

CHAPTER 11

Impacts of Diseases and Other Disturbances on Non-Timber Forest Resources: A Case Study involving Small Mammals

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Introduction

Part of the diversity of a forest is the variety of agents that can kill trees. These agents differ in the nature, magnitude, and patterns of their impacts on forest resources. Diseases, insect pests, and other small-scale disturbances are commonly assessed on the basis of their impacts on timber production. Tree mortality usually means reduced volume of living stems. Consequently, forest pathologists and entomologists have **traditionally maintained** a negative view of these disturbances.

Dead trees have traditionally invoked a different perspective for wildlife biologists. To them, dying trees either embody important habitat structures or lead to conditions that support animal existence (Maser et al., 1979; Thomas et al., 1979; Raphael and White, 1984; Ramotnik, 1997). For example, fallen trees create openings in forest canopies that stimulate development of plant understory: tree seedlings, shrubs, forbs, and grasses that in turn provide food and cover for small mammals (Carey et al., 1999). Fallen trees also provide small mammals with refuge from predators, nesting sites, and nursery conditions for production of other food sources, such as arthropods and fungi (Goodwin and Hungerford, 1979; Hayes and Cross, 1987; Carey et al., 1999). Several forest pathology and entomology studies have speculated on the ecological significance of diseases and insects pests, but few have actually addressed their impacts on wildlife habitat (Hart 1993; Bennetts et al. 1996).

In addition to diseases and insects, the most frequently cited disturbances in forests are fire, logging, and livestock grazing (Shaw et al., 1993; Swetnam and Baisan, 1994; Tkacz et al., 1994; Geils et al., 1995; Kaufmann et al., 1998). The most commonly recognized expression of a disturbance is probably tree mortality. Not all disturbances kill trees in the same way. Because they often act selec-

tively, the canopy gaps they cause can have distinctive characteristics depending on which trees are killed, what woody structures remain, and how succession proceeds. We hypothesize that particular tree killing pathogens, insects and other disturbances can have specific effects on small mammal habitat, and that the relative importance of different tree-killing agents depends on their nature, magnitude, and spatial patterns.

Here we evaluate this hypothesis using a test case involving five species of small mammals common to the forests of the southwestern United States. These small mammals are common prey of a threatened raptor, the Mexican spotted owl (*Strix occidentalis lucida*) (Ward and Block, 1995). Information detailing influence of biotic factors and linkages with the abundance and distribution of these species will be useful for defining restoration prescriptions that may help conserve these wildlife species.

Methods

Study sites. This study was conducted on three sites that spanned an ecological gradient in the Sacramento Mountains of south-central New Mexico. The gradient was determined by altitude, aspect, topography, and vegetation. We categorized our sampled sites as xeric, transitional, or mesic.

The vegetation at the xeric site represented coniferous woodlands below 2200 m. This woodland was comprised primarily of pinyon pine (*Pinus edulis*) and juniper (*Juniperus* spp.) with limited occurrence of ponderosa pine (*Pinus ponderosa*). Vegetation at the mesic site was comprised of mixed conifer forest, including Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), and southwestern white pine (*Pinus strobiformis*). The mesic site was above 2200 m and classified as upper montane conifer forest.

The transitional site occurred where ponderosa pine, and less frequently, pinyon and juniper were associated with the mixed conifer species. The vegetation at this site represented a transition between upper and lower montane coniferous forests (Dick-Peddie, 1993). These sites were selected at random from 106 areas known to be occupied by Mexican spotted owls. Tree cutting and livestock grazing had occurred historically at all three sites.

We established a 4-ha plot at each of the three sites to characterize horizontal structure of the forest canopy, assess **tree-killing** agents, quantify amounts of downed woody debris, and the distribution of small mammals. We further subdivided each plot into a grid of stations to systematically sample some of these parameters. Intervals between stations varied according to the parameter sampled, as described below.

