# SECTION V EFFECTS OF FOREST HARVESTING

# Managed Forests in the Western Cascades: The Effects of Seral Stage on Bat Habitat Use Patterns

JANET L. ERICKSON AND STEPHEN D. WEST

## ABSTRACT

Timber harvest and stand-management practices have restructured the forest landscape of the Pacific Northwest. To investigate the impact of such practices on bats and other wildlife, a research project funded through the Washington State Timber, Fish and Wildlife Cooperative was initiated in 1992. As part of this project, we conducted a stand-level survey of bat activity within managed forests during the summers of 1993 and 1994. To assess patterns of habitat use across a gradient of managed forest conditions, we selected six replicates from each of four distinct, post-harvest seral stages: clearcut (2–3 yrs); pre-commercially thinned (12–20 yrs); young, unthinned (30–40 yrs); and mature (50–70 yrs) stands. Using Anabat II bat detectors, each site was monitored for bat activity on six nights throughout each summer. The number of detections recorded were not significantly different between years, but were different among seral stages. Overall, activity levels were low, with 46.2% of the nights having no detections. The highest detection rates were in clearcut stands while young, unthinned stands had no detections. Members of the genus *Myotis* were detected within all stand types except young, unthinned stands, but were most often detected in mature stands. Calls of big brown bats (*Eptesicus fuscus*), silver-haired bats (*Lasionycteris noctivagans*), and Townsend's big-eared bats (*Plecotus townsendii*) were recorded most often in clearcuts, but never in mature stands.

## INTRODUCTION

Among mammals of their size, bats are unique in having long lives, low reproductive rates, and relatively long periods of infant dependency (Findley 1993). This combination of characteristics places them at risk of population decline in the presence of habitat alteration (Soule 1986). In western Washington, where approximately 3.9 million ha of forest is managed for timber harvest, there is growing concern over the status of forest-dwelling bats. Mitigating for effects of timber management activities is difficult due to a lack of knowledge concerning bat response to forest age and structure (Christy and West 1993).

In 1983, the U.S. Forest Service's Old Growth Wildlife Habitat Program (OGWHP) was initiated to determine the degree to which wildlife, including bats, were associated with old-growth Douglas-fir (*Pseudotsuga menziesii*) stands. Using ultrasonic detection, Thomas and West (1991) monitored bat activity over a broad range of unmanaged forest conditions in the southern Washington Cascade and Oregon Coast ranges. In Washington, detection rates were 2.5 to 9.8 times greater in old growth (200+ yrs) than in younger stands (35–195 yrs). These findings suggest that old growth is an important habitat for forest-dwelling bats, and that its conversion to younger, managed stands may be detrimental to bat populations.

Recognizing the need to extend research from unmanaged to managed stands, a project funded through the Washington State Timber, Fish and Wildlife Cooperative was initiated in 1992 to investigate the impact of forest management on bats and other wildlife. Here, we describe results from a stand-level survey of bat activity within intensively managed forests in the western Cascade Range during the summers of 1993 and 1994.

## METHODS

### Study Area

Field work was conducted during the summers of 1993 and 1994 in managed forests located in the Western Hemlock Zone (Franklin and Dyrness 1973) of the Cascade mountains. This is the most extensive vegetation zone in western Washington and the most important in terms of timber production. The area is characterized by wet winters and dry summers with annual precipitation ranging from 800 mm at low elevations to over 3000 mm at high elevations (Franklin and Dyrness 1973). Average monthly precipitation over the period of this study was 0.68 mm in 1993 and 0.61 mm in 1994.

Study sites were located on intensively managed forest lands owned by the Champion International Corporation and the Weyerhaeuser Company. The primary management activities included timber production by staggered-set clearcutting as well as the operations associated with this type of harvesting (road building, competing vegetation management, conifer planting, and pre-commercial and commercial thinning). The last significant old-growth in the study area was converted to second-growth plantations in the mid-1980s, and the forests are currently harvested at a rotation of 50–60 years.

