BAT ACTIVITY IN THINNED, UNTHINNED, AND OLD-GROWTH FORESTS IN WESTERN OREGON

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Abstract: Many aspects of the influences of forest management activities on bats (Chiroptera) in the Pacific Northwest are poorly known. We compared thinned and unthinned forest stands of the same age and old-growth forest stands to determine potential differences in structure and amount of use by bats. We hypothesized that activity levels of bats would differ in stands differing in structure as a result of management history and that activity of bats would be similar in stands of similar structure. We used automated ultrasonic detectors (Anabat II) to record calls of bats in 50–100-year-old thinned and unthinned stands, and in old-growth (≥200 yr old) stands in the Oregon Coast Range during the summers of 1994 and 1995. Our median index of bat activity was higher in old-growth than in unthinned stands and higher in thinned than in unthinned stands. We were not able to detect a significant difference between the index of median bat activity for old-growth and thinned stands. More than 90% of identifiable passes were identified as calls from *Myotis* species. The 3 stand types we examined differed in certain structural characteristics such as density and size of trees, and amount of overstory and understory cover. We concluded that the structural changes caused by thinning may benefit bats by creating habitat structure in young stands that bats are able to use more effectively.

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Ten species of bats occur in the Oregon Coast Range and are associated with forests for either roosting or foraging activities (Maser et al. 1981). Of these, Townsend's big-eared bat (*Corynorhinus townsendii*), silver-haired bat (*Lasionycteris noctivagans*), long-eared myotis (*Myotis evotis*), fringed myotis (*Myotis thysanodes*), and long-legged myotis (*Myotis volans*) are classified as Species of Concern by the U.S. Fish and Wildlife Service and are considered Sensitive (likely to become threatened or endangered) in Oregon (Oregon Department of Fish and Wildlife. 1997. Oregon sensitive species list, unpublished. Portland, Oregon, USA).

Information on the ecology of these species is limited. Several recent studies on the ecology of bats in the Pacific Northwest have focused on roosting (Betts 1996, Chung-MacCoubrey 1996, Vonhof 1996, Vonhof and Barclay 1997, Ormsbee and McComb 1998) and on habitat use as determined by mistnetting (Perkins and Cross 1988) or by recording echolocation calls made by bats (Thomas 1988, Erickson 1993, Hayes and Adam 1996). Some of these studies have found that habitat use differs in stands of different ages. Thomas (1988) reported higher levels of activity by bats as indicated by higher numbers of echolocation calls in old-growth forest than in young and mature (40–165 yr old) forests in the Oregon Coast Range and Washington Cascades. In managed stands in the Washington Cascades, Erickson (1993) reported higher levels of activity by bats in 51–62-year-old stands than in 10–13-year-old stands, but reported even greater activity in 4–7-year-old stands. These studies raise the question of whether activity of bats differs in stands of similar ages subjected to different management practices.

Thinning is a forestry management practice that has been applied in even-aged Douglas-fir (*Pseudotsuga menziesii*) stands in the Pacific Northwest for the last 20–30 years (Tappeiner 1992). Thinning is defined as the reduction in density of overstory trees through removal of selected trees (Smith 1986, Tappeiner 1992), and historically has been used to maximize timber production and revenue. In addition to increasing rates of diameter growth of uncut trees, thinning results in enhanced development of tree crowns and establishment of hardwoods,

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Table 1. Ages, site indices, time of thinning, tree densities, and stand sizes for 11 pairs of forest stands in the Oregon Coast Range, 1994–95 (na = not applicable, no old-growth sampled).

				Thinned			Unthinned	Old-growth
Site	Age	Site index[a]	Year sampled	Year thinned	% volume removed	Stand size (ha)	Stand size (ha)	Stand size (ha)
Adams Siding	75	37.8	1995	1976	Unknown	28	63	na
Bald Mountain[b]	70	36.6	1994	1976	33	38	20	na
Bear Creek[b]	100	40.9	1994	1972	27	16	20	20
Beaver Flat	50	39.6	1994–95	1974	51	21	10	70
Black Rock	70	34.1	1995	1974	Unknown	22	73	25
D-Line[b]	60	36.9	1994	1972	12	34	40	20
Elliot	100	39.9	1995	1973	54	29	57	40
Gnome	60	36.6	1994–95	1983	43	10	40	50
Highpass[b]	90	34.8	1994	1971	20	18	10	30
North Ward	50	39.6	1995	1985	50	46	17	25
Sand Creek[b]	70	39.0	1994	1971	32	40	40	25

[a] Site index = height (m) of the dominant and codominant trees at 50 years of age (King 1966).
[b] Data from Bailey (1996).

conifers, and shrubs in the understory, thereby leading to development of multistoried stands (Tappeiner 1992, Barbour et al. 1997, Hayes et al. 1997, Bailey and Tappeiner 1998). These observations have led scientists to suggest the use of thinning to accelerate development of structural characteristics typical of old-growth stands (Nyberg et al. 1987, McComb et al. 1993, Hayes et al. 1997).

