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Chapter 15:

Monitoring the Effects of Fire on Nonnative Invasive Plant Species

Monitoring, as defined by Elzinga and others (1998), is "the collection and analysis of repeated observations or measurements to evaluate changes in condition and progress towards meeting a management objective." Analyses of monitoring data may indicate that a project is meeting land management goals, or it may indicate that goals are not being met and management methods need to be adapted to reach them. Monitoring is an essential step in adaptive management (Chong and others 2006). For many federal agencies, monitoring is required by Agency or Congressional mandates (Elzinga and others 1998).

Monitoring can be qualitative or quantitative and can be applied with varying levels of rigor (see Elzinga and others 1998 for a complete discussion). Monitoring with a high level of rigor is essential for change to be detected **and** for cause and effect relationships to be inferred. In other words, a high level of rigor is needed for monitoring to produce defensible results that are useful for management decisions. In the rest of this chapter, when I use the term "monitoring," I mean monitoring with a high level of rigor.

Monitoring is essential for understanding the relationship between fire and invasive species, whether documenting new invaders following fire, postfire changes in established nonnative populations, recovery of native plant communities after wildfire (fig. 15-1), or efficacy of prescribed fire in controlling nonnative plant species. Monitoring can be used to detect change between sampling periods (before and after fire) or between treatments (burned and unburned areas), and it provides quantitative data for statistically analyzing the probability that the observed differences are due to chance. Statistics provides an objective and defensible means of evaluating the relationship between invasives and fire; it provides "high quality information" as described in chapter 12. However, statistical significance does not necessarily imply biological significance (see "Statistical Analysis" page 285).

This chapter is not a guide on how to monitor nonnative invasive plants. Many such guides are available, some in textbooks and others in agency manuals, which are referenced throughout the chapter. Instead of providing how-to instructions, this chapter (1) identifies

Figure 15-1—Monitoring effect of fire on understory vegetation in the Selway-Bitterroot Wilderness Area, northern Idaho, one year after wildfire. (Photo by Steve Sutherland.)

common elements of effective monitoring programs and suggests sources for additional information on those elements, (2) provides examples of how decisions on monitoring design can affect results and interpretation of the results, and (3) stresses the importance of integrating vegetation, fire behavior, and fire effects monitoring to better understand the impact of fire on nonnative, invasive species.

Vegetation Monitoring

In the past 10 years, many Federal Agencies have produced vegetation monitoring manuals (table 15-1) with two goals: (1) help managers improve monitoring and (2) provide a standard methodology for measuring plant attributes. Three of the manuals have associated relational databases for storing, managing, and statistically analyzing monitoring data. Efforts are currently underway to integrate the Fire Monitoring Handbook (FEAT) and FIREMON databases to create a new monitoring tool (Lutes and others, in press). Although none of these manuals specifically address monitoring nonnative invasive species, the standard methodologies for vegetation monitoring apply to monitoring of invasives.

Wirth and Pyke (2007) reviewed these seven publications and two national assessment programs (National Resources Conservation Service's National Resource Inventory (Spaeth and others 2003) and U.S. Department of Agriculture, Forest Service's Forest Inventory and Analysis (U.S. Department of Agriculture, Forest Service 2003)) and found seven common elements of effective monitoring program design:

- Objectives,
- Stratification,
- Controls (untreated plots),
- Random sampling,
- Sample size (data quality),
- Statistical analysis, and
- Field techniques.

Objectives

Managers need to be strategic about monitoring vegetation (Elzinga and others 1998; Lutes and others 2006). Elzinga and others (1998) describe the process in detail. The steps, as related to invasive species and fire, include (1) gathering and reviewing background information on invasive species, fire, and native communities; (2) identifying the priority invasive species and native communities; and (3) determining resources available for monitoring (for example, funding and personnel with botanical and ecological expertise). Once priorities are established and the amount of available resources is determined, the scale (local or regional) and intensity of monitoring can be determined.

Because resources are limited, the number of priority species and communities to be monitored may be inversely related to the scale and intensity of monitoring. As the number of priority species and communities increases, the scale and/or intensity of monitoring these species often decreases to stay within limited resources. Often managers are faced with the decision to monitor a few invasive species intensively at a few locations and monitor other species either qualitatively or not at all.

Well defined management and monitoring objectives are essential for successful monitoring. Management objectives provide a standard for determining management success and indicate which variables should be measured to determine when success has been achieved (Wirth and Pyke 2007). Management objectives should be realistic, specific, and measurable (Elzinga and others 1998). Monitoring objectives should be paired with each management objective. Monitoring objectives should specify the desired level of precision (desired confidence level and confidence interval width) or the desired minimum detectable change, acceptable probability of detecting a change when there is none (alpha or type I error), and acceptable probability of not detecting a change when there is one (beta or type II error). These variables also influence adequate sample size (see Elzinga and others (1998) and Wirth and Pyke (2007) for more details).

Table 15-1—Selected monitoring publications by federal entities.

