

Describing the Conditions of Forest Ecosystems Using Disturbance Profiles

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Abstract.—Data from a study on the effect of small-scale disturbances on small mammal prey of the Mexican spotted owl illustrates how spatial models of canopy cover and disturbance profiles of forest stands might be used to define forest stand condition and develop silvicultural prescriptions.

INTRODUCTION

Many facets of forest health have been addressed in several excellent papers at this workshop. These papers suggest that good health is a consistent characteristic of productive forest stands. These papers also show that forest health is difficult to describe because it is composed of so many interacting components. Characterizing and quantifying this complexity has been a difficult puzzle to solve (Kolb and others 1994).

Despite its complexity, managers still must make day-to-day, stand-level decisions that affect forest health. The quality of these decisions will depend on the managers' judgement of what a 'healthy forest stand' looks like, and on what silvicultural tools they have to measure and manipulate stands.

Silviculturists are applied ecologists who manipulate stands to achieve specific goals (Smith 1962). In addition to timber production, these goals include providing habitat for wildlife, maintaining or enhancing biodiversity, old growth maintenance, and other non-timber objectives. Silviculturists intervene by mimicking or redirecting small-scale disturbances (Oliver and Larson 1990). These interventions should be based on a keen understanding of the disturbance and recruitment processes underlying forest stand structure.

This paper builds upon two others presented earlier at this workshop. In the first paper (Geils and others, *these proceedings*), Brian Geils argued that silviculturists may need new ways of measuring and assessing stands to deal with the increasing diversity of management objectives. In the second paper (Beatty and others, *these proceedings*), Jerry Beatty described two potentially useful tools that are currently being assessed in a joint project between the USDA Forest Service's Rocky Mountain Forest and Range Experiment Station and Region 6 - Forest Pest Management; these tools included a spatial model called a patterned isopleth (which he referred to as a "gapogram"), and a multivariate metric called "disturbance profile". The purpose of this paper is to weave together the thoughts presented by Geils and Beatty by showing how spatial models and disturbance profiles might eventually be used to make silvicultural decisions involving small-scale disturbances. The discussion was developed from on-going studies in the Sacramento Mountains, New Mexico (Lundquist, Geils and Ward 1994). Since this is a discussion of early developmental efforts, much of this is still hypothetical; some of the assumptions are tenuous. It should, however, provide insight into a potential tool for silviculturists.

In 1992, a study was initiated to examine the effect of small-scale disturbances on small mammalian prey of the Mexican spotted owl (*Strix occidentalis lucida*) in stands representative of the major forest types in the Sacramento Mountains (Lundquist, Geils and Ward 1994). The Mexican

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spotted owl dwells in montane forests and canyons in Southwestern United States and Mexico. In 1993, this owl was listed by the United States Department of the Interior (USDI) Fish and Wildlife Service as a federally threatened species in the United States (USDI Fish and Wildlife Service 1993). At that time, little was known about how specific silvicultural practices or natural small-scale disturbances influence the quality of owl habitat (MacDonald and others 1991).

METHODS

The discussion here is based on data collected in a mixed-conifer stand named Delworth, which was composed primarily of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), southwestern white pine (*Pinus strobiformis* Engelm.), and white fir (*Abies concolor* (Gordon & Glend.) Lindl.). This stand had been selectively harvested at various times since the turn of the century.

Methods described earlier in these proceedings (Beatty and others 1995) were used to generate the patterned isopleth shown at the top of figure 1. This isopleth is composed of 1681 cells, each representing 25 m² for a total combined area of 4-ha. A value of 0 to 100% canopy density is attributed to each cell, which is classified into 3 groups: full canopy (dark cells, 75–100%), intermediate canopy (hatched, 60–74%), and open canopy (white cells, <60%).

In a concurrent study, wildlife biologists live-trapped small mammals on a grid with 20 m intervals between trap station. Additional details on methods used to sample these small mammal populations can be found in Ward and Block (1994). Traps were positioned at coordinates in the same plot used to develop the patterned isopleth. Trapping data represent presence/absence of individuals. Only first-time captures of individuals were used in the analysis. Repeat visits to the same traps or subsequent visits to other traps by previously captured individuals were not included in presented analyses. For this presentation, only data during August 1992 were used.