Characterization of Forest Canopy. We characterized forest canopy structure by quantifying the pattern of canopy gaps, edges, and forest matrix following procedures described by Lundquist (1995). At each plot, we sampled the horizontal projection of crown cover and crown length using a concave, spherical optical densiometer. Densiometer values provided a relatively standard index of crown density (percent canopy density or PCD) in a conical sample volume above each observation point. PCD values ranged from 0% where no crown was detected to 100% where the crown occupied the entire sample view. We recorded PCD at 1681 observation points per plot (a grid with 5-m intervals between points). We normalized PCD by subtracting from it the plot mean and dividing by its standard deviation. We classified contiguous areas where the normalized percent canopy density (NPCD) exceeded 0 as closed canopy (forest), and areas with an NPCD less than 0 as canopy gaps (gap). These procedures provided operational and replicable definitions for describing canopy structure over a variety of forest conditions ranging from open, short stature woodlands to dense, tall forests. We imported NPCD into a geographic information system (IDRISI, Eastman, 1992) to map the location of gaps and compute gap number and area.

Characterization of gaps. We used the maps of forest gaps to relocate individual gaps in the field. For each gap, we assessed probable causes, measured gap size more precisely, and estimated amount and condition of down woody debris.

We used a team of plant pathologists, entomologists, and ecologists to ascertain gap causes (AGENT). This team ascertained causes by examining local conditions and developing a consensus about the agents that actually **killed** trees to create a specific gap. Diagnosis of causal agents was based on a careful evaluation of obvious symptoms and signs. For example, strong winds were commonly associated with uprooting and stem breakage. Ice and snow commonly caused trees with slender stems to bend, especially trees at the edges of existing gaps. Lightning often caused vertical bark strips up to many centimeters

wide along the stem. Blackened stems and/or duff signified wildfire.

Dwarf mistletoes were identified by their vegetative and fruiting structures on stems and branches. Bark beetles often caused total foliage discoloration and death associated with egg galleries and frass under the bark. Root diseases caused a general progressive crown decline, with red or chlorotic needles, basal resinosis, stunted internodes, and needles, and sometimes a limited cone crop. Stem cankers caused discolored and necrotic portions of stems and branches and flagging and spiketops in crowns. Human activity other than timber harvesting commonly involved road building and other clearing in the forest. Juniper **dieback**, caused by an unknown agent, was indicated by dead branches and stems, and missing bark. Stem fall occurred when dominant trees fell on and toppled codominant neighboring trees.

Symptoms commonly varied continuously in quality and intensity due to age, host, and environment. We recorded best guesses when disturbance agents were not obvious. Where diagnosis was not possible, we noted the cause as unknown.

We measured gap size as an area determined from two perpendicular axial lengths, L and D. L represented the longest length in a gap, and D was measured as the length perpendicular to L. We calculated area of each gap (GAPAREA) as the area of an ellipsoid using $3.414 * L * D / 4$ (Runkle, 1992). Because the ellipses approximated the boundaries of gaps, gap sizes included some area of forest edge.

We assessed the amount and condition of woody debris by measuring and classifying downed logs found within gaps. We classified the decomposition state of each downed log (>12 cm at widest end and > 2 m length) according to diagrams and definitions developed originally for spruce (*Picea spp.*)/fir forests in the Pacific Northwest (Maser et al., 1979; Thomas et al., 1979; Fahey, 1983) that we modified slightly. Log decomposition classes ranged from 1 to 5 corresponding to a gradient of freshly fallen to mostly decomposed. We recorded number of logs (LOGCOUNT) and average decomposition condition of logs (LOGMEAN) in each gap. We calculated log density (INTENSITY) as LOGCOUNT/GAPAREA.

Distribution of small mammals. We quantified the distribution and abundance of deer mice (*Peromyscus maniculatus*), brush mice (*Peromyscus boylii*), Mexican voles (*Microtus mexicanus*), long-tailed voles (*Microtus longicaudus*), and Mexican woodrats (*Neotoma mexicana*) using mark-recapture procedures. We captured small mammals with 121 large (8 X 9 X 23 cm) and 57 extra-large (10 X 18 X 60 cm) live-traps (Sherman, Tallahassee, FL) at each site placed at stations spaced 20 m (large traps) or 40 m (extra-large traps) apart (Ward, 2001). We trapped for 8 consecutive nights, once at each plot during July through August in 1992, 1993, and 1994. We marked captured individuals with unique ear tags (National Band and Tag, Co., Newport, KY). Systematic sampling from trap stations

allowed us to document the spatial distribution of individuals of each species during each period. We used the number of individuals (at time of first marking) that occurred at each trap station during a given period as a measure of small mammal distribution.