Our objectives were to assess the influence of thinning on use of forest stands by bats by comparing activity of bats in thinned and unthinned stands of the same age and by comparing activity of bats in these stands to activity of bats in old-growth stands. We hypothesized that activity of bats would differ among stands differing in structure as a result of management history, and that activity of bats would be similar in stands with similar structure.

STUDY AREA

We conducted this study in the western hemlock (*Tsuga heterophylla*) zone of the Oregon Coast Range (Franklin and Dyrness 1984). The climate in this region is characterized by wet winters and dry summers, with annual precipitation ranging from 150 to 300 cm. Temperatures are mild, with low temperatures in January averaging −1°C and high temperatures in July averaging 26°C (Franklin and Dyrness 1984).

We used the following criteria to select 11 pairs of forest stands for study: (1) stand ages were ≥50 years and ≤100 years old; (2) part of the original stands were thinned between 1971 and 1985, generating paired thinned and unthinned stands; (3) unthinned stands were otherwise similar to thinned stands (e.g., elevation, slope, and aspect); (4) if possible, pairs were located within 15 km of an old-growth stand (200+ yr) exhibiting multistoried stand structure; and (5) each stand was at least 10 ha in size (Table 1). All stands were adjacent to roads and were within 1 km of streams. Because old-growth stands are rare in the Oregon Coast Range, we were not able to locate old-growth stands for all pairs of stands. Old-growth stands were found at elevations similar to those of the younger stands; however, the slope and aspect of these stands sometimes varied from the slope and aspect of the younger stands.

The thinned and unthinned paired stands regenerated naturally in the early to mid-1900s, following cutting and burning often associated with railroad logging (Bailey 1996). Each of these stands was composed primarily of 1 age cohort, with few large trees or snags remaining from the previous stand. Overstories in the young stands were dominated by Douglas-fir, with western hemlock, western redcedar (*Thuja plicata*), and true firs (*Abies* spp.) present in some stands.

The old-growth stands had little or no evidence of human disturbance and had structural characteristics typically associated with old growth, including large diameter trees, a multilayered canopy, and abundant large snags (Franklin and Spies 1991). Overstories in old-growth stands generally were dominated by Douglas-fir and western hemlock. Common understory shrubs included salal (*Gaultheria shal-*

Table 2. Minimum frequency (kHz) and duration (milliseconds) of echolocation calls of bats in 6 call-types recorded in the Oregon Coast Range, 1994 and 1995, based on call characteristics described in Thomas and West (1989) and Erickson (1993), and through observations of S. Cross, Southern Oregon University, and J. P. Hayes, Oregon State University.

Group	Species included	Frequency range	Duration
MYTH	Fringed myotis	<30.0	3–7
NON-MY[a]	Big brown bat (*Eptesicus fuscus*)	<33.5	>5
	Silver-haired bat		
	Hoary bat (*Lasiurus cinereus*)		
MYEV	Long-eared myotis	30.0–36.5	<4
MYVO	Long-legged myotis	34.0–47.0	>4
MYLU	Little brown myotis	37.0–47.0	<4
CA-YU	California myotis	≥47.5	<5
	Yuma myotis		

[a] The NON-MY group is characterized by calls with substantial narrowband FM portions; all other groups are characterized by broad-band FM calls.

lon), dwarf Oregon-grape (*Berberis nervosa*), and vine maple (*Acer circinatum*).