To assess patterns of habitat use by bats across a gradient of managed forest conditions, we selected six replicates from each of four distinct, post-harvest seral stages: clearcut (2–3 yrs); pre-commercially thinned (12–20 yrs); young, unthinned (30–40 yrs); and mature (50–70 yrs) stands for a total of 24 sites. Clear-cut stands were 2–3 years post-harvest with seedlings of Douglas-fir 1 to 2 m high. Weedy invaders, such as bracken fern (*Pteridium aquilinum*), red alder (*Alnus rubra*), and Canada thistle (*Cirsium arvense*), were consistently associated with these sites. Pre-commercially thinned sites were 10–13 year-old Douglas-fir stands within which light still reached the ground between trees. The understorey consisted primarily of bracken fern, sword fern (*Polystichum munitum*), elderberry (*Sambucus racemosa*), and other forbs and grasses. Young, unthinned stands were 30–40 years old, with high tree density representing a wide range of stem diameters. Light interception was high with little vegetative growth on the forest floor. Mature forest sites were 51–62 years old, commercially thinned stands dominated by Douglas-fir or western hemlock (*Tsuga heterophylla*). Other tree species present included western redcedar (*Thuja plicata*), red alder, vine maple (*Acer circinatum*), and big leaf maple (*A. macrophylum*). Understorey vegetation was dominated by salal (*Gaultheria shallon*), Oregon grape (*Berberis nervosa*), sword fern, and red huckleberry (*Vaccinium parvifolium*).

## The Bat Fauna

The area west of the Cascade Range crest in Washington is believed to support 11 species of bats (Barbour and Davis 1969; Thomas and West 1991). These include seven species of *Myotis* (*M. californicus*, *M. evotis*, *M. keenii*, *M. lucifugus*, *M. thysanodes*, *M. volans*, and *M. yumanensis*), big brown bats (*Eptesicus fuscus*), silver-haired bats (*Lasionycteris noctivagans*), Townsend's big-eared bats (*Plecotus townsendii*), and hoary bats (*Lasiurus cinereus*). At present, four of the *Myotis* species are on the Washington state monitor-species list (*M. evotis*, *M. keenii*, *M. thysanodes*, and *M. volans*). In addition, Townsend's big-eared bat is designated as a species of special concern, and is being considered for federal listing under the Endangered Species Act. Basic population information for many of these species, such as distribution, seasonal occurrence, and range is lacking, but all potentially occur in the study area.

## Sampling Design

Ultrasonic detection is a relatively simple but effective way to monitor habitat-use patterns of bats. The automated detectors we used (Anabat II detectors and delay switches; Titley Electronics, Ballina, N.S.W., Australia) consist of a divide-by-n circuit board that counts the waves in the ultrasonic signal and constructs a new wave at the rate of one-for-n. This brings the signal into the range of human hearing and is compatible with cassette-tape storage. A sound-activated tape-recorder stores the bat passes as they occur along with time announcements entered at the time of detection.

Following the sampling protocol developed in the OGWHP (Thomas and West 1991), a detector was left in place for two consecutive nights then rotated to another site. We visited each stand at least three times for a minimum of six nights monitored in each. Samples at each site were spread over a 2–3 month period from mid-July to mid-September. On any given night, one to five of the 24 sites were monitored. Sampling began at dusk (approximately 2045 h) and continued for eight hours. No sites were sampled in heavy rain due to the decrease in bat activity associated with precipitation (Erkert 1982) and continual triggering of the detector system by raindrops.

Within a site, we placed a detector one metre from the ground and oriented it 30° from horizontal at a location greater than 100 m from the stand edge. Variation in recording conditions among heavily forested sites was minimized by placing the detector in a small gap within the stand. The same detector location was used each time a site was sampled.

## Analytical Procedures

A detection, or bat pass (Fenton 1970), was operationally defined as two or more pulses recorded as a bat flew through the airspace sampled by the microphone. To compare habitat use among seral stages, bat activity was indexed as the average number of detections per night within each site. Nightly activity patterns were evaluated as the number of bat detections per 30-minute interval. High-repetition-rate "feeding buzzes," associated with an attack on prey, were identified as feeding activity (Griffin 1958).

