fuel: combustible plant material, both living and dead that is capable of burning in a wildland situation.

fuel arrangement: the spatial distribution and orientation of fuel particles within a fuel bed.

fuel bed: an array of fuels usually constructed with specific loading, depth, and particle size, to meet experimental requirements; also commonly used to describe the fuel composition in natural settings.

fuel bed depth: average height of surface fuels contained in the combustion zone of a spreading fire front.

fuel continuity: the degree or extent of continuous or uninterrupted distribution of fuel particles in a fuel bed, a critical influence on a fire's ability to sustain combustion and spread. This applies both to aerial fuels and surface fuels.

fuel depth: see fuel bed depth.

fuel loading: the weight of fuels in a given area, usually expressed in tons per acre, pounds per acre, or kilograms per square meter.

fuel model: a characterization of fuel properties of a typical field situation. A fuel model contains a complete set of inputs for the fire spread model.

fuel moisture content: the amount of water in a particle of fuel, usually expressed as a percentage of the oven dry weight of the fuel particle.

fuel size class: a category used to describe the diameter of down dead woody fuels. Fuels within the same size class are assumed to have similar wetting and drying properties, and to preheat and ignite at similar rates during the combustion process.

- G -

glowing phase: phase of combustion in which a solid surface of fuel is in direct contact with oxygen, and oxidation occurs, usually accompanied by incandescence, and little smoke production.

graminoid: grasslike plant, including grasses, sedges, rushes, reeds, and cattails.

gravimetric: of, or pertaining to, measurement by weight.

grazing management (strategy): the manipulation of the grazing use on an area in a particular pattern, to achieve specific objectives.

grazing pattern: dispersion of livestock grazing within a management unit or area.

ground fire: fire that burns the organic material in the soil layer (e.g. a "peat fire") and often also the surface litter and low-growing vegetation.

ground fuels: all combustible materials below the surface litter layer, including duff, tree and shrub roots, punky wood, dead lower moss and lichen layers, and sawdust, that normally support glowing combustion without flame.

growth stage: the relative ages of individuals of a species, usually expressed in categories such as seedlings, juvenile, mature, and decadent.

guild: see habitat guild.

- H -

habitat: the sum total of environmental conditions of a specific place occupied by a wildlife species or a population of such species

(Thomas 1979).

habitat guild: a group of species having similar ecological requirements and/or foraging strategies and therefore having similar roles in the community (Cooperrider et al. 1986).

heading fire: a fire front spreading, or ignited to spread with the wind, up a slope, or influenced by a combination of wind and slope.

heat content: the net amount of heat that would be given off if fuel burns when it is absolutely dry, noted as Btu per pound of fuel.

heat per unit area: total amount of heat released per unit area as the flaming front of the fire passes, expressed as Btu/square foot; a measure of the total amount of heat released in flames.

heavy fuels: dead fuels of large diameter (3.0 inches or larger) such as logs and large branchwood.

height: the vertical measurement of vegetation from the top of the crown to ground level.

herbivorous: feeding on plants; phytophagous (Cooperrider et al. 1986).

humidity: see relative humidity.

hydrophobicity: resistance to wetting exhibited by some soils, also called water repellency. The phenomena may occur naturally or may be fire-induced. It may be determined by water drop penetration time, equilibrium liquid-contact angles, solid-air surface tension indices, or the characterization of dynamic wetting angles during infiltration.

- I -

ignition method: the means by which a prescribed fire is ignited, such as hand-held drip torch, heli- torch, and backpack propane tanks.

ignition pattern: the configuration and sequence in which a prescribed fire is ignited. Patterns include, for example, spot fire, strip-head fire, and ring fire (same as ignition technique).

ignition technique: see ignition pattern.

illuviation: soil development process by which materials are translocated from an upper soil horizon and immobilized in a soil horizon at a lower level in the soil profile.

imbibe: to absorb liquid or moisture.