Ward and Block (1994) showed that the diet of the Mexican spotted owl in the Sacramento Mountains is primarily deer mice (*Peromyscus*



Figure 1.—Patterned isopleths representing canopy-structure of the 4-ha Delworth plot. These diagrams were derived from ground observations of canopy density at 1681 points and classified into gaps (white), edges (hatched), and interior (solid). Each side is 200 m long and each cell represents a 25 m² block of forest. The upper diagram represents the plot before treatment. The lower diagram represents plot after existing gaps were enlarged and cut trees were left on the ground, as described in text.

maniculatus), brush mice (*P. boylii*), long-tailed voles (*Microtus longicaudus*), Mexican voles (*M. mexicanus*), and Mexican woodrats (*Neotoma mexicana*). We compared the distribution of each of these mammal species to the distribution of canopy density by overlaying the two images in a Geographic Information System (IDRISI, J.R. Eastman, Clark University; fig. 2).

USING PATTERNED ISOPLETHS AND GIS TO DESCRIBE HABITAT

The image overlays shown in figure 2 suggest that the distribution of some of the owl's prey may be related to canopy structure. For instance, during the August 1992 period, Mexican voles were associated with the interiors of relatively large gaps; long-tailed voles were associated with fragmented parts of the stand where gap edges were numerous; Mexican woodrats avoided gaps; and deer mice did not discriminate between gaped and non-gaped areas of the stand.² Observations like

these would be difficult or impossible to make without spatially referenced data. Non-spatial metrics like basal area, stems per hectare, and average dbh can not describe gap shape, gap placement, canopy fragmentation or other spatially-dependent features that can influence wildlife.

More importantly, the data suggest that managers might be able to control the abundance and distribution of mammals by manipulating canopy structure. For instance, long-tailed vole populations might increase and their spatial distribution be spread more widely if small gaps were enlarged or introduced to non-gaped portions of the stand, as portrayed in the bottom isopleth of figure 1. Mexican vole populations might increase if existing gaps were enlarged. Mexican woodrat populations might increase if edge trees were encouraged to fill gap openings. This is a relatively simple example of the potential use of patterned isopleths, and spatially-referenced data to make stand-scale silvicultural decisions.

The isopleths shown in figure 1 represent only a small portion of the Delworth stand. To meet the purpose of our research study, (i.e., to establish the wildlife/canopy-structure associations), the intensity of sampling was necessarily intense, and the study area limited. If similar maps of the canopy distribution could be economically generated for the entire stand, decisions about where to conduct specific silvicultural manipulations would be enhanced and these kinds of spatial models would be much more useful to management. Remote sensing coupled with image processing procedures may soon offer an alternative to the need for such intense field surveys, and make stand-scale images practical (Lundquist and Sommerfeld unpublished).

INTERPRETING DISTURBANCE PROFILES

Manipulating animal abundance and distribution may require more than simply cutting holes in