The analysis of detections occurred at two levels. First, calls were summed regardless of species to determine the general distribution of detections among sites and trends in activity patterns. Second, calls were grouped into "call categories" using zero-crossing analysis and signal processing software (Anabat II, Titley Electronics, Ballina, N.S.W., Australia). The software displays the echolocation call as a function of frequency and time (sonagram) allowing each detection to be analyzed, edited, and saved as a file.

Because the echolocation calls of certain species were not distinguishable, detections were grouped into categories based on similar call characteristics. These could be associated with a particular species or group of species based on comparisons to calls of known identity. A library of known bat calls was created for this purpose using recordings made from free-flying bats, and from call characteristics obtained from the literature (Fenton and Bell 1981; Thomas and West 1989). For this study, six categories of call types were recognized. These were associated with the following species: Type 1, big brown bat; Type 2, hoary bat; Type 3, silver-haired bat; Type 4, Townsend's big-eared bat; Type 5, *Myotis* group (*M. californicus*, *M. evotis*, *M. keenii*, *M. lucifugus*, *M. thysanodes*, *M. volans*); and Type 6, *Yuma myotis*.

## Vegetation Sampling

As part of the broader research program, overstorey and understorey vegetation was sampled at each of the 24 sites during the summer of 1993. For purposes of this study, we tallied live trees by species and diameter at breast height (DBH) within twelve 12-$m^2$ plots and thirteen 45-$m^2$ plots on each site. Trees <10 cm and 10–50 cm DBH were recorded within the 12-$m^2$ plot, while trees 50–100 cm DBH were counted within the 45-$m^2$ plot. Stumps and snags were counted by species, diameter class (<10 cm, 10–50 cm and >50 cm DBH), height class (<1.5 m, 1.5–15 m and >15 m), and decay class (1–3, from hardest to most decayed, modified from Maser et al. 1979). Only stumps and snags >50 cm DBH were recorded within the 45-$m^2$ plots. All other classes were recorded within the 12-$m^2$ plot. Sampling criteria conformed with standard protocols established for the OGWHP.

## Statistical Analysis

Mean detection rates were calculated for all species combined, all members of the genus *Myotis*, all non-*Myotis* species, and each call category. Differences between years and among seral stages were examined using a two-way ANOVA. When significant results were obtained, Tukey's pairwise comparison tests were used to locate the differences. Mean values for the vegetation characteristics were determined for each seral stage. Data were analyzed using SYSTAT (Wilkinson 1992) with a significant level of $\alpha$ = 0.05 unless otherwise indicated. Means ± SE are presented.

### Vegetation

Young, unthinned stands had the highest mean density of trees <50 cm DBH, while trees >50 cm DBH reached highest densities in mature stands (Table 1). Large snags >15 m in height were found only in pre-commercially thinned and mature stands, with the latter having significantly greater densities.

### Effect of Seral Stage

We monitored bat activity for over 2500 hours during 1993 and 1994, resulting in 967 echolocation calls recorded. Each site was sampled on six nights in each year with the exception of one pre-commercially thinned stand that was not sampled in 1994.

The mean number of detections per night did not vary significantly between years ($p$ = 0.4; n = 47 ANOVA), with an average of 3.75 (0.84) detections per night in 1993 and 3.07 (0.79) in 1994. Significant differences were found, however, among seral stages ($p$ <0.001; n = 47 ANOVA; Figure 1). Clearcuts accounted for 57% of all detections, while young, unthinned stands had none. Pre-commercially thinned and mature stands had

TABLE 1 *Means of vegetation characteristics for each seral stage where CC = clearcut, PCT = pre-commercially thinned, YU = young unthinned, and M = mature.*