Title	Topics covered by monitoring protocols			
	Vegetation	Invasives	Fire	Relational database
Measuring and monitoring plant populations (Elzinga and others 1998). U.S. Department of the Interior, Bureau of Land Management	Y	N	N	N
Sampling vegetation attributes (Interagency Technical Reference 1999). U.S. Department of the Interior, Bureau of Land Management	Y	N	N	N
Fuel and fire effects monitoring guide (U.S. Department of the Interior, Fish and Wildlife Service 1999)	Y	N	Y	N
Fire monitoring handbook (U.S. Department of the Interior, National Park Service 2003)	Y	N	Y	Y
Monitoring manual for grassland, shrubland, and savanna ecosystems (Herrick and others 2005a,b). U.S. Department of Agriculture, Agricultural Research Service	Y	N	N	Y
FIREMON: fire effects monitoring and inventory protocol (Lutes and others 2006). U.S. Department of Agriculture, Forest Service	Y	N	Y	Y
Range and training land assessment (U.S. Army, Sustainable Range Program 2006)	Y	N	N	N

Stratification

Stratification divides the treatment unit into ecologically similar areas to reduce variation and increase precision (Wirth and Pyke 2007). Use of GIS with data layers for elevation, aspect, slope, fire perimeters, fire severity, treatment areas, soils, roads, and watersheds may be useful for stratification. (See U.S. Department of the Interior, National Park Service (2003), Lutes and others (2006), Herrick and others (2005b), and Wirth and Pyke (2007) for more details on stratification). Because of limited monitoring resources, there may be a trade-off between the number of strata that can be monitored and monitoring intensity. For example, changing a study from two burn severities in three plant communities (2 X 3 = 6 strata) to two burn severities in three plant communities on north vs. south slopes (2 X 3 X 2 = 12 strata) doubles the number of strata sampled. In this example, unless stratification reduces variance so it reduces the needed sample size by half, the sampling effort will have to increase to cover all strata adequately.

Figure 15-2 illustrates the advantage of stratification. When spotted knapweed (*Centaurea biebersteinii*) density was compared on burned vs. unburned plots, data indicated that knapweed density was 40 percent lower in burned areas. However, when the burned areas were stratified by fire severity, more information was available. Knapweed density on low-severity burned plots was virtually the same as on unburned plots (38 vs. 34 stems/m^2), but severely burned plots had only 6 percent the knapweed density of unburned plots in the first postfire year (Sutherland, unpublished data, 2008). If management decisions are based on

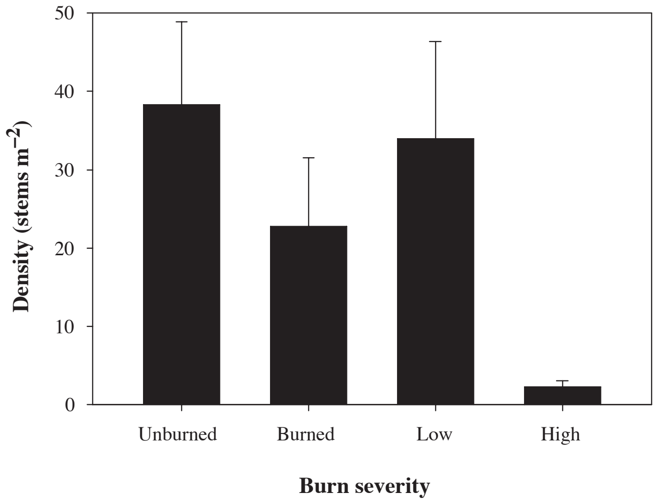

Figure 15-2—Spotted knapweed density (mean + standard error). "Burned" bar shows data from all burned plots, while "low" and "high" bars show the same data broken down (stratified) by fire severity classes. Data are from burned and unburned plots with spotted knapweed 1 year after wildfire in western Montana. (Data from Sutherland, unpublished, 2008.)

knapweed density, then stratifying the data according to fire severity could result in more efficient measures for controlling this nonnative invasive species.

Controls

While only two of the monitoring manuals in table 15-1 (Fire Monitoring Handbook, and FIREMON: Fire Effects Monitoring and Inventory Protocol) mention the use of controls (untreated plots), Wirth and Pyke (2007) stress that controls are essential for understanding treatment effects. Controls allow managers to determine whether or not a specific treatment caused the observed change, as opposed to other factors, such as year-to-year variation in weather conditions (Christian 2003). To avoid pseudoreplication (Hurlbert 1984), controls should be placed randomly within each monitoring unit rather than in an adjacent unburned (untreated) area, which may differ in some environmental variables from the treatment unit (see "Other Elements of an Effective Monitoring Program Design" page 288). While this may be possible for prescribed fires, it may not be possible for wildfires. If monitoring after wildfire, multiple wildfires and unburned areas adjacent to each can be treated as replicates.

The importance of controls can be illustrated using an example of postfire herbicide application to control leafy spurge (*Euphorbia esula*) in western Montana (fig. 15-3). There was a significant, 70 percent increase in leafy spurge cover 1 year after application of picloram (2 years after fire) (Sutherland, unpublished data, 2008). Because there was no control, the cause of the increase in leafy spurge density could not be determined. It was possible, but not likely, that picloram caused an increase in leafy spurge cover. A more likely explanation is that leafy spurge density increased because precipitation was 20 percent higher the year after herbicide application than the year before. An untreated control would have allowed these two hypotheses to be tested.

Random Sampling

Random sampling is a requirement for statistical analysis and the basis for defensible monitoring (Sokal and Rohlf 2000; Zar 1999). Simple random sampling requires that each member of a population has an equal chance of being sampled. It ensures that the data are unbiased and representative of the monitoring unit. There are several types of random sampling (for example, simple, stratified, systematic, restricted, cluster, two-stage, double, and individual plants). Elzinga and others (1998) review the advantages and disadvantages of these eight types of random sampling.