METHODS

Activity of Bats

We used Anabat II bat detectors coupled with delay switches (Titley Electronics, Ballina, New South Wales, Australia) and tape recorders (Model VSC-2002; Radio Shack, Fort Worth, Texas, USA) to record echolocation calls of bats throughout the night in each stand (Hayes and Hounihan 1994). Although automated bat detectors avoid some of the biases of other methods for surveying bats (Thomas and West 1989), there are limitations associated with this method. Because we were not able to distinguish between multiple passes by a single bat and single passes by several bats when we used detectors, the number of bat passes was not a direct measure of the abundance of bats. However, bat detectors can provide an index to relative activity of bats in different habitats (Thomas and West 1989) when temporal patterns are accounted for (Hayes 1997). In addition, bat detectors do not detect all species equally well. Bats with high-intensity calls are more likely to be recorded at greater distances than are those with low-intensity calls.

We placed detectors on wooden frames approximately 1 m aboveground and oriented detector microphones upwards at a 30° angle and faced them toward the interior of the stand, away from stand edges, water, or prominent trails. We placed 1 detector in each stand, at least 25 m inside the stand from the stand edge (usually ≥50 m), at a different random location during each sampling period.

We used a blocked sampling design in which a stand pair and the associated old-growth stand

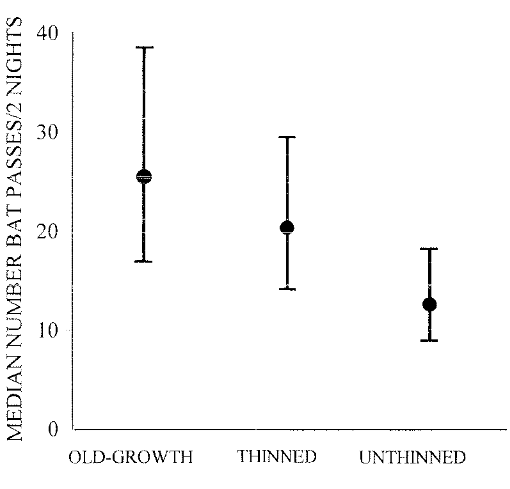

Fig. 1. Median number of bat passes per 2 nights and 95% confidence limits in 3 stand types at 11 sites in the Oregon Coast Range, 1994–95. Medians are back-transformed least-squares means.

Table 3. Mean number of bat passes per 2-night sampling period in 3 stand types at 11 sites in the Oregon Coast Range, 1994–95.

Site	Old-growth	Thinned	Unthinned
Adams Siding		10.8	8.2
Bald Mountain		14.5	8.8
Bear Creek	9.4	20.8	50.0
Beaver Flat	40.4	38.8	21.9
Black Rock	51.8	28.5	15.9
D-Line	19.9	14.0	8.5
Elliot	7.8	7.7	10.5
Gnome	21.0	18.0	17.1
Highpass	37.1	18.9	8.9
North Ward	28.7	28.1	3.6
Sand Creek	93.2	47.3	18.0

Table 4. Median number of bat passes per 2-nights for 6 call-types by stand type in the Oregon Coast Range, 1994–95.

Call type[a]	Old-growth	Thinned	Unthinned
MYTH	1.3	1.1	1.0
NON-MY	1.3	1.2	1.1
MYEV	1.8	2.3	2.1
MYVO	2.1	1.7	1.4
MYLU	7.0	5.7	3.8
CA-YU	4.4	3.0	2.8

[a] See Table 2 for definitions of call types.

(1 site) were sampled simultaneously to increase sampling efficiency (Hayes 1997). Our sampling period was 2 consecutive nights, and each stand was sampled 4 times (a total of 8 nights). We sampled 7 sites between 20 June and 24 September 1994; we sampled an additional 4 sites between 23 May and 8 September 1995. To assess year-to-year variation, we sampled 2 sites both years.

Taped echolocation calls were analyzed via a Zero-Crossing Analysis Interface Module (ZCAIM; Titley Electronics, Ballina, New South Wales, Australia) along with Anabat signal processing software (Version 5.1). We considered each sequence of echolocation pulses separated from the next sequence by a calibration tone or by at least 2 sec to be a single bat pass. We distinguished feeding buzzes from other echolocation calls via high repetition rates of pulses (Thomas and West 1989).

In an attempt to provide greater resolution of our data, we categorized call sequences with an identifiable structure into 6 groups based on minimum frequencies and call duration (Table 2). These "call-types" are based on reference calls from the Pacific Northwest and may correspond roughly to taxonomic groupings (Thomas and West 1989, Erickson 1993, O'Farrell 1997). Identification of species of bats in North America based on characteristics of echolocation calls has not been well refined. Because of overlap in characteristics of calls emitted by different species (Betts 1998), intraspecific variation in characteristics of calls (Thomas et al. 1987), and the fragmentary nature of calls often recorded via automated bat detector systems, species identification of recorded echolocation calls with automated detection systems is often difficult or unreliable (O'Farrell et al. 1999). While we recognize there is considerable overlap of frequencies and durations of calls emitted by *Myotis* species and that misclassification of some call sequences is inevitable, our qualitative assessment is that we could reliably classify passes to call-type >75% of the time.