Relationships among disturbance agents, canopy gaps, and small mammals. We used a nonparametric analysis method called Classification And Regression Tree, CART (Breiman et al., 1984) to model the kinds of gaps in which the small mammal species were found. CART analysis was used to select significant classification variables and develop a binary decision tree. In this application, we evaluated forest community type (xeric, transitional, mesic) and several gap characteristics (area, number of logs, mean log score, and number of logs per unit area) as predictors of the numbers of gaps in which a species was or was not trapped. We used cross validation to evaluate performance of each CART model (Steinberg and Colla, 1992.) Accordingly, we used the results from the CART decision tree to describe habitat conditions of these small mammals with respect to gaps in forest canopies and causal disturbance agents.

Results

Site profiles. Each of the three sites examined had a distinct profile of characteristics that described live tree composition (tree density, basal area, and stand density index), forest canopy structure (percent canopy density, number of gaps, and gap area), and coarse woody debris (log decomposition score, log abundance, and log density) (Table 11.1). The xeric and transitional sites were more open and had fewer logs than the mesic site. The transitional site was distinguished from the xeric site by its greater number of large, live trees, its more numerous gaps, and its more decomposed logs. The xeric, transitional, and mesic sites, respectively, had 17, 36, and 19 gaps. Of these, 11, 36, and 18 gaps, respectively, were associated with one or more identifiable, tree-killing agents (Fig. 11.1). These disturbance agents were: tree cutting, wind, ice/snow, lightning, fire, mistletoes, bark beetles, root diseases,

stem cankers, human disturbance other than tree cutting, juniper decline, stem fall, soil erosion, regeneration failure, livestock grazing, and road building. Gaps were frequently caused by several agents. Multiple tree-killing agents were observed in 7 (42%) gaps at the xeric site, 12 (33%) gaps at the transitional site, and 11 (58%) gaps at the mesic site.

Each site had a unique profile for the distribution of gap area, log decomposition score, log number, and log density. In addition, the types of agents associated with gaps of distinct character varied according to site. At the xeric site, for example, very large gaps were caused only by fire and soil erosion. In addition, tree cutting, fire, and juniper dieback usually created gaps with high log densities. Gaps at the transitional site showed a broad range of values for gap area and log decomposition score. The most common gaps at the transitional site were caused by tree cutting (with well decomposed logs present), fire (with a mix of fresh to well-decomposed logs), mistletoe (large gaps with well decomposed logs), and bark beetles (with a mix of fresh to well-decomposed logs). At the mesic site, gaps were more uniform with regard to gap area and log decomposition score, but could be distinguished using log number and density. Tree cutting, wind, bark beetles, other human activities, and road building created gaps with an unusually high number and density of logs.

Disturbance agents and canopy gaps. Different disturbance agents were associated with different ranges of values for the four variables used to characterize individual gaps. Some agents were associated with variable values that were far outside the midrange. For example, fire, and soil erosion were both found in very large gaps at the xeric site, and wood cutting, fire and juniper dieback caused similar values for INTENSITY. The transitional site showed generally wider ranges of values for GAPAREA and LOGMEAN, where outliers were associated with bark beetles, dwarf mistletoes, fire, and tree cutting. At the mesic site, tree cutting, wind, bark beetles, and human caused disturbances other than tree cutting caused notable outlier values for LOGCOUNT, and tree cutting, road building and wind showed outliers for INTENSITY. All other agents caused variable values that occurred within the midrange.

Table 11.1. Elevation range, canopy, and coarse woody debris characteristics at three sites examined to investigate the association of forest disturbance and small mammal distribution.

Characteristic	Xeric	Transitional	Mesic
Elevation range (m)	2170-2237	2472-2575	2551-2591
Tree density (live trees/ha)	60	658	478
Basal area (m ² /ha)	3	23	32
Stand density index	8	190	234
Percent canopy density (mean,SD)	20(29)	53(31)	76(25)
Number of gaps (gaps/4-ha plot)	17	36	19
Mean gap area (m ²)	2351	2983	927
Median log decomposition score†	2	3	3
Log abundance (logs/gap)	5.9	6.3	12.6
Log density (logs/m ²)	0.005	0.003	0.031

†Log decomposition score is based on a five-class system for describing the stage of deterioration from 1 for a newly killed and fallen tree to 5 for a log which is thoroughly decomposed.