| Characteristic | CC $\bar{x}$(se) | PCT $\bar{x}$(se) | YU $\bar{x}$(se) | M $\bar{x}$(se) |
|---|---|---|---|---|
| *Stumps* | | | | |
| <10 cm DBH | 6.697 (0.504) | 18.222 (5.375) | 28.987 (5.654) | 44.36 (7.016) |
| 10–50 cm DBH, <1.5 m tall | 5.873 (0.347) | 6.307 (0.872) | 5.013 (1.244) | 2.027 (0.494) |
| >50 cm DBH, <1.5 m tall | 23.692 (1.117) | 10.807 (2.062) | 11.923 (1.919) | 8.063 (1.848) |
| *Snags* | | | | |
| 10–50 cm DBH, 1.5–15 m tall | 0.057 (0.036) | 0.318 (0.089) | 0.582 (0.198) | 2.585 (0.661) |
| >50 cm DBH, 1.5–15 m tall | 2.448 (1.165) | 3.128 (0.814) | 1.075 (0.207) | 1.268 (0.353) |
| 10–50 cm DBH, >15 m | 0 | 0.138 (0.068) | 0.110 (0.051) | 0.582 (0.218) |
| >50 cm DBH, >15 m | 0 | 0.013 (0.013) | 0 | 0.207 (0.076) |
| *Standing trees* | | | | |
| Trees <10 cm DBH, >3 m tall | 0.208 (0.148) | 14.253 (6.716) | 16.515 (6.298) | 5.030 (1.000) |
| Trees 10–50 cm DBH, >3 m tall | 0.013 (0.013) | 13.388 (0.906) | 22.193 (2.566) | 6.653 (1.348) |
| Large dominant trees 50–100 cm DBH | 0 | 0.142 (0.126) | 1.652 (0.379) | 18.67 (3.81) |

intermediate detection rates accounting for 14% and 30% of all detections respectively. Overall, activity levels were low, with 46.2% of the nights having no detections.

Use of seral stages differed among species groups. We detected *Myotis* within all stand types except young, unthinned stands, but they were most often detected in mature stands. In contrast, detections in clearcuts accounted for the majority of non-*Myotis* detections (81%). Big brown bats, silver-haired bats and Townsend's big-eared bats were not recorded in mature stands. Of the six call categories, the *Myotis* group, Yuma myotis, and hoary bat were the only ones detected in all three seral stages where bat use was recorded. However, all 14 hoary bat detections within the mature seral stage were recorded in one site on the same night (Table 2).

### Activity Patterns

Bat activity was not uniformly distributed throughout the night, with activity peaking during the first two hours following sunset. Within clearcuts, non-*Myotis* species gradually increased in activity and peaked between 2215 and 2245 h, followed by variable but consistently low activity (Figure 2a). This pattern was largely driven by detections attributed to the