As our index of activity of bats in each stand, we used the number of bat passes per 2-night sampling period, adjusted to reflect an average night length of 9 hr to accommodate differences in length of night. We summed the adjusted number of passes recorded during each sampling period for each stand and then calculated the mean number of bat passes for that stand from the 4 sampling periods. For the 2 sites sampled in both 1994 and 1995, we calculated overall means by using the 8 sampling periods. We did not analyze data from a given night in a block when precipitation or windy conditions resulted in the malfunction of the equipment or tapes filled with data before the night was over.

Our index of activity may be sensitive to differences in detectability of bats among stand types, as differences in amount of obstructions in a stand could influence the ability to detect bats. Because of the limited sensitivity of our equipment and the distance to the canopy in Douglas-fir forests at these ages, we believe our detections are limited to the area beneath the forest canopy. Old-growth stands have higher

Table 5. Structural variables that differed among stand types at 5 sites in the Oregon Coast Range. Significance levels were generated in a general linear models procedure via SITE as a block (ns = no significant difference).

	Old-growth		Thinned		Unthinned		Significance		
Habitat variable	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	Old-growth vs. thinned	Old-growth vs. unthinned	Thinned vs. unthinned
Trees/ha	155.3	39.2	184.3	34.3	418.2	34.3	ns	≤0.001	0.001
Dbh (cm)	73.1	5.3	55.5	4.7	41.7	4.7	0.03	0.002	0.07
Canopy cover (%)	66.1	5.4	55.9	4.7	82.9	4.7	ns	0.04	0.003
Shrub cover (%)	49.7	6.7	35.8	5.8	19.3	5.8	ns	0.007	0.08
Shrub height (m)	3.8	0.3	2.7	0.3	2.1	0.3	0.03	0.004	ns
Snag dbh (cm)	91.4	7.0	85.4	6.1	68.1	6.1	ns	0.08	0.04
Distance to gap (m)	21.5	2.5	18.7	2.2	26.2	2.1	ns	ns	0.04

basal areas relative to younger stands, as well as increased foliage in the midcanopy stratum (Bailey 1996). As a result, our methods may underestimate activity in these stands. In addition, structurally complex old-growth stands likely have a higher proportion of bat activity in higher strata (J. P. Hayes and J. C. Gruver, Department of Forest Science, Oregon State University, unpublished data), which further underestimates activity in these stands when ground-based detectors are used.

Response variables were log-transformed to meet the assumptions of normal distribution and homogeneous variance for the statistical procedures used. Back-transformed least-squares means are reported and were used to plot Figure 1. We used $\alpha = 0.10$ for all analyses. To compare bat activity among stand types, we used a general linear models procedure (PROC GLM; SAS Institute 1989) with site as a block and number of bat passes per 2-night sampling period as the response variable. We examined all possible pairwise comparisons via Fisher's protected LSD.

Habitat Characteristics

We measured characteristics of vegetation and habitat structure within 50-m-radius (0.79 ha) circular plots centered on each of the 4 locations in each stand used to monitor activity of bats in 1995 (Humes 1996). We recorded the size, decay class (Cline et al. 1980), distance, and position relative to the detector for each snag $\geq$28 cm in diameter at breast height (dbh) and $\geq$2 m in height within these plots. We also determined the presence, distance, and position of gaps (openings in the overstory canopy $\geq 3 \times 6$ m) relative to the detector. We established 10-m-radius (0.03 ha) circular subplots centered 25 m in front of the detector and at each subsequent 90° direction. Within each 10-m-radius plot, we measured diameters and estimated heights of all trees $\geq$28 cm dbh. We visually estimated cover of shrubs $\geq$1 m tall and crown closure in a 5-m-radius (0.01 ha) circular plot centered in each 10-m-radius subplot. We derived relative density of trees from field measurements based on the following equation (Curtis 1982):

$$\text{Relative density} = [\text{trees per hectare } (\text{dbh}_q/25)^{1.6}] \div 1470,$$

where dbh_q = quadratic stand diameter.