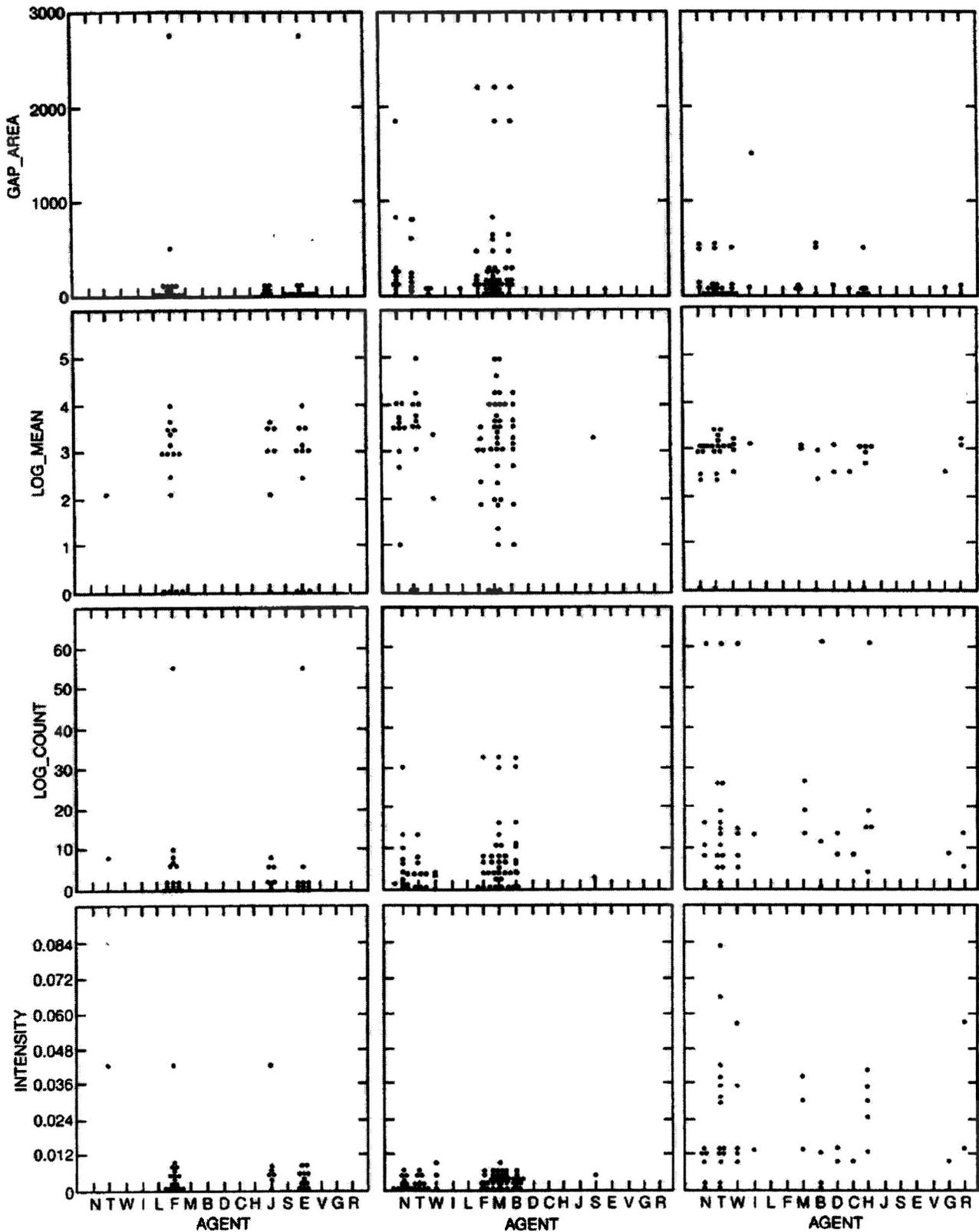


Figure 11.1. Dot plots showing the variation in values associated with disturbance agent. Values are for all plots combined. Left column represents xeric, middle column is transitional, and right column is mesic forest type. Agent codes are: N - Unknown, T - Tree cutting, W - Wind, I - Snow/ice breakage, L - Lightning, F - Fire, M - Dwarf mistletoe, B - Bark beetles, D - Root disease, C - Stem canker, H - Human activities other than tree harvesting, J - Juniper dieback, S - Stem fall, E - Soil erosion, V - Regeneration failure, G - Livestock grazing, and R - Road.