Sampling plots can be either permanently marked at random locations or randomly located in each sampling period. If plots are permanently marked and recorded

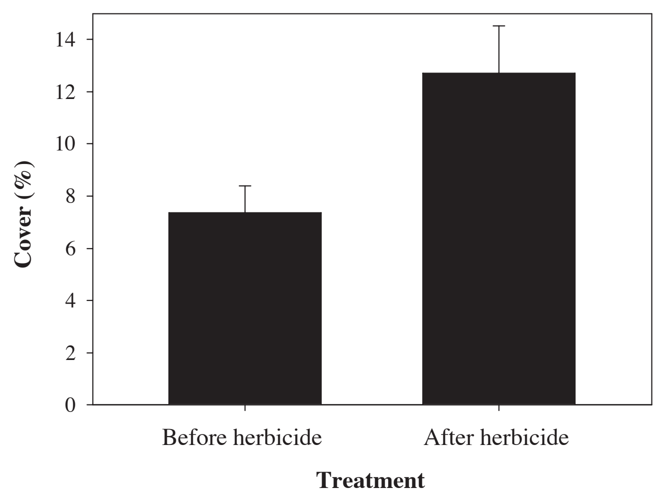

Figure 15-3—Cover of leafy spurge (*Euphorbia esula*) before and after herbicide application in a bunchgrass community in western Montana that burned in 2000. "Before herbicide" measurements were taken in summer 2001, herbicide was applied in fall 2001, and "after herbicide" measurements were taken in 2002. (Data from Sutherland, unpublished, 2008.)

in GIS, then the same plots can be remeasured each sampling period. Elzinga and others (1998) review the advantages and disadvantages of using permanent plots and conclude that permanent plots usually outperform temporary plots for detecting change. Statistical tests with permanent plots can be more powerful than tests with temporary plots, and the minimum sample size to detect a given change can be smaller with permanent plots. Locations of treatment areas including permanent plots or transects must, of course, be made known to managers to prevent management actions that would confound treatment effects and the usefulness of monitoring data.

Sample Size

Wirth and Pyke (2007) stress the importance of an adequate sample size to ensure that the manager can detect treatment-induced changes in populations. Adequate sample size depends on monitoring objectives, particularly on desired minimum detectable change and acceptable type I and type II errors (see "Objectives" page 282). Once monitoring objectives are chosen, the easiest way to determine adequate sample size is to collect preliminary data, calculate means and standard deviations, and use established equations to estimate minimum sample size. If multiple sampling techniques are used (for example, both cover and density will be measured), adequate sample size should be calculated independently for each technique. Many monitoring and statistical texts provide the needed equations (for example, Elzinga and others 1998; Lutes and others 2006; U.S. Army, Sustainable Range Program 2006; Wirth and Pyke 2007; Zar 1999).

Statistical Analysis

Statistical analysis provides an objective and defensible means of evaluating the relationship between vegetation change and treatment. Statistics assign a probability that the observed change is due to chance and allow the manager to infer that the treatment caused the change in vegetation. If the five preceding topics are properly addressed, data can be statistically analyzed. A very useful first step in this process is to examine graphic depictions of the data. Look for patterns. Do you see any trends between treated and untreated plots? Do you see differences between strata? Do you see any trends occurring over time? Did you expect to see differences not shown by the data? While statistical analysis produces defensible, quantitative results, simply *looking at* the data may provide insights as to what patterns are biologically meaningful and what trends may be occurring even if they are not captured by your data in a way that indicates statistical significance.

There are several options for statistical testing, including parametric and nonparametric methods. All of them assume random sampling; there are no statistical tests for data that are not randomly sampled. Standard parametric statistics (such as t-tests and analysis of variance) assume random sampling, normally distributed data, and equal variance among analysis groups. If the last two assumptions are not met, either the data should be transformed so that the assumptions of normality and variance homogeneity are met (see Elzinga and others 1998 for details) or other analytical methods should be used. Nonparametric statistics (including chi square, McNemar's test, Mann-Whitney U test, Wilcoxon's signed rank test, Kruskal-Wallis test, and Friedman's test) could be used to formulate tests when data are distributed similarly among groups but are non-normal (Hollander and Wolfe 1999). Generalized linear models could extend analysis of variance to data that are adequately approximated by binomial, Poisson, negative binomial, gamma or lognormal distributions (Dobson 2002), while mixed effects models (linear, generalized linear, or nonlinear) could account for correlation among observations (such as when observations are remeasured in time) or heterogeneous variance among groups (Littell and others 2006).

If the results are statistically significant, they should be examined to determine if they are biologically meaningful. Look again at graphic depictions of the data. Because all populations vary through time and space, a large sample size may make even small differences in mean values statistically significant. These differences, however, may not be biologically meaningful (Elzinga and others 1998). For example, Sutherland (unpublished data, 2008) measured total vegetation cover on burned and unburned bunchgrass plots 5 years after wildfires in 2000 in western Montana. Average total vegetation cover was 28.1 percent on burned plots and 23.5 percent on unburned plots. This 4.6 percent difference in total cover was statistically significant ($P < 0.05$) but less than the size of the cover classes (10 percent) used to record data. Thus the biological significance of the 5 percent difference in total cover on burned plots is questionable.

Do not necessarily ignore monitoring results that are not statistically significant. They may indicate trends that need further examination in the field or additional monitoring in the future using more precise sampling designs.

Field Techniques

Five monitoring methods are commonly used for estimating vegetation abundance: frequency, density, and cover measured in three ways—ocular, point-intercept, and line-intercept. Frequency is a measure of the proportion of sample plots that contain the target species.

