

## AN ABSTRACT OF THE THESIS OF

Marcia L. Humes for the degree of Master of Science in Wildlife Science presented on September 4, 1996. Title: Activity of Bats in Thinned, Unthinned, and Old-growth Forests in the Oregon Coast Range.

# *Redacted for Privacy*

Abstract approved:

  
Michael W. Collopy

Ten species of bats occur in the Oregon Coast Range and are hypothesized to be associated with late-successional forests. The development of characteristics of late-successional forests in young forest stands can be accelerated through silvicultural practices such as thinning. I examined the effects of thinning on the use of forests by bats in the Oregon Coast Range. I used automated ultrasonic detectors to record bat calls in 50- to 100-year-old thinned and unthinned stands as well as in old-growth ( $\geq 200$ -year-old) stands in 11 sites in the Oregon Coast Range during the summers of 1994 and 1995. I compared bat activity levels among the 3 stand types. In addition, I classified bat calls into 1 of 5 species groups: *Eptes/Las*, *Myev/vo*, *Myyu/ca*, *MythCory*, and *Mysp*. I measured selected vegetation and environmental variables in conjunction with bat activity. I also compared bat activity on roads with activity in the stand interior at 1 site.

Bat activity was higher in old growth than in young stands, and higher in thinned than in unthinned stands in 1995 and over both seasons combined. I did not detect a difference in bat activity among stand types in 1994, until I removed 1 site from the analysis. The *Mysp* and *MythCory* species groups exhibited differences among stand types. Bat activity along roads was higher than activity within stands.

Tree density, tree diameter, tree height, shrub cover, and shrub height varied significantly between old-growth and young stands. Tree density, tree diameter, shrub cover, canopy cover, and crown height varied significantly between thinned and unthinned stands. Bat activity, overall or by species group, was significantly related to structural

variables, including mean snag diameter, mean distance from the detector to snags, and percent shrub cover.

My results suggest that bats are sensitive to stand structure and that silvicultural practices, such as thinning, which promote development of structural characteristics found in old-growth stands, would benefit bat populations. Further study is needed to clarify the habitat preferences of separate bat species and to specify habitat elements required by bat species.

**Activity of Bats in Thinned, Unthinned, and Old-growth Forests in the  
Oregon Coast Range**

by

**Marcia L. Humes**

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Marcia L. Humes, Author

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# **Activity of Bats in Thinned, Unthinned, and Old-growth Forests in the Oregon Coast Range**

## **INTRODUCTION**

Managing forest habitat for wildlife requires knowledge of the relationships of wildlife species to their habitat. Specifically, habitat management requires an understanding of the habitat requirements of the species of interest, an understanding of the forest conditions necessary to produce these required habitat elements, an understanding of stand dynamics and how to produce desired forest characteristics with silvicultural practices, and finally, an understanding of the behavioral aspects that determine whether a species uses a habitat (Nyberg et al. 1987). An understanding of these relationships is integral to the development of forest management plans which seek to manage ecosystems and maintain biodiversity. However, the current state of knowledge about the habitat relationships of some species and groups of species is too rudimentary for an accurate analysis of the effects of forest management on these animals. In particular, during the development of recent forest management plans in the Pacific Northwest, managers and scientists expressed concern about the lack of information on basic biology and habitat requirements of bats (Forest Ecosystem Management Assessment Team (FEMAT) 1993).

Twelve species of bats occur in Douglas-fir forests in western Oregon and Washington (Christy and West 1993); 10 of these species occur in the Oregon Coast Range and are hypothesized to be associated with late-successional forests for either roosting or foraging (Maser et al. 1981, FEMAT 1993; Table 1). Six of these species are listed as sensitive species in the state of Oregon (Oregon Department of Fish and Wildlife (ODFW) 1996), and 5 species were classified as candidates for federal listing as threatened or endangered (U.S. Department of the Interior (USDI) 1994).

Table 1. Bat species occurring in the Oregon Coast Range.