To compare characteristics of stands, we calculated a mean value for each habitat variable in each of the 17 stands. For the discrete variables associated with presence or absence of gaps, the mean represents a relative index of the occurrence of gaps in stands. We used a general linear models procedure (PROC GLM; SAS Institute 1989), with site as a block, to compare characteristics among stand types. We estimated power to detect differences in numbers of snags via the randomized block analysis of variance (ANOVA) model in PASS software (J. L. Hintze. 1991. NCSS, power analysis and sample size. Version 1.0, unpublished. Kaysville, Utah, USA.). We assessed the power to detect differences of 4 snags/ha, with a resulting effect size of 0.45. We used Pearson's product-moment correlation (PROC CORR; SAS Institute 1990) to examine correlations among the measured habitat variables to identify habitat variables highly correlated with each other. Using this analysis and our assessment of the biological importance of similar variables, we reduced our variable set to the following 7 variables that were not highly correlated with each other: average diameter of trees, relative density, percent cover of shrubs, height to live crown, density of snags, height of snags, and distance to nearest snag. We then examined correlations between these 7 variables and the index of bat activity.

RESULTS

Habitat Use

We recorded 6,325 bat passes over 2 years. Only 43 of these passes (<1%) could be determined as including feeding buzzes. We were able to classify 54% of the echolocation calls to genus; 97% (n = 3,316) of all identifiable passes were identified as calls from *Myotis* species. The remaining 3% (n = 100) were identified as calls of non-*Myotis* species.

Total activity of bats differed among the 3 stand types ($F_{2,18} = 3.51$, $P = 0.05$; Fig. 1). Our index of median bat activity was 1.9 times higher in old-growth than in unthinned stands ($F_{2,18} = 6.34$, $P = 0.02$), and 1.6 times higher in thinned than in unthinned stands ($F_{2,18} = 3.59$, $P = 0.07$). We were not able to detect a difference in the index of median bat activity between old-growth and thinned stands ($F_{2,18} = 0.59$, $P = 0.45$).

All but 2 sites exhibited the same trends in activity of bats (Table 3). At these 2 sites, we recorded higher activity in unthinned than in thinned stands, and old-growth stands had very low levels of bat activity. At the 2 sites sampled both years, trends in activity were the same, and annual variation did not appear to be a significant source of variability for this study.

When call-types were examined independently, only calls classified in the groups CAYU, MYEV, MYLU, and MYVO (see Table 2 for group names) occurred frequently enough to warrant statistical analysis. Old-growth stands had higher numbers of passes classified as CAYU than did unthinned ($F_{2,18}$ = 4.67, P = 0.04) or thinned ($F_{2,18}$ = 3.93, P = 0.06) stands, and higher numbers of passes classified as MYLU than did unthinned stands ($F_{2,18}$ = 9.4, P = 0.007; Table 4). Thinned stands also had higher numbers of passes classified as MYLU than did unthinned stands ($F_{2,18}$ = 5.02, P = 0.04). We did not detect significant trends in mean number of passes with respect to stand type for passes classified as MYEV ($F_{2,18}$ = 0.77, P = 0.48) or MYVO ($F_{2,18}$ = 1.82, P = 0.19).

Structural Characteristics of Stands

We found that several structural characteristics varied among the 3 stand types. In comparison to unthinned stands, old-growth stands had fewer trees per hectare, larger diameters of trees, less canopy cover, greater percent cover of shrubs, taller heights of shrubs, and larger snags (Table 5). Similarly, thinned stands had fewer trees per hectare, larger diameters of trees, less canopy cover, higher percent cover of shrubs, larger snags, and more gaps than did unthinned stands. Compared to thinned stands, old-growth stands differed only in having larger trees and taller shrubs. Density ($\bar{x}$ ± SE) of snags was 11.0 ± 2.8 in old-growth stands, 6.7 ± 2.5 in unthinned stands, and 5.2 ± 2.5 in thinned stands. Because of high variability among stands, density of snags was not different among stand types ($F_{2,9}$ = 1.3, P = 0.32).

Mean percent cover of shrubs was positively correlated with our index of bat activity (r = 0.44, P = 0.08, n = 17). No other structural variables examined were significantly correlated with the index of bat activity (Ps > 0.10).