Density is a measure of the number of individual plants or stems per given area. Cover measurements estimate the proportion of ground covered by target species. Each method has its strengths and weaknesses (see table 15-2), and the various methods may or may not give similar qualitative or quantitative results. Two examples of studies using a variety of measurement methods illustrate what can be learned from different methods.

Leafy spurge abundance in two unburned bunchgrass communities in western Montana was examined using frequency, ocular cover, point-intercept cover, and density measures (fig. 15-4). The methods produced similar qualitative results (leafy spurge abundance was lower in community B), but the absolute difference in spurge abundance varied with method. Spurge abundance was 22 percent lower in community B than in community A based on frequency measurements, 67 percent lower based on point intercept cover measurements, 70 percent lower based on ocular cover measurements, and 82 percent lower based on density measurements.

Sutherland (unpublished data, 2008) examined spotted knapweed abundance in 2001 and 2002 for a western Montana bunchgrass community using frequency, ocular cover, and density measures (fig. 15-5). He found that each method indicated a different pattern of change over time. Frequency did not change between the first and second postfire years, while cover decreased and density increased.

Why do these monitoring methods produce different results? As a measure of vegetation abundance, frequency is sensitive to the size, density, and distribution of the vegetation and also to the size and shape of

Table 15-2—Comparison of five monitoring methods.

Method		Advantage	Disadvantage
Frequency (How many plots contain the target species?)		• Sensitive to changes in spatial arrangement • Effective in monitoring establishment and spread of invasive species • Stable throughout growing season • Objective and repeatable • Easiest and fastest	• Affected by spatial arrangement, size, and density of vegetation • Difficult to interpret biologically • Sensitive to size and shape of sampling frame
Cover estimates (How much ground does the target species cover?)	Ocular (Visual estimate)	• Equalizes contribution of species • Most directly related to biomass • Does not require identification of individuals • Good for diversity and species richness • Easy and fast	• Changes during growing season • Sensitive to changes in number and vigor • Not sensitive to reproduction • Change detection is difficult with broad cover classes • Observer bias (but see discussion below)
	Point intercept (What proportion of the points hit the target species?)	• Least biased and most objective cover estimate	• Changes during growing season • Sensitive to wind • Sensitive to angle of point • Overestimation of cover with large pins • Not effective for species with low cover
	Line intercept (What proportion of a transect is occupied by the target species?)	• Effective for shrubs • Effective for mat-forming plants	• Less effective for single-stem plants • Less effective for grasses • Not effective for species with low cover
Density (How many stems per area of the target species?)		• Effective for recruitment and mortality • Independent of quadrat shape • Measurements are repeatable • Observer bias is low	• Less sensitive to changes in vigor • More time consuming • Difficult to use with bunchgrasses

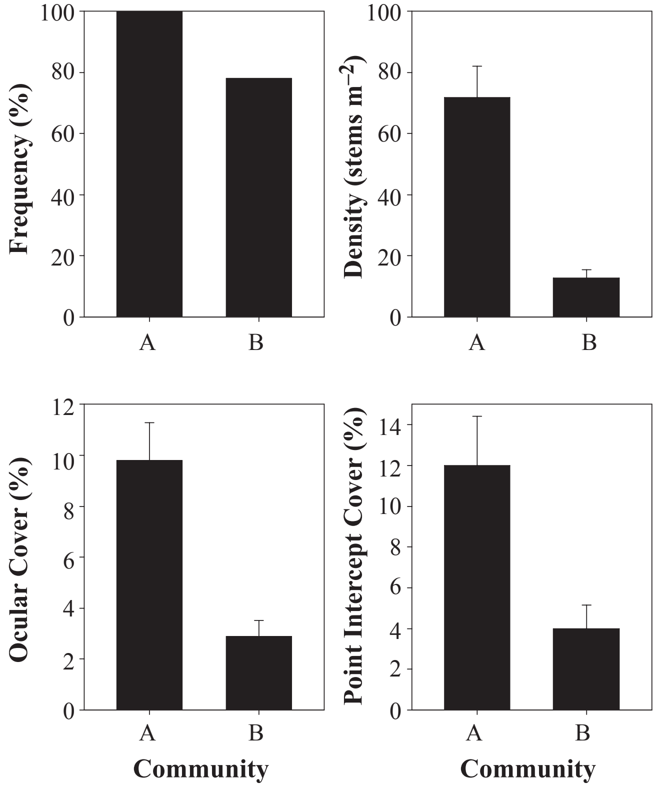

Figure 15-4—Results of four monitoring techniques used to characterize leafy spurge abundance in two unburned bunchgrass communities (A and B) in western Montana. (Unpublished data on file at USDA, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT.)

the sampling frame (table 15-2). Therefore, the same size and shape sample frame must be used throughout monitoring, and only studies using the same sample frame should be compared. Because frequency varies with frame size, the absolute frequency has no biological meaning. It is the relative frequency and change in frequency that are important. To detect change, Elzinga and others (1998) recommend frequencies between 30 percent and 70 percent. Frequency can be adjusted by altering frame size; in general, a larger sampling frame will increase frequency and a smaller frame will decrease frequency. The optimal frame size for one species may not be optimal for other species. If you are monitoring several species, a series of nested quadrats may be useful—smaller frames for common species and larger frames for uncommon and rare species.

The 22 percent difference in spurge frequency shown in figure 15-4 resulted from using a 1-m^2 sampling frame. If a different sampling frame had been used, a different change in spurge frequency would have been observed. Sample-frame size also explains why Sutherland's spotted knapweed frequency (fig. 15-5) was not different in bunchgrass communities 1 and 2 years after fire. The 1-m^2 frame was so large that spotted knapweed frequency was 100 percent in both years. A smaller sample frame, that produced an initial spotted knapweed frequency of 30 percent to 70 percent, would have allowed an increase in knapweed to be detected.