Canopy gaps and small mammals. Few gaps were not occupied at one time or another by the studied small mammal species. Over three years of trapping, at least one capture was obtained on 68% of the stations at the xeric site, 65% at the transitional site, and 82% at the mesic site. The number of individual captures at these stations varied among sites and years (Table 11.2). More mammals were captured at the mesic site than at either of the other two. Each of the 5 small mammal species was captured at least once during all 3 years at all 3 plots with the following exceptions: Mexican voles were not captured at the xeric site, brush mice were not captured at the mesic site, and long-tailed voles were not captured at xeric or transitional sites.

Deer mice were the most commonly captured species at the mesic site. Brush mice were the most commonly captured species at the xeric and transitional sites.

CART analysis for brush mice showed a gap association pattern that depended on site, gap size, and mean log decomposition class (Fig. 11.2). The model predicted that brush mice would occur only at xeric and transitional forest sites in gaps that were either 1) > 2368 m², or 2) < 1026 m²

with LOGMEAN < 1.2. The cross-validation table showed this model with a misclassification rate of 41%. Twelve out of 13 gaps that were > 2368 m² were occupied by brush mice. Eight of 9 gaps < 1026 m² and with LOGMEAN < 1.2 had brush mice present. Gaps between 1026 m² and 2368 m² in size and with LOGMEAN > 1.2 were occupied in only 2 of 28 cases. Dwarf mistletoes and bark beetles were the most common causes of gaps > 2368 m², but several other agents occasionally caused these conditions, including tree cutting, wind, fire, and human disturbance other than tree cutting (Fig. 11.1). All disturbances could cause gaps < 1026 m², but only dwarf mistletoes and bark beetles were most commonly associated with the lower log decomposition scores (Fig. 11.1). Furthermore, low scores reflected less decomposition and, by inference, more recent mortality.

The CART decision tree for Mexican voles split on 2 nodes based on gap area (Fig. 11.3) with a cross-validation table that showed a 24% rate of misclassification. The model predicted that Mexican voles would occur in gaps that were > 2368 m². For example, at the transitional forest plot

Table 11.2. Distribution of captures (number of different individuals) by mammal species, study site, and calendar year. Trapping was conducted at 121 stations per site over 8 consecutive nights during July and August.

Xeric Species	Transitional				Mesic				1992	1993	1994	Total
	1992	1993	1994	Total	1992	1993	1994	Total				
Deer mouse	15	4	10	29	17	19	21	57	34	20	38	92
Brush mouse	57	24	22	103	32	6	7	45	0	0	0	0
Mexican woodrat	11	1	0	12	8	10	4	22	7	3	0	10
Long-tailed vole	0	0	0	0	0	0	0	0	55	23	2	80
Mexican vole	0	0	0	0	12	0	0	12	10	0	0	10
Total	83	29	32	144	69	35	32	126	106	46	40	192