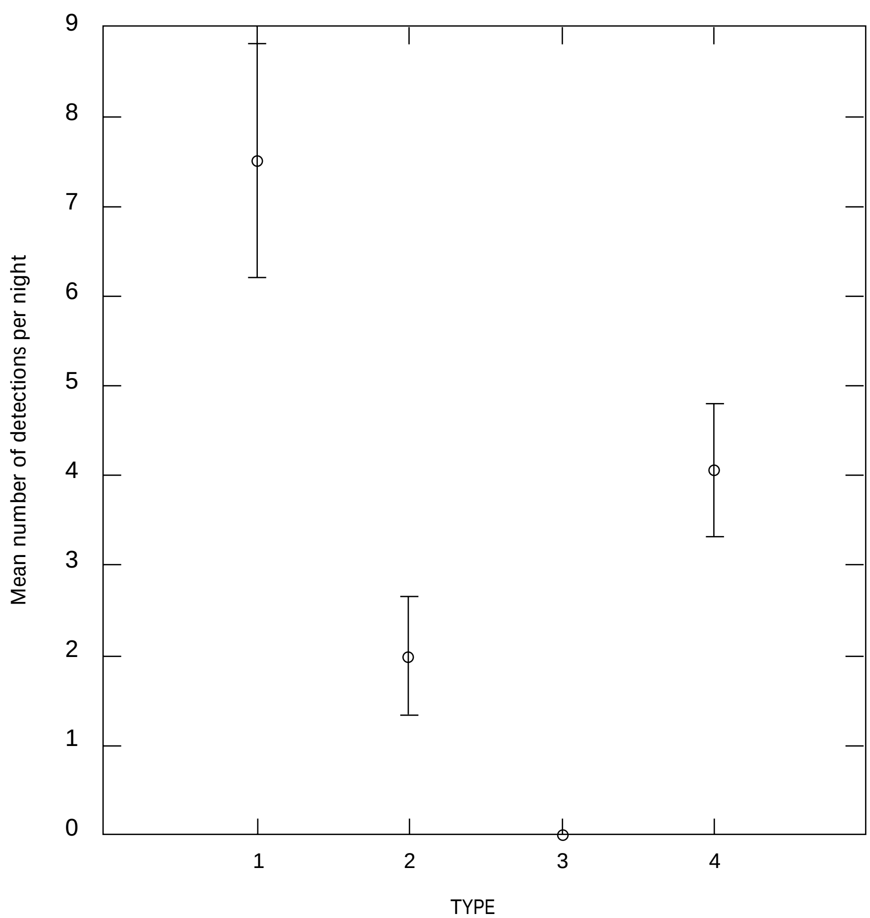


FIGURE 1 *Mean number of detections per night where 1 = clearcut, 2 = precommercially thinned, 3 = young unthinned, and 4 = mature stands.*

TABLE 2 *Mean detection rates for bats in clearcut (CC), pre-commercially thinned (PCT), young unthinned (YU), and mature (M) stands. Where ANOVA was significant, means not significantly different from each other are indicated with letters: $\alpha = 0.05$).*

| Species | CC $\bar{x}$(se) | PCT $\bar{x}$(se) | YU $\bar{x}$(se) | M $\bar{x}$(se) |
|---|---|---|---|---|
| Big brown bat | 0.808 (0.185) | 0.031[a] (0.021) | 0[a] | 0[a] |
| Silver-haired bat | 2.327 (0.627) | 0.407[a] (0.164) | 0[a] | 0[a] |
| Townsend's big-eared bat | 0.113[a] (0.056) | 0.031[a] (0.021) | 0[a] | 0[a] |
| Hoary bat | 0.587[a] (0.267) | 0.150[a] (0.080) | 0[a] | 0.194[a] (0.194) |
| *Myotis* group | 2.093[a] (0.580) | 0.405[b] (0.157) | 0[b] | 1.959[a] (0.532) |
| Yuma *Myotis* | 0.788[abc] (0.329) | 0.394[ab] (0.210) | 0[bc] | 0.910[a] (0.224) |
| All *Myotis spp.* | 1.107[ab] (0.262) | 0.408[ac] (0.160) | 0[c] | 1.266[b] (0.248) |
| All non-*Myotis* | 0.834 (0.200) | 0.154[a] (0.061) | 0[a] | 0.053[a] (0.039) |
| Total | 7.504[a] (1.300) | 1.989[bc] (0.652) | 0[b] | 4.058[c] (0.738) |

silver-haired bat. *Myotis* spp. followed a similar pattern, but peaked between 2145 and 2215 h (Figure 2b). Mature stands had elevated activity during the first hour after dusk (2045–2145 h), with a smaller secondary peak near sunrise (0515 h), while activity in pre-commercially thinned stands was more evenly distributed throughout the night (Figure 3).

Feeding activity was very low within all stands. Of the 967 detections, only 13 were identified as feeding activity. Clear-cut stands had the highest number of feeding buzzes (n = 10), which were recorded for both non-*Myotis* and *Myotis* spp. The three feeding buzzes detected in mature stands were all identified as *Myotis* spp.

## DISCUSSION

### Patterns of Habitat Use

Bat activity within a habitat is primarily related to the availability of foraging and roosting resources. Although commuting bats also contribute to activity levels, the differences in habitat use among seral stages observed in this study are likely related to the differential availability of these resources.

Patterns of activity of insectivorous bats have often been interpreted in relation to the availability of prey (Kunz 1973; Erkert 1982). Several studies have documented insect abundance to be higher in clearings than in