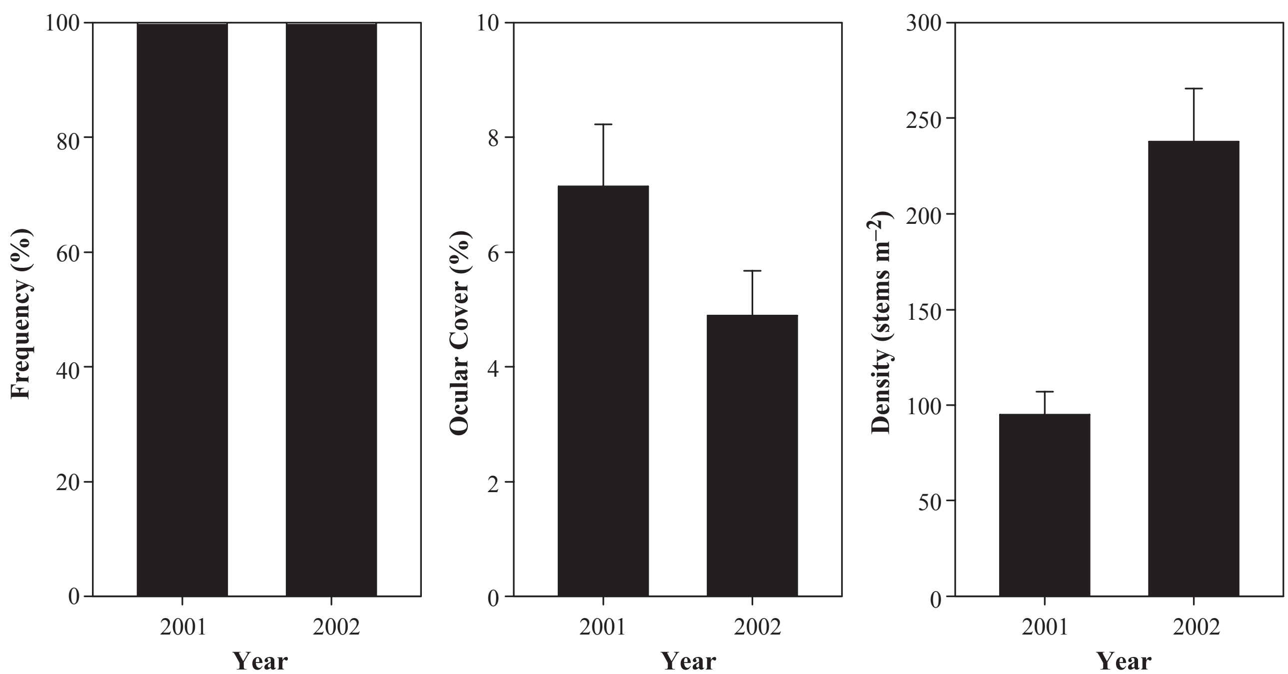

Figure 15-5—Comparison of three monitoring techniques used to detect change in spotted knapweed abundance between 2001 and 2002 in a western Montana grassland burned in 2000. (Data from Sutherland, unpublished, 2008.)

While Wirth and Pyke (2007) do not recommend using frequency for monitoring postfire vegetation treatments, they do acknowledge that frequency may be important in detecting invasion by nonnative species. Sutherland (unpublished data, 2008) used frequency data to document the establishment of new nonnative species on 24 burned plots in western Montana and northern Idaho between 1 and 3 years following wildfire. Sampling frequency at a large scale (30 m by 30 m macroplot) was more effective in detecting establishment than sampling at smaller scales (multiple 1 m by 1 m quadrats). Monitoring to detect new invasives should focus on invasion pathways and disturbed areas (see chapter 14 for more details).

Monitoring vegetation frequency is easy, fast, repeatable, and objective, but the results may be difficult to interpret. If there is a change in nonnative species frequency, it is unknown whether the change is caused by an increase in numbers, size, or distribution of nonnative species. Cover estimates or density measurements can be used to determine if the change in frequency is due to an increase in numbers, size, or distribution.

Where individual plants can be identified, density measures are repeatable with little observer bias. Density measures are independent of frame size and are effective for documenting mortality and reproduction. The counting unit must be identified (individual or stem), and adults and seedlings should be counted separately. Density monitoring may be time-consuming if the densities are high.

Cover estimates have the advantage of being fairly easy and fast, are related to biomass (Elzinga and others 1998), and are sensitive to changes in number and size of individuals. Disadvantages of cover estimates include (1) cover changes throughout the growing season so plots need to be resampled when the plants are in the same phenological condition each year, (2) cover is sensitive to changes in both numbers and vigor, and (3) cover is not effective for detecting changes in species with low cover (for example, rare species or species with seedlings).

The line-intercept method of cover estimation is usually used for shrubs, while ocular estimation and point-intercept methods are used for herbaceous vegetation. Ocular cover estimation has been considered more subjective than point- or line-intercept methods (Wirth and Pyke 2007). However, Booth and others (2006) found little difference between ocular and point-intercept estimations of known plant covers, whereas line-intercept consistently underestimated the known covers. Korb and others (2003), using unknown plant cover, concluded that ocular estimates of cover were more accurate than point-intercept because of violations of point-intercept assumptions (variable point size and non-vertical projection). Violations of these two assumptions can be avoided by training and consistent use of standard techniques.