Inceptisol: soil that is usually moist and has pedogenic horizons of alteration of parent material but not of illuviation. Generally, the direction of development is not evident, or is too weak to classify in another soil order. Inceptisols are approximately equal to Ando, Sol Brun Acide, some Brown Forest, Low-Humic Gley, and Humic Gley soils of the pre-1966 classification scheme.

increaser species: plant species of the original vegetation that increase in relative amount, at least for a time, under overuse. Commonly termed increasers.

independent crown fire: a fire that advances in the tree crowns alone, not requiring any energy from the surface fire to sustain combustion or movement.

intensity: see fireline intensity.

interspersion: the intermixing of plant species and plant communities that provide for animals in a defined area (Thomas 1979).

introduced plant species: a species not a part of the original fauna or flora of an area.

invader species: plant species that were absent in undisturbed portions of the original vegetation and will invade under disturbance or continued overuse. Commonly termed invaders.

- J -

juxtaposition: the arrangement of stands of vegetation in space (Thomas 1979).

- K -

Kcal: a kilogram-calorie is the amount of heat needed to raise the temperature of one kilogram of water (1 liter) by 1 degree Celsius.

key forage species: forage species of particular importance in the plant community or which are important because of their value as indicators of change in the community.

- L -

ladder fuels: fuels that can carry a fire from the surface fuel layer into the aerial fuel layer, such as a standing dead tree with branches that extend along its entire length.

leach: removal of soluble constituents from ashes or soil by percolation of water.

life-form: a group of wildlife species whose requirements for habitat are satisfied by similar successional stages within given plant communities (Thomas 1979).

lignotuber: a mass of woody tissue from which roots and stems originate, which often covered with dormant buds (James 1984); same as root crown.

litter: the top layer of forest floor, typically composed of loose debris such as branches, twigs, and recently fallen leaves or needles; little altered in structure by decomposition. The L layer of the forest floor (Deeming et al. 1977). *Also* loose accumulations of debris fallen from shrubs, or dead parts of grass plants laying on the surface of the ground.

live fuel moisture content: ratio of the amount of water to the amount of dry plant material in living plants.

live fuels: living plants, such as trees, grasses, and shrubs, in which the seasonal moisture content cycle is controlled largely by internal physiological mechanisms, rather than by external weather influences.

live herbaceous moisture content: ratio of the amount of water to the amount of dry plant material in herbaceous plants, i.e., grasses and forbs.

live woody moisture content: ratio of the amount of water to the amount of dry plant material in shrubs.

- M -

mast: the fruit of trees suitable as food for livestock and wildlife (Ford-Robertson 1971).

mean: see arithmetic mean.

meristem: growing points of grasses, from which leaf blade elongation occurs during active growing periods.

mesotopic: having an intermediate range of suitable ecological conditions.

mho: meter/kilogram/second unit of electrical conductance, equal to the conductance of a conductor in which a potential difference of one volt maintains a current of one ampere.

midflame windspeed: the speed of the wind measured at the midpoint of the flames, considered to be most representative of the speed of the wind that is affecting fire behavior.

millimho: a unit of electrical conductance, equal to 0.001 mho.

moisture content: see fuel moisture content.

moisture of extinction: the moisture content of a specific fuel type above which a fire will not propagate itself, and a firebrand will not ignite a spreading fire.

Mollisol: soil with nearly black, organic-rich surface horizons and high supplies of bases; they may accumulate large amounts of organic matter in the presence of calcium. They have mollic epipedons and base saturation greater than 50% in any cambic or argillic horizon and are approximately equal to Chestnut, Chernozem, Brunizem, Rendzina, some Brown, Brown Forest, and associated Solonetz and Groundwater Podzols of the pre-1966 classification scheme.

mosaic: the intermingling of plant communities and their successional stages in such a manner as to give the impression of an interwoven design (Ford-Robertson 1971).

muck: a highly decomposed layer of organic material in an organic soil (Buckman and Brady 1966).

mycorrhiza (pl. mycorrhizae): a mutually beneficial (symbiotic) association between a plant root and a fungus, that enhances the ability of the root to absorb water and nutrients.