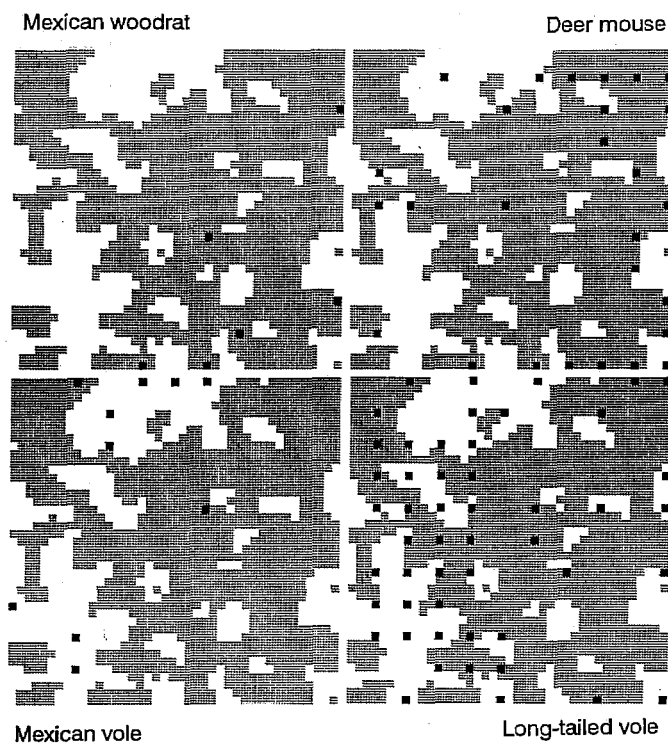


Figure 2.—Composite maps of canopy-structure Delworth plot overlaid with distribution of four small mammal species. Unshaded areas are identified as canopy gaps; shaded areas include both edge and interior; solid squares indicate trap sites where at least one individual was recovered.

²It should be noted that these isopleths summarize only one year's data; small mammal populations can vary considerably from year to year. Conclusive statements would have to be based on several years' data.

Table 1.—Current disturbance profile for one 4-ha plot in one mixed-conifer stand (Delworth) in the Sacramento Mts, New Mexico, and a set of hypothetical desired condition for maintaining adequate diversity and abundance of small mammal prey for the Mexican spotted owl. Letter in parentheses indicate that current stand conditions are high (H) or low (L), and may need to be adjusted.

Index	Units	Current	Desired condition
Ave. stem diameter	cm	29.8	30–40
Stem density	stems/ha	437(H)	150–250
Basal area	m ² /ha	30	25–35
Gap frequency	gaps/ha	26	20–30
Mean gap diameter	m	13.6	10–20
Skewness (gap dia distr)	g ₁	0.6	0.5–2.0
Kurtosis (gap dia distr)	g ₂	–0.7	–0.8–0.5
No. cause pathways	Number	68	40–70
Shannon-Weaver (causes)	H'	8.8	4.0–9.0
Snag frequency	snags/ha	211(H)	50–200
Log frequency	logs/ha	214(L)	300–400
Ave. densiometer	%	84(H)	40–70
Skewness (densio distr)	g ₁	–1.4	–2.0–2.0
Kurtosis (densio distr)	g ₂	5.9	3.0–7.0
Shannon-Weaver (densio)	H'	0.7	0.5–2.0
Dominance	c	0.7	0.1–0.9
Contagion	C	2.0(H)	.5–1.5
Number of edges	Number	218(L)	300–500
Ave gap area	No 100 m ² cells	3.2	3–7
Fractal dimension	D	1.3	1.2–1.4
Variogram sill	semivariance	133	120–200
Variogram range	lag distance	26	20–30

the canopy. Gaps at Delworth, for example, are composed of downed logs and other coarse woody debris, snags, recolonizing vegetation, and other elements that together make individual gaps differ from one another. Unique combinations of these components give each gap a unique signature. Furthermore, stands are composed of multiple gaps, each contributing a different signature to the composition of the stand. The number of ways a stand can be characterized is vast.

Disturbance profiles are multivariate metrics composed of various spatial and non-spatial statistics based on crown cover, coarse woody debris, live vegetation and composition of disturbance agents (Lundquist 1995b). A disturbance profile of the Delworth plot is presented in Table 1. This profile is composed of 22 variables. Fractal dimension—a measure of gap complexity (Stewart 1989), variogram range—a measure of spatial dependency (Isaaks and Srivastava 1989), contagion—a measure of gap clustering (Gustafson and Parker 1988), and other spatial statistics (O'Neill

and others 1988) in the profile may be unfamiliar to many managers. Spatial statistics like these, however, describe patterns of the stand that cannot be illustrated using non-spatial statistics. Undoubtedly, these kinds of metrics will become more important as the use of GIS becomes more prevalent.