Because it is difficult to make exact ocular estimation of plant cover, plants are usually placed in cover classes. Table 15-3 lists some common cover classes. The breadth of cover classes can impact monitoring results. For example, Sutherland (unpublished data, 2008) examined spotted knapweed after a BAER application of picloram in fall of 2001 in a bunchgrass community in western Montana, using the fine scale EcoData (Jensen and others 1993) cover classes in the initial data collection. If he had used Daubenmire's (1959) broader cover classes, then the eradication of spotted knapweed in 2002, its re-establishment in 2003, and the exponential increase in 2004 would have been undetected (see fig. 15-6). Daubenmire's (1959) and Braun-Blanquet's (1965) 25 percent cover classes are probably too coarse to detect change in many nonnative species populations.

The observed differences in Sutherland's data between estimates of spotted knapweed cover and density in non-herbicided plots (fig. 15-5) are caused by a postfire increase in spotted knapweed seedlings but no increase in adults. Total spotted knapweed density more than doubled, but the seedlings contributed little to cover.

Other Elements of an Effective Monitoring Program

There are two additional elements of an effective monitoring program: (2) avoiding pseudoreplication and (2) monitoring for multiple years. Hurlbert (1984)

Table 15-3—Percent cover classes recommended by Daubenmire (1959), Braun-Blanquet (1965), and EcoData (Jensen and others 1993).

Class	Daubenmire	Braun-Blanquet	EcoData
1	0-5	<1	0-1
2	6-25	1-5	1-5
3	26-50	6-25	6-15
4	51-75	26-50	16-25
5	76-95	51-75	26-35
6	96-100	>76	36-45
7			46-55
8			56-65
9			66-75
10			76-85
11			86-95
12			96-100

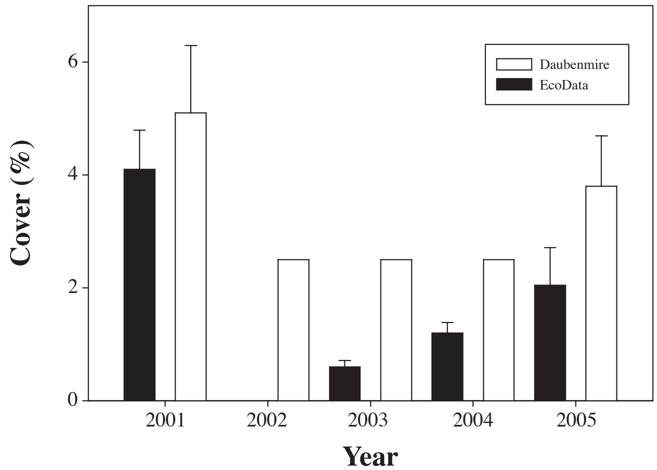

Figure 15-6—Comparison of percent cover as measured by EcoData and Daubenmire cover classes for documenting the efficacy of picloram in controlling spotted knapweed in a bunchgrass community in western Montana. Plots were burned by wildfire in 2000, sprayed with picloram in fall 2001, and monitored in summer 2001 to 2005. (Data from Sutherland, unpublished, 2008.)

defined pseudoreplication as the use of inferential statistics on data from treatments that are not replicated or replicates that are not statistically independent. For most nonnative monitoring programs, site heterogeneity and sampling efficiency require that data be collected from many sampling frames or transects per treatment unit. This is especially true for ocular cover and density measurements, where data can be collected efficiently only from relatively small sampling frames. These frames (see fig. 15-7) and transects are subsamples rather than experimental units; they should be treated as subsamples or averaged before statistical analyses. Defining a target population for a study and concurrently defining independent elements of the target population help distinguish between replicates and subsamples. Ideally, treatments and controls should be physically interspersed to minimize the effects of environmental gradients and random events. While this may be possible for prescribed fire, it is virtually impossible for wildfires.

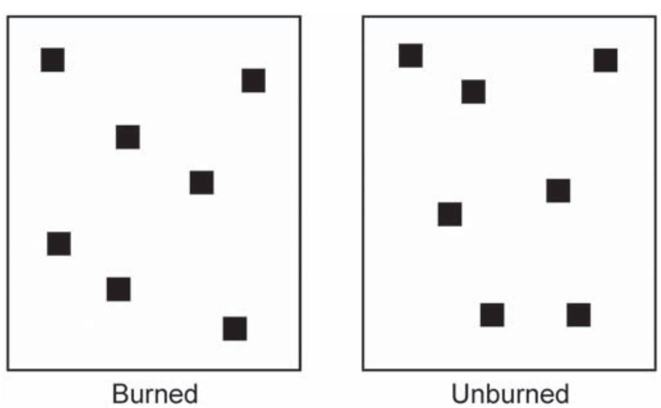

Figure 15-7—Pseudoreplication. The large rectangles are treatment units in a nonreplicated study, and the small squares (sample frames) within are subsamples. If statistics were performed using the subsamples as independent samples, that would be pseudoreplication.

Most studies of the impact of fire on nonnative invasive plants are of short duration. Seventy percent of the fire effects studies available for reviews of nonnative invasive plants written for the Fire Effects Information System from 2001 to 2006 were only followed for 1 year after fire (chapter 12). If postfire effects are ephemeral or delayed, then plant response the first year after fire may not reflect the true impact of fire on nonnative plants or the ecosystems where they reside. Managers and scientists agree that monitoring must cover periods long enough to provide results that can inform future management actions (White 2004). Two examples of studies using multiple-year sampling illustrate what can be learned from data sets that cover several years.