Scientific name	Common name
<i>Corynorhinus townsendii</i> <sup>abc</sup>	Townsend's big-eared bat
<i>Eptesicus fuscus</i>	Big brown bat
<i>Lasionycteris noctivagans</i> <sup>b</sup>	Silver-haired bat
<i>Lasiurus cinereus</i>	Hoary bat
<i>Myotis californicus</i>	California myotis
<i>Myotis evotis</i> <sup>ab</sup>	Long-eared myotis
<i>Myotis lucifugus</i>	Little brown bat
<i>Myotis thysanodes</i> <sup>ab</sup>	Fringed myotis
<i>Myotis volans</i> <sup>ab</sup>	Long-legged myotis
<i>Myotis yumanensis</i> <sup>ab</sup>	Yuma myotis

<sup>a</sup> Federal Category 2 species: information indicates that proposing to list as threatened or endangered may be appropriate, but further study is needed (U.S. Department of the Interior 1994).

<sup>b</sup> Oregon Department of Fish and Wildlife Sensitive Species: likely to become threatened or endangered throughout all or part of its range in Oregon (ODFW 1996).

<sup>c</sup> Formerly *Plecotus townsendii*.

### *Ecology of bats in the Pacific Northwest*

All of the bats which occur in western Oregon are nocturnal and insectivorous. They feed on a variety of insects, including flies, moths, beetles, and crickets (Whitaker et al. 1977, Fenton and Barclay 1980, O'Farrell and Studier 1980, Kunz 1982, Kunz and Martin 1982, Shump and Shump 1982, Warner and Czaplewski 1984, Manning and Jones 1989, Kurta and Baker 1990), with most species exhibiting opportunistic feeding behavior.

Most insectivorous bats use echolocation for locating prey and for orientation. Echolocating bats emit pulses of patterned, high-frequency, high-intensity sound which are reflected by objects, providing information to the echolocating bat about its surroundings (Novick 1977).

There are two basic strategies used by echolocating bats in the Pacific Northwest. Hoary bats, silver-haired bats, big brown bats, and pallid bats (*Antrozous pallidus*) produce low frequency calls with a relatively long, shallow, frequency modulated (FM) component which is concentrated in a narrow frequency band. These types of calls which carry long distances are suited for foraging in open or edge habitats (Fenton 1990). *Myotis* bats typically produce higher frequency calls which tend to be steep and extend through a broad band of frequencies. These calls are efficient in more complex habitats (Fenton 1990). When approaching and capturing a prey item, bats increase their echolocation pulse repetition rate in a recognizable feeding buzz (Thomas and West 1989).

Ultrasonic detectors use microphones to detect the ultrasonic signals produced by bats. Divide-by-n detectors use a broad-band microphone with a circuit that divides the input frequencies by a suitable divisor, rendering the echolocation calls audible for recording and later analysis (Thomas and West 1989). This technique makes it possible to survey for bats in different environments, and allows for comparisons of relative amounts of activity among different habitats.

Most bat species occurring in western Oregon use forested habitat for either roosting or foraging (Fenton and Barclay 1980, O'Farrell and Studier 1980, Kunz 1982, Kunz and Martin 1982, Shump and Shump 1982, Warner and Czaplewski 1984, Manning

and Jones 1989, Kurta and Baker 1990, Nagorsen and Brigham 1993). Big brown bats, silver-haired bats, California myotis, long-eared myotis, little brown bats, fringed myotis, and long-legged myotis have been found roosting under the bark of trees and in cavities or crevices of trees or snags (Manning and Jones 1989, Nagorsen and Brigham 1993, Betts 1995, Chung-MacCoubrey 1995, Crampton and Barclay 1995, Vonhof 1995, Ormsbee 1996). Hoary bats roost primarily in tree foliage (Shump and Shump 1982).