- N -

National Fire Danger Rating System: a multiple index scheme designed to provide fire and land management personnel with a systematic means of assessing various aspects of fire danger on a day-to-day basis.

native species: a species which is a part of the original fauna or flora of the area in question.

natural fuels: fuels resulting from natural processes and not directly generated or altered by land management practices. (See activity fuels.)

NFDRS: see National Fire Danger Rating System.

niche: (habitat niche) the peculiar arrangement of food, cover, and water that meets the requirements of a particular species.

NIFMID: National Interagency Fire Management Integrated Database.

nonparametric tests: statistical testing techniques that are not dependent on a given distribution. (See parametric tests.)

normal distribution: a continuous frequency distribution whose graphic representation is a bell-shaped curve that is symmetrical about the mean, which by definition has a mean of 0 and a variance of 1. Many other types of distributions exist that have different shaped curves, such as hypergeometric, Poisson, and binomial.

number: the total population of a species or classification category in a delineated unit, a measure of its abundance.

nutrient: elements or compounds that are essential as raw materials for organism growth and develop ment, such as carbon, oxygen, nitrogen, and phosphorus. There are at least 17 essential nutrients.

- O -

obligate: restricted to a particular condition of life, as an obligate seeder, a plant that can only reproduce by seed.

off-site colonizers: plants that germinate and establish after a disturbance from seed that was carried from off of the site (Stickney 1986).

onsite colonizers: plants that germinate and establish after a disturbance from seed that was present on the site at the time of the disturbance (Stickney 1986).

one-hour timelag fuels: dead fuels consisting of dead herbaceous plant material and roundwood less than 0.25 inches (0.64 cm) in diameter, expected to reach 63 percent of equilibrium moisture content in one hour or less.

one-hundred hour timelag fuels: dead fuels consisting of roundwood in the size range from 1.0 to 3.0 inches (2.5 to 7.6 cm) in diameter, estimated to reach 63 percent of equilibrium moisture content in one hundred hours.

one-thousand hour timelag fuels: dead fuels consisting of roundwood 3.0 to 8.0 inches (7.6 to 20.3 cm) in diameter, estimated to reach 63 percent of equilibrium moisture content in one thousand hours.

organic matter: that fraction of the soil that includes plant and animal residues at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population.

organic soil: a soil with a percentage content of organic matter greater than about 20 to 25 percent (Buckman and Brady 1966).

- P -

packing ratio: the percentage of a fuel bed that is composed of fuel particles, the remainder being air space among the individual particles (Burgan and Rothermel 1984); the fuel volume divided by fuel bed volume.

palatability: the relish that an animal shows for a particular species, plant or plant part; how agreeable the plant is to the taste.

parameter: a variable which can be measured quantitatively; sometimes, an arbitrary constant; associated with populations. One of the unknown values that determine a model. (See statistic.)

parametric tests: statistical tests that are based on normal distributions. (See nonparametric tests).

particle size: the size of a piece of fuel, often expressed in terms of size classes.

particulate matter: any liquid or solid particles present in the atmosphere. Particulate matter diameter is measured in microns.

passive crown fire: a fire in the crowns of trees in which trees or groups of trees torch, ignited by the passing front of the fire. The torching trees reinforce the spread rate, but these fires are not basically different from surface fires.

peat: a deposit of slightly or non-decayed organic matter (Buckman and Brady 1966).

percolation: passage of liquid through a porous body, as movement of water through soil.

perennial plant: a plant that continues to grown year after year (Benson 1967). (See annual plant and biennial plant.)

permafrost: a short term for "permanently frozen ground"; any part of the earth's crust, bedrock, or soil mantle that remains below 32 F (0 C) continuously for a number of years (Brown 1970 in Viereck and Schandelmeier 1980). (See active layer.)

petroglyph: a type of rock art in which a design is pecked into stone.

pH: the negative logarithm (base =10) of the hydronium ion concentration, in moles per liter. It is a numerical measure of acidity or alkalinity on a scale of 1 to 14, with the value of 7.0 being neutral.

phenology: the relationship of the seasonal sequence of climatic factors with the timing of growth and reproductive phases in vegetation, such as initiation of seasonal growth, time of blooming, time of seed set, and development of new terminal buds (Daubenmire 1968b).

phreatophyte: a plant that derives its water from subsurfaces, typically having roots that reach the water table, and is therefore somewhat independent of precipitation. Obligate phreatophytes require this situation, whereas facultative phreatophytes merely take advantage it.

pictograph: a type of rock art in which a design is painted onto stone.

pile burning: burning of logging slash that has been arranged into individual piles. (See broadcast burning.)