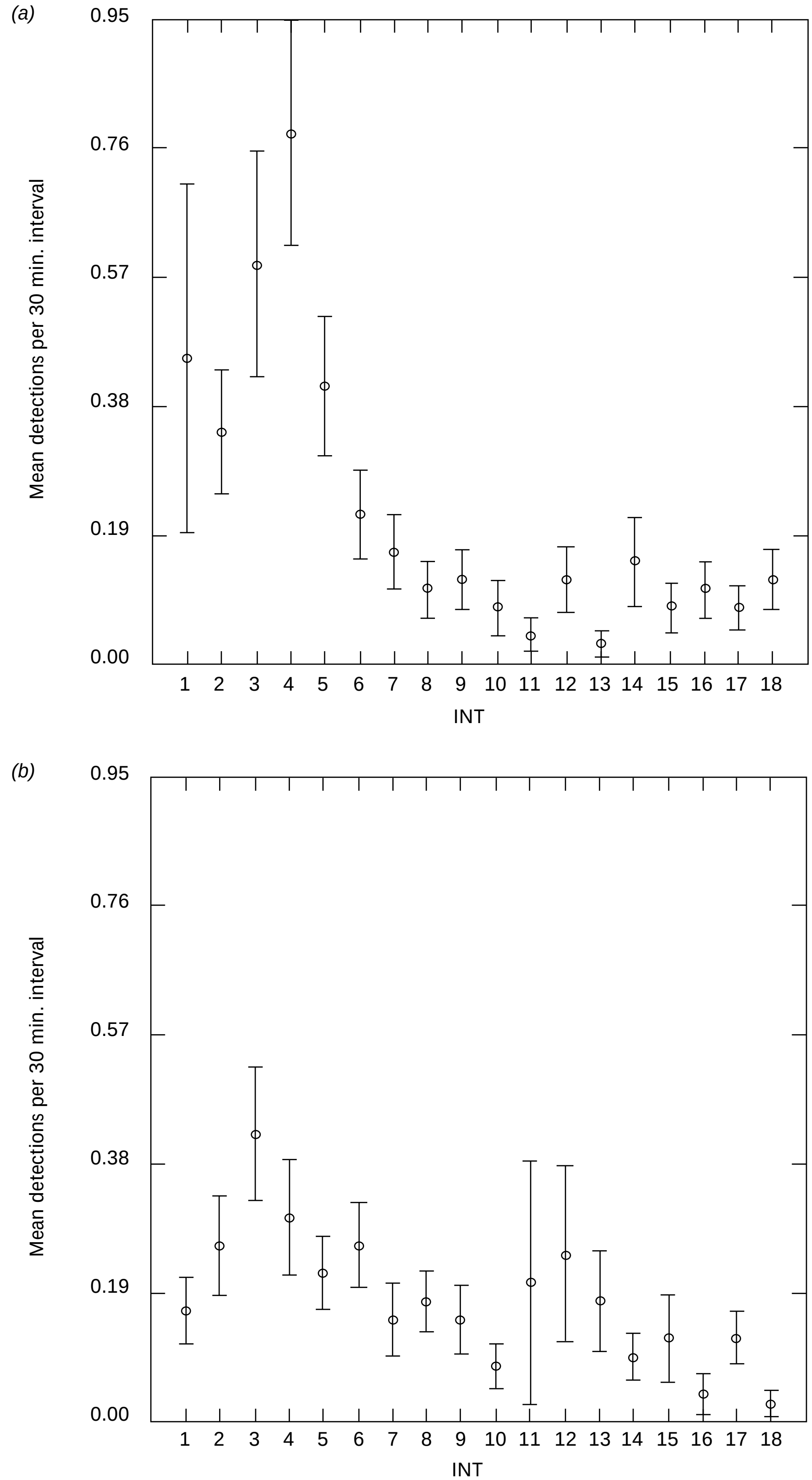


FIGURE 2 *Mean number of detections per interval in clear-cut stands for (a) all non-*Myotis *bats and (b) all members of the genus* Myotis.