We envision using disturbance profile information like that in Table 1 for guiding stand assessment or prescriptions. For example, let us assume for illustrative purposes that the management objective of the Delworth stand is to maintain Mexican spotted owl habitat, but that the diversity and abundance of small mammal prey is low. The manager wants to determine why and how to correct the situation. Let us also assume that the target profile for this objective has been established. For this exercise, 'healthy' is defined as a state of the stand in which the populations of small mammal prey for the Mexican spotted owl are adequately diverse. In this context, diverse includes species richness and abundance of each target species. "Adequate" means enough diversity to increase the availability of the owl's prey. Thus, an adequate condition should not eliminate the potential for owls to forage in the stand while increasing prey diversity. Keeping canopy gap sizes below a critical threshold would help to insure the adequate condition is met. In addition, "health" is a relative term that depends on the stand's current state relative to the desired or target state. Threshold values of health depend on and vary with management objectives.

When compared to the hypothetical profile for enhancing habitat of the owl and its prey (presented as desired condition in Table 1), the current Delworth profile shows a few out-of-range variables. Specifically, stem density of all tree species, canopy density of overstory, and contagion are high; log (downed woody debris >1 m long and > 10 cm diameter at widest end) frequency is low; and snag frequency and average gap area are slightly low. A silviculturist would have to determine whether these values indicate the need for silvicultural intervention.

Interpreting disturbance profiles might present a formidable task. A silviculturist might ask a plant pathologist, entomologist, wildlife biologist, or other specialist for help in interpreting the profile,

much as a general practitioner asks help of various specialists to interpret results of a blood profile. The manager might consider disturbance profiles of adjacent stands and the spatial/temporal distribution of proposed treatments among these stands. Different stands may have various objectives, and individual stands themselves may have multiple objectives. Methods of dealing with multiple stand-multiple profiles need to be developed. Until we have more diagnostic experience using disturbance profiles, interpretations will depend on logic, good judgement, and field experience.

A silviculturist might derive the following from the data presented in Table 1:

Interpretation—Delworth has too many trees, too strongly clustered canopy gaps, and not enough logs on the ground.

Prescription—enlarge small gaps in less-gaped parts of the stand (use the gapograms to guide placement of gaps) to diameters ranging between 5 m and 15 m and leave the cut trees (> 10 cm diameter and > 1 m length) on the ground within gaps.

By indicating specific abnormal stand-level functions, disturbance profiles would offer a mechanistic basis for making silvicultural decisions. Eventually, root diseases, bark beetles, spot fires and other disturbance agents themselves might be used as silvicultural tools to adjust stands. However, until a much better understanding of their biology and dynamics is developed through research and field observations, the chainsaw will probably remain the major disturbance agent used by the silviculturist. Silvicultural prescriptions could be based on styling gaps to mimic natural disturbances. Gap size could be increased or specific gap shapes fashioned. Dead wood could be imported. Individual trees could be killed and left standing to create snags. Grasses could be planted. These would be very aggressive management actions, and cost effectiveness would certainly be questioned. These actions, however, do illustrate tools available to silviculturists. As the value of non-timber resources becomes better understood, an examination of the cost effectiveness of these actions may yield unexpected results.

The range of values for target condition in this example are only hypothetical and undoubtedly

simplistic. Indeed, current on-going studies have shown that the habitat requirements of the Mexican spotted owl are probably much more complex than the above statements indicate. For instance, site potential would also need to be considered in developing prescription. Enlarging tree canopy gaps at xeric locations of a stand, for example, may not enhance habitat of long-tailed voles over Mexican voles because grasses, forbs and herbs may not have the potential to produce thick cover needed by voles. Furthermore, there may be interspecific competition among the targeted mammals. Long-tailed voles and Mexican voles tend to exclude deer mice from open areas. Thus, when vole populations are high, deer mice are not found in gaps; when voles are low, deer mice populations are relatively high within the gaps.

One aspect of our current research at the Rocky Mountain Experiment Station is to identify associative patterns and establish target conditions. For some objectives, however, initial operational target values could be derived from best guesses (or informed decisions) by combined research/management teams that periodically monitor, evaluate and revise their decisions. Additional iterations would yield better and better values for target ranges. Ultimately, however, target profiles will need to be based on a solid understanding of how disturbance and recovery processes integrate with managed forest resources.

SIMPLIFYING INTERPRETATION OF DISTURBANCE PROFILES

An array of statistical analyses can be used to analyze multivariates like disturbance profiles (Dillon and Goldstein 1984). Statistical analyses may be useful in simplifying the interpretation of this metric. In a study conducted in the Black Hills, for example, several ponderosa pine stands were grouped using cluster analysis based on disturbance profiles (Lundquist 1995c).