PM_{10}: particles with an aerodynamic diameter smaller than or equal to a nominal ten micrometers.

$PM_{2.5}$: particles with an aerodynamic diameter smaller than or equal to a nominal 2.5 micrometers.

population: all possible values of a variable; the entire group that is examined. (See sample.)

precision: the closeness of repeated measurements of the same quantity. (See accuracy.)

preignition phase: preliminary phase of combustion in which fuel elements ahead of the fire are heated, causing fuels to dry. Heat induces decomposition of some components of the wood, causing release of combustible organic gases and vapors.

prescribed burning: controlled application of fire to wildland fuels in either their natural or modified state, under specified environmental conditions that allows the fire to be confined to a predetermined area, and produce the fire behavior and fire characteristics required to attain planned fire treatment and resource management objectives.

prescribed fire: an intentionally or naturally ignited fire that burns under specified conditions that allow the fire to be confined to a predetermined area and produce the fire behavior and fire characteristics required to attain planned fire treatment and resource management objectives.

prescription: a written statement defining the objectives to be attained as well as the conditions of temperature, humidity, wind direction and speed, fuel moisture, and soil moisture, under which a fire will be allowed to burn. A prescription is generally expressed as acceptable ranges of the prescription elements, and the limit of the geographic area to be covered.

prevention of significant deterioration: a provision of the Clean Air Act with the basic intent to limit degradation of air quality, particularly in those areas of the country where the air quality is much better than standards specified in the Law.

probability: a measurement that denotes the likelihood that an event occurred simply by chance.

probability of ignition: the chance that a firebrand will cause an ignition when it lands on receptive fuels.

productivity: weight of dry matter produced in a given period by all the green plants growing in a given space (Daubenmire 1968b).

PSD: see prevention of significant deterioration.

pyrolysis: the thermal or chemical decomposition of fuel at an elevated temperature. This is the pre- ignition phase of combustion during which heat energy is absorbed by the fuel that, in turn, gives off flammable tars, pitches, and gases.

- R -

ramet: an individual member of a clone. For example, every individual stem in an aspen clone is a ramet.

random: the assignment of treatments to experimental units, or the selection of samples, such that all units or samples have an equal chance of receiving the treatment being estimated. It serves to assure unbiased estimates of treatment means and experimental error.

rate of spread: see forward rate of spread.

RAWS: see Remote Automated Weather Station.

reaction intensity: the rate of heat release, per unit area of the fire front, expressed as heat energy/area/time, such as Btu/square foot/minute, or Kcal/square meter/second.

regeneration: see vegetative regeneration.

regional haze: atmospheric haze over a large area with no attributable source.

relative frequency: see frequency of occurrence.

relative humidity: the ratio, in percent, of the amount of moisture in a volume of air to the total amount which that volume can hold at the given temperature and atmospheric pressure. Relative humidity is a function of the actual moisture content of the air, the temperature, and the atmospheric pressure (Schroeder and Buck 1970).

Remote Automatic Weather Station (RAWS): a self contained meteorological platform that automatically acquires, processes, and stores local weather data for subsequent transmission through a satellite to an earth receiving station.

reproduction: see vegetative reproduction.

residence time: the time required for the flaming zone of the moving front of a fire to pass a stationary point; the total length of time that the flaming front of the fire occupies one point.

residual colonizers: plants that germinate after a disturbance from seed that was present on the site (Stickney 1986).

respiration: oxidation of food in living cells, with the resulting release of energy; part of the energy is transferred to other compounds and some is used in the activation of certain cell processes (Meyer et al. 1973).

rhizome: a horizontal plant stem, growing beneath the surface, and usually covered with dormant buds.

root crown: a mass of woody tissue from which roots and stems originate, and which are often covered with dormant buds (James 1984); same as lignotuber.

running crown fire: a fire moving in the crowns of trees, dependent upon, or independent from the surface fire.