In the previous example of postfire application of picloram to control spotted knapweed in a Montana bunchgrass community (fig. 15-6), spotted knapweed cover was 0 percent 1 year after herbicide application. If the study had only lasted 1 year after treatment, the results would have suggested that BAER application of picloram was effective in controlling spotted knapweed after wildfire. The 5-year study indicated that the effect of picloram treatment was ephemeral; 4 years after herbicide treatment, spotted knapweed cover was half of pretreatment cover, and cover was doubling annually.

In the second example, Sutherland (unpublished data, 2008) found that spotted knapweed density was five times higher on unburned than burned ponderosa pine (*Pinus ponderosa*) plots 1 year after wildfire (fig. 15-8). By 3 years after fire, the pattern had reversed and spotted knapweed density was four times higher on burned than unburned plots. Two years later (5 years after fire), spotted knapweed density was five times higher on burned than unburned plots. This pattern was attributed to fire damage to seeds in 2000 and higher seed production and germination on burned plots in 2001 to 2005. If the study had only lasted 1 year (as do many fire effect studies), he would have concluded that wildfire reduces spotted knapweed; in reality, fire promoted spotted knapweed in ponderosa pine plots in western Montana.

While research and monitoring results are sparse regarding the relationship between fire and nonnative invasive species in the first decade after fire, there is almost no information on these relationships after the first postfire decade.

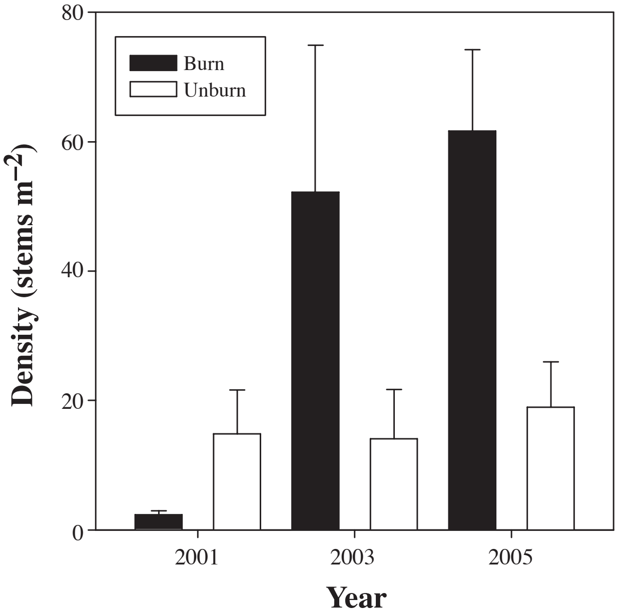

Figure 15-8—Spotted knapweed density on burned and unburned ponderosa pine (*Pinus ponderosa*) plots 1 to 5 years after wildfire in western Montana. (Data from Sutherland, unpublished, 2008.)

Fire Monitoring

To understand the impact of fire on nonnative invasive species, fire behavior and effects need to be monitored along with vegetation. Because invasion by nonnative species may be sensitive to severity of disturbance (chapter 2), fire monitoring can provide the context for understanding variations in postfire changes in invasive species as they relate to fuels and fire characteristics. Three of the monitoring manuals (Fuels and Fire Effects Monitoring Guide, Fire Monitoring Handbook, and FIREMON: Fire Effects Monitoring and Inventory Protocol) specifically address fire monitoring (tables 15-1 and 15-4).

Fire Behavior

Fire Monitoring Handbook (U.S. Department of the Interior, National Park Service 2003) and FIREMON: Fire Effects Monitoring and Inventory Protocol (Lutes and others 2006) suggest monitoring flame length, flame depth, and rate of spread. These fire behavior measurements are indicators of fire intensity (the rate of heat released by the flaming front during a fire). Other researchers have used instrumentation, temperature sensitive paint (Iverson and others 2004), and remote sensing (Hardy and others 2007) to measure fire intensity and maximum temperatures. But fire intensity and maximum temperature may be unrelated to fire severity (chapter 2; U.S. Department of the Interior, Fish and Wildlife Service 1999) and thus may be poor predictors of postfire responses of nonnative invasive species. Monitoring of changes in fuels and fire severity indicators may be more useful for understanding fire effects on vegetation.

Fuel Loading

Fuel load monitoring measures amount of litter, duff, and downed woody debris and is commonly based on Brown's (1974) planar intercept method (see U.S. Department of the Interior, Fish and Wildlife Service 1999; U.S. Department of the Interior, National Park Service 2003; or Lutes and others 2006 for further detail). Fuel consumption influences the magnitude and duration of soil heating, lethal soil temperatures, and consequent mortality of buds and seeds in the organic and mineral soil horizons. Fuel load monitoring is most useful when pre- and postfire data are collected and fuel consumption is calculated. Fuel consumption data can then be used to create relative fire severity classes or as input into models such as the First Order Fire Effects Model (FOFEM) (Reinhardt and others 1997) to estimate depth of lethal temperatures.

Table 15-4—Contents of federal vegetation and fire monitoring manuals. "X" indicates topics covered in each manual.