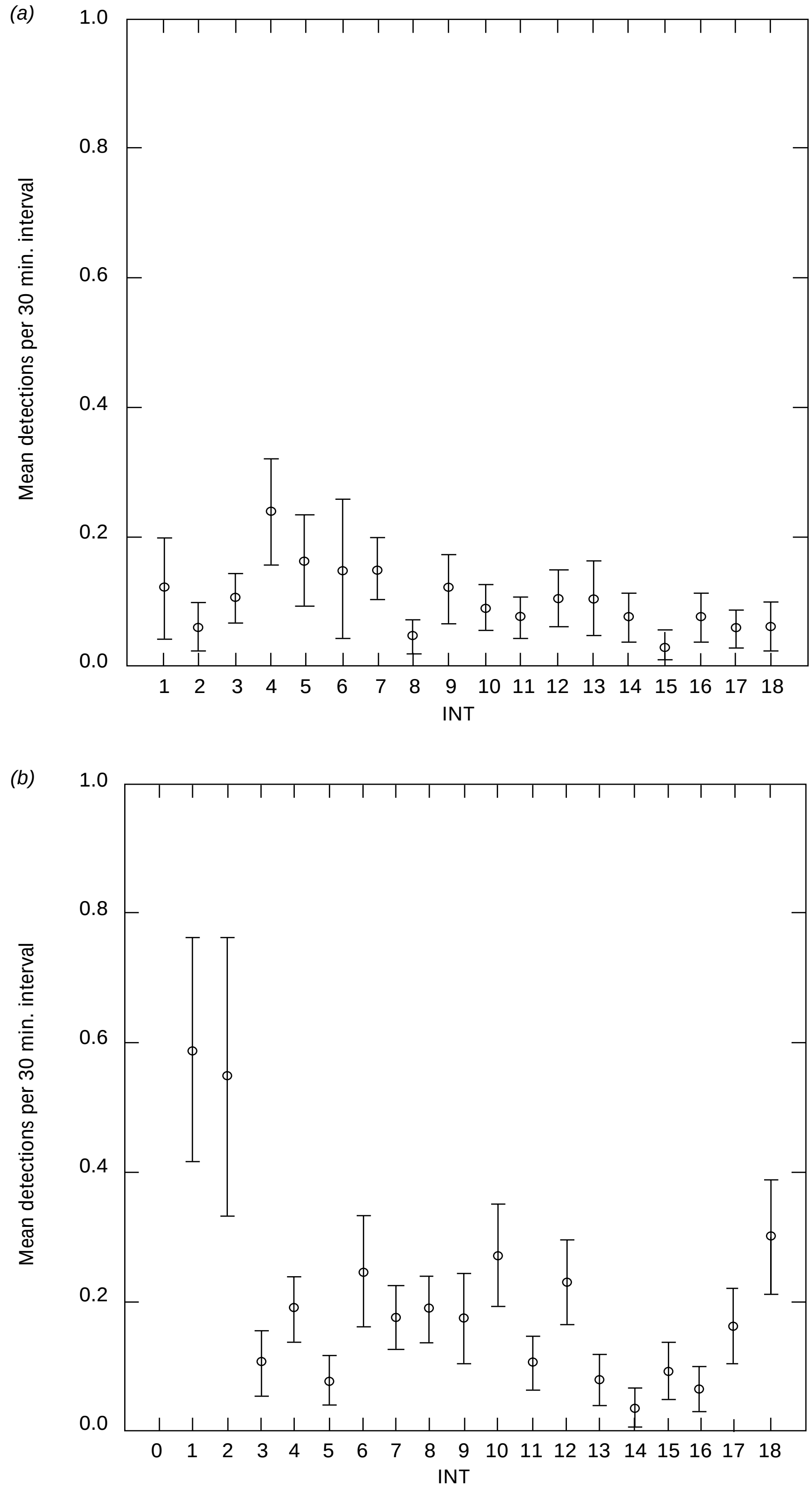


FIGURE 3 *Mean number of detections per interval in (a) pre-commercially thinned and (b) mature stands.*

surrounding habitats (Lunde and Harestad 1987; de Jong 1994). Within this context, the high detection rate, presence of feeding buzzes, and low abundance of roosting structures within clear-cut stands suggest these sites were used for foraging.

Although we detected bats in each call category, other studies have documented the avoidance of clearings by certain species. When de Jong (1994) compared habitat preferences of four species of bats in Uppsala, Sweden, two of them (*M. brandti* and *M. nattereri*) were found to significantly avoid open habitats. Similarly, in British Columbia, Lunde and Harestad (1986) found that *Myotis lucifugus* avoided clear-cut areas. In general, smaller species of bats closely follow edges and avoid open areas, whereas larger species readily use clearings (Limpens et al. 1989). The grouping of species (i.e., *Myotis* group) during call analysis in this study masks individual species' response to clearcuts, but at least some species of *Myotis* used clear-cut stands frequently.