- S -

sample: part of a population; that portion of the population that is measured.

sample size: the number of items or observations in a sample; usually denoted by lower case letter n.

SASEM: Simple Approach Smoke Estimation Model (SASEM), a computer model for the analysis of smoke dispersion from prescribed fires. It is a screening model, in that it uses simplified assumptions and tends to over predict impacts, yielding conservative results.

second order fire effects (SOFE): the indirect effects of fire treatment that occur over the longer term.

seedbank: the supply of viable seeds present on a site. Seeds include those recently dispersed by plants, long-lived seeds buried in organic and soil layers, or those stored in cones in a tree canopy.

semi-serotinous: cones of coniferous trees that open and release their seeds over a period of years (Zasada 1986).

senescence: period of declining productivity after the period of most active growth, referred to both in terms of the seasonal life cycle of a plant, and the total life of a perennial plant.

seral: pertaining to a succession of plant communities in a given habitat leading to a particular climax association; a stage in a community succession (Cooperrider et al. 1986).

sere: the stages that follow one another in an ecological succession (Hanson 1962).

serotiny: storage of coniferous seeds in closed cones in the canopy of the tree. Serotinous cones of lodgepole pine do not open until subjected to temperatures of 45 to 50 C (113 to 122 F), causing the melting of the resin bond that seals the cone scales.

severity: see burn severity.

short-life species: a plant that grows several years before being replaced by a species more adapted to the changing site conditions.

simulation: a realistic visual portrayal which demonstrates the perceivable changes in landscape features caused by a proposed management activity. This is done through the use of photography, art work, computer graphics and other such techniques.

sinter: clustering of clay particles that occurs when pottery is fired.

SIP: see State Implementation Plan.

slash: concentrations of wildland fuels resulting from human activities such as logging, thinning, and road construction, and natural events such as wind. Slash is composed of branches, bark, tops, cull logs, uprooted stumps, and broken or uprooted trees.

smoldering phase: a phase of combustion that can occur after flames die down because the reaction rate of the fire is not high enough to maintain a persistent flame envelope. During the smoldering phase, gases condense because of the cooler temperatures, and much more smoke is produced than during flaming combustion.

soil structure: the combination or arrangement of primary soil particles, units, or peds. Examples include platy, prismatic, columnar, blocky, angular blocky, subangular granular, and crumb.

soil texture: the relative proportions of the various soil separates, primarily sand, clay, and silt. Subdivisions of the three basic separates, such as very fine sand, are often used.

spall: disintegration of a rock by breaking away of an outer layer.

species composition: a term relating the relative abundance of one plant species to another using a common measurement; the proportion (percentage) of various species in relation to the total on a given area.

species richness: a measurement or expression of the number of species of plants or animals present in an area; the more species present, the higher the degree of species richness (Thomas 1979).

spot fire: fire caused by flying sparks or embers outside the perimeter of the main fire.

spot forecast: a customized prediction of atmospheric conditions at a specific site that is issued by the National Weather Service, usually requested in connection with a wildfire incident or a prescribed fire.

spot weather forecast: see spot forecast.

spotting: production of burning embers in the moving fire front that are carried a short distance ahead of the fire, or in some cases are lofted by convective action or carried by fire whirls some distance ahead.

standard deviation: a measure of the variation, or spread, of individual measurements; a measurement which indicates how far away from the middle the statistics are; usually denoted by the lower case s for sample data; mathematically equal to the square root of variance.