Topic	FFEMG[a]	FMH[b]	FIREMON[c]
Fire behavior:			
Flame length		X	X
Flame depth		X	X
Spread rate		X	X
Fuel loading:			
Litter	X	X	X
Duff	X	X	X
1 hour	X	X	X
10 hour	X	X	X
100 hour	X	X	X
Fire severity:			
Crown scorch	X	X	X
Char height	X	X	X
Burn severity			
Substrate	X	X	X
Vegetation	X	X	X

[a] Fuel and Fire Effects Monitoring Guide (U.S. Department of the Interior, Fish and Wildlife Service 1999)
[b] Fire Monitoring Handbook (U.S. Department of the Interior, National Park Service 2003)
[c] FIREMON: Fire Effects Monitoring and Inventory Protocol (Lutes and others 2006)

Duff pins (Gundale and others 2005; U.S. Department of the Interior, Fish and Wildlife Service 1999) are an inexpensive way to measure changes in litter and duff. The pins are placed before fire with their tops or cross pieces at the top of the litter layer. After fire, the length of the exposed pin is measured to determine absolute litter-duff consumption, and residual duff depth is measured to determine percent litter-duff consumption. These data can also be used to create fire severity classes or estimate depth of lethal temperatures using FOFEM.

Monitoring fuel loads is most useful for prescribed fires, because pre- and postfire measurements can be taken. With wildfire, prefire measurements are uncommon, and other measurements (described below) must be taken to estimate fire severity.

Fire Severity

Crown scorch, char height, and vegetation burn severity classes are used to estimate aboveground fire severity (Lutes and others 2006; U.S. Department of the Interior, Fish and Wildlife Service 1999; U.S. Department of the Interior, National Park Service 2003). Crown scorch is expressed as maximum scorch height (from ground to highest point of foliar death) (U.S. Department of the Interior, Fish and Wildlife Service 1999; U.S. Department of the Interior, National Park Service 2003) or percent canopy scorch (Lutes and others 2006; U.S. Department of the Interior, Fish and Wildlife Service 1999; U.S. Department of the Interior, National Park Service 2003). Bole char height is measured as either maximum char height (ground to highest point of char) (U.S. Department of the Interior, Fish and Wildlife Service 1999; U.S. Department of the Interior, National Park Service 2003) or continuous char height (ground to lowest point of continuous char) (Lutes and others 2006). Crown scorch and char height are usually used to predict postfire tree mortality for species that do not sprout.

Vegetation burn severity monitoring is a visual estimate of fire damage to aboveground vegetation, and individual plants are assigned to a burn severity class based on amount of consumption: not burned; foliage scorched; foliage and small twigs partially consumed; foliage and small twigs consumed and branches partially consumed; or all plant parts consumed (U.S. Department of the Interior, National Park Service 2003). Vegetation burn severity may be an accurate predictor of plant mortality for species that do not sprout, but many perennial nonnative species sprout after being top-killed (chapter 2).

Although crown scorch, char height, and forest burn severity classes are not accurate predictors of mortality for sprouting species, they may predict changes in light levels that may impact invasive understory vegetation. Other methods to measure changes in light levels include measurements of photosynthetically active radiation and gap light analysis from digital photographs (Frazer and others 1999).

Substrate burn severity monitoring is a visual estimate of fire-caused changes in litter, duff, and soil (fig. 15-9). A sample point is assigned to a burn severity class based upon litter and duff consumption

Figure 15-9—Monitoring substrate burn severity in the Selway-Bitterroot Wilderness Area, northern Idaho, 1 year after wildfire. (Photo by Steve Sutherland.)

and changes in soil properties: not burned; litter blackened and duff unchanged; litter charred or partially consumed and upper duff charred; litter consumed and duff deeply charred; litter and duff consumed with mineral soil exposed and red (U.S. Department of the Interior, National Park Service 2003). Substrate severity may be correlated with soil heating, lethal temperature regimes, and bud and seed mortality.

Success and Failure in Monitoring Programs

Several common problems, both technical and institutional, determine the success of monitoring programs. Technical problems can be caused by poor monitoring design where the management and/or monitoring objectives are not well identified, where the minimum detectable change and type I and type II errors are inappropriate, where controls (untreated plots) are not included and sample size is too small or sampling period is too short, or where an inappropriate sampling method is selected. Success of a program is also influenced by personnel; failures can occur if staff have inadequate botanical skills, high observer error (especially ocular estimation of cover), or inadequate statistical skills. If the monitoring design and data collection are appropriate, the organization must be committed to documenting the information adequately, storing it appropriately (with backup copies), analyzing it with statistical skill, and protecting sampling sites from impacts that would confound treatment effects.

Monitoring may fail to detect change or differences between burned and unburned plots because the treatment impacts are smaller than natural variations in the plant populations over the time period measured. This outcome is a biologically meaningful result, not a failure of the monitoring program. It may indicate that additional variables should be measured in the future. Lack of statistically significant results should not necessarily be interpreted as a sign that a site is "safe" from invasion after fire and monitoring can be discontinued; the time period measured may simply be too short for significant differences to be detected.

Long-term agency commitment to monitoring determines its ultimate success and the usefulness of monitoring data for management planning and decisions. Failure of agency commitment at any stage in the monitoring process will degrade the results and can render them useless. A monitoring program can be well designed but never implemented; pretreatment data can be collected but post-treatment data not collected; pre- and post-treatment data may be collected but not analyzed; data may be collected and analyzed but the results never presented; and data may be collected, analyzed, and presented but ignored. In many cases these failures are due to inadequate resources (personnel and equipment) over an extended time and can be related to changing budgets, priorities, or politics.

Monitoring may be difficult to plan, implement, analyze, interpret, and integrate into the adaptive management process, but long term monitoring on permanent plots often provides the best way, and sometimes the only way, to evaluate the impact of fire on nonnative invasive plant species and make defensible decisions regarding management of fire and invasives.