DISCUSSION

Old-growth stands and thinned stands differed from unthinned stands in several structural characteristics, as well as in amount of use by bats. Old-growth stands and thinned stands were more similar in structure to each other, and they did not differ significantly in amount of use by bats. These results suggest forest management activities influence use of forest stands by bats and that stand age alone is not an adequate predictor of habitat use by bats. The similarity in use in thinned and old-growth stands by bats is consistent with findings from other studies that suggest the influence of forest management activities on habitat may exceed influences of stand age (deMaynadier and Hunter 1996, Hayes et al. 1997).

Thomas and West (1991) hypothesized that bats would not use managed stands where damaged trees and snags had been removed; our findings do not fully support this hypothesis. We recorded activity of bats in managed stands having few damaged trees or snags. Stands lacking adequate snags for roosting by some species of bats may be used for other activities such as foraging or commuting. Old-growth and thinned stands had snags of larger diameters than those in unthinned stands. Large diameter snags provide an important resource for roosting bats (Betts 1996, Sasse and Pekins 1996, Vonhof 1996, Ormsbee and McComb 1998), and stands with abundant roost sites and foraging opportunities are probably the highest quality habitat for bats (Betts 1996, Sasse and Pekins 1996, Vonhof 1996, Ormsbee and McComb 1998).

Activity of bats in thinned stands was intermediate between that in unthinned young and old-growth stands, except at the Bear Creek and Elliot sites where the highest levels of activity were recorded in the unthinned stands (Table 3). Because Bear Creek and Elliot were very productive sites, as indicated by their high site indices (Table 1), and the thinned stands at these sites had been thinned at a more advanced age than most of the other stands in our study, the contrast in structure between thinned and unthinned stands at these sites was likely less pronounced than at other sites. At the time of our study, the unthinned stands at Bear Creek and Elliot had self-thinned substantially more than at other sites. The differences in patterns of activity of bats in these stands suggests effects of thinning on activity of bats may vary with the structure of the stand when thinning occurs, site productivity, and the intensity of thinning.

Of the calls we were able to classify, 97% were *Myotis* species. Other studies conducted in the Pacific Northwest also have reported that the great majority of bat calls detected were *Myotis* species (Thomas 1988, Erickson 1993, Hayes and Adam 1996). Our results suggest bats emitting calls classified as the CA-YU call-type (most likely California myotis [*Myotis californicus*] and Yuma myotis [*M. Yumanensis*]) may use old-growth stands more frequently than they use either thinned or unthinned stands, and bats emitting calls classified as the MYLU call-type (most likely little brown myotis) may use old-growth or thinned stands more frequently than unthinned stands. However, because of difficulties in identification of echolocation calls to species, we suggest caution in application of taxon-specific results.

Scope of Inference and Context

The stands sampled in this study were geographically distributed throughout much of the Coast Range, but stands were not randomly selected, and therefore caution should be used in applying the results to the entire region. Although our study sites were limited to forest stands in the Oregon Coast Range, species of bats in our study sites likely would respond to forest structure in a similar manner in similar coniferous forests.

Our survey approach was ground-based, but patterns of use of the upper canopy may sometimes differ from those at ground level (J. P. Hayes and J. C. Gruver, Department of Forest Science, Oregon State University, unpublished data). Stands with complex vertical structure, such as old-growth stands, have the potential to increase the number of niches available for exploitation by flying bats, and we suspect ground-based equipment may underestimate actual differences among the stand types we studied.

Finally, our study examined activity of bats at the stand level. We did not take into account the character of the landscape surrounding the stands. Although all stands were located within a managed forest landscape, we did not measure all factors relating to the landscape which may have influenced activity of bats in these stands.

MANAGEMENT IMPLICATIONS

The high amount of use of old-growth forests suggests that older forests provide important habitat for bats; maintaining older forest habitats will likely benefit bats. In the short term, the structural changes caused by thinning may benefit bats by creating habitat structure in young stands that bats are able to use more effectively. In addition, by accelerating the development of structural characteristics typically found in old-growth stands, thinning may provide long-term benefits to bats. Approaches to thinning that maintain or create roost structures, specially large diameter snags, should be most beneficial to bats.

Our data also demonstrate a relation between shrub cover and level of activity of bats; however, the data do not establish a causal relation. We recommend experimentally testing the following hypotheses: (1) that maintaining high shrub cover benefits bat populations; (2) that manipulating other structural characteristics, such as sizes of snags, affects activity of bats; (3) that high thinning intensities create better habitat for bats than low thinning intensities; and (4) that alternative silvicultural systems, such as individual or group selection harvest, improve habitat for bats.

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