State Implementation Plan: a plan that describes how a State intends to achieve Federal and State standards relative to the Clean Air Act, usually containing State regulations related to maintenance of air quality.

statistic: the number that results from manipulating raw data according to a specified procedure; associated with samples. (See parameter.)

statistics: the scientific study of numerical data based on natural phenomena.

stenotopic: having a narrow range of suitable ecological conditions (Pennak 1964).

stochastic: of, or pertaining to, randomness.

stolon: a branch of a plant which grows along the surface of the ground and produces plants and roots at intervals.

structure (vegetative): the form or appearance of a stand; the arrangement of the canopy; the volume of vegetation in tiers or layers (Thomas 1979).

succession: the process of vegetational development whereby an area becomes successively occupied by different plant communities of higher ecological order (Range Term Glossary Committee 1974).

successional change: see succession.

sum: the amount obtained by adding numbers or quantities; total; usually denoted by an upper case Greek sigma, .

surface area to volume ratio: the ratio between the surface area of an object, such as a fuel particle, to its volume. The smaller the particle, the more quickly it can become wet, dry out, or become heated to combustion temperature during a fire.

surface fire: fire that burns surface litter, dead woody fuels, other loose debris on the forest floor, and some small vegetation.

surface fuels: fuels that contact the surface of the ground, consisting of leaf and needle litter, dead branch material, downed logs, bark, tree cones, and low stature living plants.

survivors: plant species with established plants on the site that can vegetatively regenerate after the fire (Stickney 1986).

- T -

TAC: total available carbohydrates.

ten-hour timelag fuels: dead fuels consisting of roundwood 0.25 to 1.0 inches (0.6 to 2.5 cm) in diameter, estimated to reach 63 percent of equilibrium moisture content in ten hours.

thermoluminescence: a property of fired materials, such as ceramics, causing them to become luminous when gently heated again. Because this property decays at a known rate, the age of a ceramic artifact can be estimated by heating it and measuring the amount of phosphorescence.

tiller: new growth in a graminoid that originates from dormant axillary buds in the plant crown or on rhizomes (Dahl and Hyder 1977).

tillering: process of producing new grass growth from dormant axillary buds in the plant crown or on rhizomes (Dahl and Hyder 1977).

timelag: the time necessary for a fuel particle to lose or gain approximately 63 percent of the difference between its initial moisture content and its equilibrium moisture content.

torch: ignition and subsequent envelopment in flames, usually from bottom to top, of a tree or small group of trees.

total available carbohydrates (TAC): carbohydrates that are in a form that can be utilized as a readily available source of energy by a plant, including sugars, starch, dextrins, and fructosans (Smith et al.

1964 in Trlica 1977).

total fuel: all plant material, both living and dead, on a site.

trachea: in air breathing vertebrates, the tube that serves as the principal passage for conveying air to the lungs.

treatment: a procedure whose effect can be measured and compared with the effect of other procedures. Examples include a fall burned prescribed fire, an unburned "control", or an area burned with a specific ignition method or pattern.

- U -

underburning: prescribed burning in activity-created or natural fuels beneath a forest canopy, usually with the objective of preserving the dominant overstory trees.

utilization rates (limits): the proportion of the current year's forage production that is removed by grazing or browsing animals. It may refer to particular species or to the entire plant community and is usually expressed as a percentage.

- V -

vapor pressure: the contribution to total atmospheric pressure due to the presence of water molecules in the air (Schroeder and Buck 1970).

variable: any changing characteristic; in statistics, a measurable characteristic of an experimental unit.

variance: the sum of the squares of the deviates divided by one less than the total number of deviates; a measure which indicates how far away from the middle the statistics are; usually denoted by the lower case s^2. Variance is the standard deviation squared. In practice, it is easier to compute the variance, then take the square root to obtain the standard deviation. (See standard deviation.)

vegetative regeneration: development of new aboveground plants from surviving plant parts, such as by sprouting from a root crown or rhizomes. Even if plants form their own root system, they are still genetically the same as the parent plant (Zasada 1989).

vegetative reproduction: establishment of a new plant from a seed that is a genetically distinct individual (Zasada 1989).

vigor: a subjective assessment of the health of individual plants in similar site and growing conditions; or a more specific measure based upon a specific facet of growth, such as seed stalk or tiller production per plant or per unit area.

- W -

weight: as used in vegetation inventory and monitoring, the total biomass of living plants growing above the ground in a given area at a given time.

wildfire: a free burning and unwanted wildland fire requiring a suppression action.

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