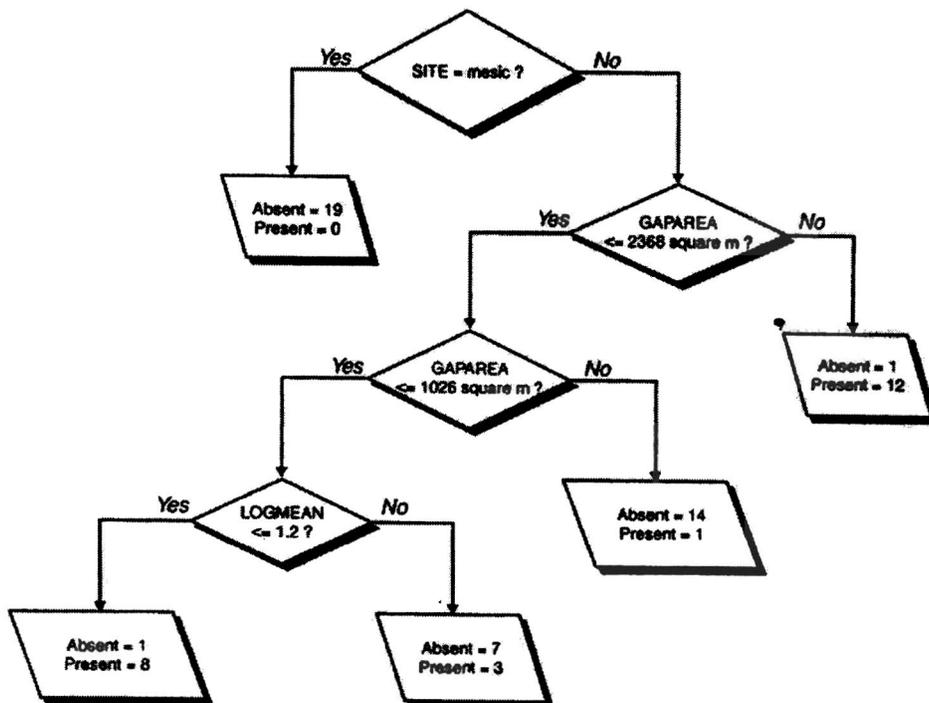


Figure 11.2. CART classification tree using SITE, GAPAREA, LOGMEAN, LOGCOUNT and INTENSITY as predictor variables and presence or absence of brush mice trapped within gaps (all plots and years combined) as dependent variables. LOGCOUNT = total number of logs within each gap. LOGMEAN = average log decomposition score. INTENSITY was calculated as LOGCOUNT/GAPAREA.

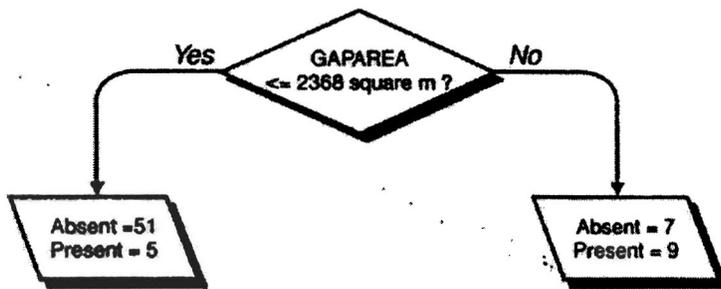


Figure 113. CART classification tree using SITE, GAPAREA, LOGMEAN, LOGCOUNT and INTENSITY as predictor variables and presence or absence of the Mexican vole as the dependent response. LOGCOUNT = total number of logs within each gap. LOGMEAN = average log decomposition score. INTENSITY was calculated as LOGCOUNT/GAPAREA

Mexican voles occurred in 6 of the 7 large gaps. Many of these larger gaps were clusters of smaller gaps. Various killing agents caused gaps that were suitable to Mexican voles. Over all plots, dwarf mistletoes and bark beetles were the most common causes of gaps within the size range of gaps used by Mexican voles. Several other agents occasionally caused these conditions, including tree cutting, wind, fire, and human disturbance other than tree cutting (Fig. 11.1).

The CART procedure failed to create decision trees for deer mice, Mexican woodrats, and long-tailed voles, suggesting that habitat choices by these species were made on the basis of criteria other than those measured.

Discussion

Composition and intensity of disturbance agents are expressed by the spatial extent and patterns of canopy gaps, and composition of coarse woody debris and patterns of recolonizing vegetation within those gaps. Bradshaw (1992) states that gaps "acquire their character from the magnitude and nature of various edge effects." In contrast, Coates and Burton (1997) emphasize the importance of gap size and position. Our results indicate that some small mammal species are influenced by gap characteristics and some are not. For those that are, gap size can be a major factor determining their distribution. For other small mammals, multiple characteristics associated with gaps and edges are likely important.

The size of any forest gap is determined by a complex interaction of different agents; the details of this interaction may be useful in explaining animal behavior (Bradshaw, 1992). In our study, the spatial distribution of large forest gaps was commonly caused by bark beetles, dwarf mistletoes, and fire. Tree cutting, wind, human disturbance other than tree cutting, and soil erosion sometimes created large gaps, but infrequently and hence, less predictably.