Other ordination techniques are currently being examined for determining target values and quantifying health (Lundquist and King unpublished). For example, multidimensional scaling (Dillon and Goldstein 1984) has been used to represent similarity among stands as the distance between points in

CONCLUSIONS

Small-scale disturbance processes help shape forest ecosystems. Using small-scale natural disturbances as tools of silviculture will require solid scientific knowledge about how disturbances affect the environment and the many resources of societal value within the environment. Managers need methods to quantify and predict ecological effects to make appropriate decisions on the use of natural disturbance. Inventory and data collection efforts must be able to adequately assess the positive impacts of forest disturbances, as well as the negative impacts. Researchers who try to understand the processes controlling the forest environment, and managers who try to manipulate these processes, will rely more and more on each other as they are forced to manage a greater and more complex mix of resources.

The spatial models and disturbance profiles discussed above are still mostly hypothetical. The odds are that no single or complex metric will ever be able to capture the true complexity and dynamicism of a forest stand. But, disturbance profiles may be able to capture enough of the complexity to make them useful tools to silviculturists. Much work remains to be done before they can become operational. Nonetheless, we believe that disturbance profiles (or some multivariate metric like them) will meet the five criteria required of a metric to relate disturbance and forest health (Geils and other 1995, these proceedings): 1) sensitive and responsive to disturbance and recovery; 2) relates to ecological patterns and processes at a scale that silvicultural decisions are made; 3) links to multiple scales; 4) corresponds to ecological functions that affect resource values; and 5) can portray the impact of management actions in quantitative models. We believe that eventually spatial models and disturbance profiles will be able to define the condition of a stand as well as to help guide silviculture.

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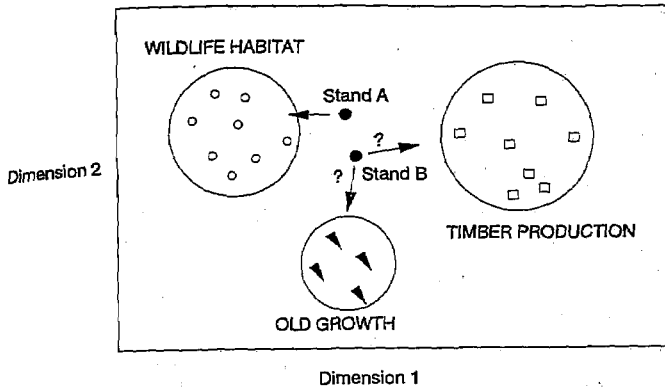


Figure 3.—Hypothetical two-dimensional clustering of the disturbance profiles associated with stands used for three different management objectives. Each box, triangle, or circle represents a single stand. Objectives include: timber production (boxes), old growth landscape (triangles), and enhancement of Mexican spotted owl habitat (empty circles). The three large circles each define target conditions for each objective. The arrow signifies the trajectory or direction and magnitude of change that must be induced by silvicultural manipulations to make stands A and B suitable for one of the objectives. Stand A (which represents Delworth) is closest to the wildlife habitat cluster, and management interventions would probably best be aimed at that objective. Stand B is equidistant from the clusters for timber production, old growth landscape, and wildlife habitat; more information would be needed before silvicultural prescriptions can be developed (Lundquist and King, unpublished).

2-dimensional space (fig. 3). With this procedure, desired stand conditions are quantitatively defined as a clustered space on the multidimensional model.

Operationally, a silviculturist would be presented with a computer image, as shown in figure 3. The current condition of a stand would be represented by a point in this space. If this point were outside the target cluster, then silvicultural manipulations or alternative objectives would be necessary. The objective of silvicultural manipulations would be to move this point to within the target space by selectively manipulating the values composing the disturbance profile. An adjusted profile would be calculated and displayed as a newly positioned point. The direction and length of point movement (its trajectory) would be a quantitative measure of the effectiveness of the silvicultural manipulation. The distance between the point and the target area would be a quantitative measure of the stand's health.

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