The pre-commercially thinned and young, unthinned seral stages had little or no activity. The absence of activity in young, unthinned sites indicates that these stands are unsuitable habitat for forest-dwelling bats. Although a high density of snags was present, these were typically small-diameter Douglas-fir whose lack of crevices and hollows make them unlikely roost sites. In addition, tree density within these stands may be too high for most bat species to negotiate given the limitations of their sonar systems and flight capabilities. Such impediments to flight may be particularly challenging to newly volant bats (Constantine 1966).

Mature sites had the second-highest detection rates, and were the only seral stage to have a secondary peak in activity during the early morning hours. This activity pattern is similar to that described by Thomas and West (1991) for old-growth stands (185–200+ yrs) of the southern Washington Cascades. They concluded that these peaks of activity after sunset and before sunrise, coupled with low foraging rates, indicated that bats were dispersing away from roosts located in old-growth and commuting elsewhere to feed. If Thomas and West's interpretation of the observed activity patterns are accurate, it would appear that at least *Myotis* spp. can also roost in mature second growth. Large trees (50–100 cm DBH) and snags (>50 cm DBH and >15 m tall), which are "roost-type" trees for certain species in Washington (Christy 1993; Campbell 1993), were most abundant in these stands. Suitable roosting conditions may not be present for all forest-dwelling species, however, as infered by the absence of calls for the big brown bat and silver-haired bat within the mature stands.

Unfortunately, specific roost characteristics of forest-dwelling bats are poorly known, and it is currently impossible to measure roost availability within the mature stands for most species (but see Campbell 1993). With recent advances in the miniaturization of radio-transmitters, however, radio-tracking of small bats has become feasible and presents the only practical means of gathering information on roost-site characteristics. Results from recent radio-telemetry studies in the Pacific Northwest (Christy 1993; Campbell 1993) concur with findings in other regions of the world, with bats preferentially roosting in the largest and oldest trees available (Taylor and Savva 1988; Lunney et al. 1988; this volume). These results suggest that retention and recruitment of appropriate snags in managed forests may prove effective in encouraging bat presence in otherwise unsuitable habitat. More radio-tracking studies are needed, however, to provide additional information on roost-site characteristics and the availability of appropriate roosts in second-growth forests.

Because bats are highly mobile animals, restricting interpretation of habitat selection to the stand level will limit our understanding of bat habitat associations. Consideration must also be given to the influence of the surrounding landscape. Reduction in forests having large snags and trees will not only affect roost availability, but may also increase the distance between roosting, foraging, and drinking sites. The additional energy costs of increased travel may be of particular importance to reproductive females (Kunz 1987). As forests are fragmented, certain species that avoid crossing large openings when foraging or commuting (Limpens and Kapteyn 1991) may be restricted from accessing distant resources. For some bat species, corridors have proven valuable, not only as hunting habitats, but also as travel corridors between roosting and foraging areas (de Jong 1994). The spatial patterns and corridors among stands will be an important consideration in designing future landscapes appropriate for bats.

## Limitations of Ultrasonic Detection

Although ultrasonic detection has been used successfully in the field to identify bats based on species-specific call characteristics (Fenton 1970; Fenton and Bell 1981; Fenton 1982), it is important to emphasize that this technique relies on several assumptions: that species will consistently use the same call under a variety of conditions, that calls are equally detectable in different habitats, and that comparisons to reference recordings obtained from a limited geographic region are sufficient to identify field detections over broader regions. Evidence suggests that some bats may vary properties of their calls under different environmental conditions (Schrumm et al. 1991) and across geographical regions (Thomas et al. 1987). To date, variation in call structure is poorly understood, but call variability seems sufficiently high to warrant caution in species identification. Future call analysis will be facilitated by obtaining high-quality reference recordings from multiple individuals of each species under a variety of environmental conditions to determine the extent of natural variation present. Such a library is currently being compiled by the authors and other researchers for bats of the Pacific Northwest. In spite of its limitations, ultrasonic detection is rapidly becoming a valuable tool for surveying free-ranging bats. It is the most appropriate method for assessing patterns of distribution and activity on a large scale, and eliminates many of the problems associated with extracting ecological data from trapping studies (Thomas and West 1989).

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