The Mexican vole was captured only within the largest gaps of the studied forest types. This species also attained high densities in open meadows of the Sacramento Mountains (Ward, 2001). In contrast, the long-tailed vole occupied all but the smallest gaps that could be created by nearly any of the disturbance agents.

In addition to gap size, the character of woody debris in those gaps may influence small mammal distribution (Ma-

ser et al., 1979). Our analysis of brush mouse distribution suggests that gap size, log abundance, and log condition may have affected the mouse's foraging patterns and travel. Like gap size, the condition of logs found within a gap also depends on type of agent responsible for tree mortality. For example, road building and human disturbances other than tree cutting leave unique signatures. They act over a very limited period of time and are associated with the selective removal of certain parts of the stem. Because they leave a restricted range of debris compared to other agents, they create a disturbance pulse that is reflected in the limited range of variability in decomposition classes. Bark beetles similarly kill groups of trees over a short time, leaving snags that eventually become logs. Root diseases and dwarf mistletoes, on the other hand, usually act more slowly, but continuously, accumulating dead logs with time. The disturbance agents undoubtedly impact small mammals differently because of different dynamics associated with coarse woody debris, and variability in small mammal requirements.

Based on the observations described above, we hypothesize that 1) dwarf mistletoe, bark beetles, and to a lesser extent, wildfire influence the presence, abundance, and distribution of Mexican voles and brush mice more than other small-scale killing agents in the Sacramento Mountains of New Mexico, and 2) all killing agents equally influence the presence, abundance, and distributions of deer mice, Mexican woodrats, and long-tailed voles.

Canopy structure is among the most easily measured and manipulated features of the forest. Assuming a connection can be shown between canopy structure and the distribution of small mammals, then canopy structure might be a basis for prescriptive silviculture aimed at creating or maintaining foraging habitat for predators such as the Mexican spotted owl, or small carnivores. For example, recent experiments by van Pelt and Franklin (1999) that created 0.2-ha gaps in late seral douglas-fir forests increased production of understory trees. Experiments like these are needed with the addition of monitoring wildlife responses.

Management Implications. Most disturbances are not devastating epidemics or vast conflagrations that destroy everything in their path. Most disturbances are modest tree killing events, which selectively impact various ecological and economic elements of the forest. Relatively little is known about the impacts of small-scale disturbances, yet

these are major drivers of the **patterns** and processes necessary for healthy, sustainable forest ecosystems.

Forests are managed for a wide variety of objectives. Because of the traditional emphasis on timber production, silvicultural prescriptions are usually written at the stand scale. Stand-based prescriptions give limited guidance for making decisions at the sub-stand scale because they usually do not reflect the within-stand spatial heterogeneity of canopy structure, coarse woody debris, recolonizing vegetation, and regeneration that can impact wildlife habitat and other non-timber resources. Coates and Burton (1997) argue that the traditional stand-based systems "... are too narrowly focused to meet ecosystem management objectives", and propose a canopy gap-based silvicultural system. They suggest that by manipulating the population of canopy gaps, stand level heterogeneity could be deliberately and more appropriately changed to meet a wide range of timber and non-timber resource objectives. We propose that, **under** some circumstances, **silviculturists** may even need to mimic canopy gaps created by specific disturbance agents. Because silvicultural manipulations can create, replace, or influence many of the characteristics of disturbances caused by insects, pathogens, or other factors, they can be a valuable tool for establishing and maintaining conditions suitable for non-timber resources.

The study we describe here is based on relatively few data collected over a limited geographic range. Nonetheless, the results suggest that disturbances differ in their relative importance in creating small mammal habitat. The literature describing the effects of canopy gaps on various animals is extensive, but studies linking these effects to specific disturbances are rare (Holah *et al.* 1997). Most of these studies treat disturbance as a generic event and do not distinguish among specific causes. Small-scale disturbances create canopy gaps that influence the presence, abundance, and distribution of some small mammals, but our case study described here suggests that not all disturbance agents create conditions suitable for all species. Managing forest resources is an increasingly complex business. If disturbances are necessary to sustain forest ecosystems, then managers need to know why. Managers may need to know more about these associations, and how they can be measured and monitored.

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