In an effort to understand the types of forest habitat used by bats, researchers have compared the activity of bats in forested habitats of different ages. Thomas (1988) reported more bat activity in old (> 200 years), unmanaged forest than in young and mature (40 to 165-years), unmanaged forest in the Oregon Coast Range and Washington Cascades. He found little evidence of feeding activity in these forested habitats and hypothesized that bats commute from roosts in the forest to distant feeding areas. Erickson (1993) studied bat activity in managed stands of different ages in the Washington Cascades and reported less activity in managed stands 30 to 70 years old than in 4- to 7-year-old regenerating stands. Krusic et al. (1996) researched bat activity in the White Mountains of New Hampshire and found higher bat activity in old hardwood stands (> 119 years) and in 0- to 9-year-old regenerating hardwood and softwood stands than in forest stands of intermediate ages.

Thomas and West (1991) associated higher bat activity in the Oregon Coast Range and Washington Cascades with abundance of damaged or diseased trees or snag size and decay states. They predicted that bats would not use managed stands where damaged trees and snags had been removed.

Although bats seem to be associated with older forests and regenerating stands, little is known of how forest management affects bats. Additionally, the habitat elements required by individual bat species remain unknown. This lack of information makes it difficult to understand how to provide habitat that will meet the requirements of individual bat species.

### *Forest management for wildlife habitat*

Of the 24.2 million acres of commercial forests in the Oregon Coast Range, 57% are managed by the federal government, 38% by private industry or other private landowners, and 5% are managed by the state or other owners (Tappeiner et al. 1986). Since 1945, the focus of timber harvest has been on old-growth and second-growth stands, and Douglas-fir (*Pseudotsuga menziesii*) forests in the Oregon Coast Range have been harvested largely by clearcutting, with salvage of individual trees and commercial thinning occurring in some areas (Tappeiner et al. 1986). The present landscape mosaic in many watersheds in the Coast Range consists of plantations between 0 and 40 years of age and scattered stands of old trees (Tappeiner 1992). As a result, the emphasis of forest management has changed from harvest of old-growth and second-growth stands to the management of young stands.

One of the objectives of current forest management plans is to maintain ecosystems. For example, forest management plans in the Pacific Northwest, implemented by the Forest Service and the Bureau of Land Management, call for the establishment of Late Successional Reserves to maintain late-successional and old-growth forest ecosystems. These reserves are assumed to provide habitat for populations of species associated with late-successional forests and to ensure the conservation of late-successional species diversity (U.S. Department of Agriculture (USDA) and USDI 1994). Within the reserves, the objectives of management are to protect and maintain old forest (> 200 years) and to manage young forests for development of old-forest characteristics (USDA and USDI 1994). Old-growth forest in the Oregon Coast Range Province is rare, and the remaining old growth is highly fragmented and isolated (FEMAT 1993). Therefore, Late Successional Reserves are of particular importance in this area.

Although no programmed timber harvest is allowed in Late Successional Reserves, silvicultural treatments which enhance development of old forest characteristics and which impede large-scale disturbances by fire, wind, insects, and diseases, are encouraged (USDA and USDI 1994). Some structural characteristics which are typical of

old forests include large diameter trees, numerous large diameter snags, fallen trees and logs, canopy gaps, and multiple canopy layers (Franklin and Spies 1991).

Thinning is one silvicultural tool that can be used to accelerate development of old-forest characteristics in young stands (Tappeiner 1992). Thinning is the practice of reducing the density of overstory trees through removal of selected merchantable trees, and is usually performed in even-aged stands (Smith 1986). Thinning shortens the stem-exclusion stage of stand development described by Oliver and Larson (1990). The stem-exclusion stage is characterized by high tree densities and low plant diversity and leads to the mortality of suppressed trees, a process known as self-thinning (Oliver and Larson 1990). The effects of thinning vary depending on the species composition of a stand, site productivity, the age, size, number and spatial distribution of the trees, and the intensity of the thinning (Tappeiner 1992, Bailey 1996). Thinning alters the structure of a stand by increasing diameter growth rates of remaining trees and enhancing crown development. In addition, thinning enhances establishment of hardwoods, conifers, and shrubs in the understory, leading to development of multi-storied stands (Tappeiner 1992, Bailey 1996).

Changes to stand structure caused by thinning may influence wildlife use of these stands. The effects of thinning on wildlife habitat have been addressed previously in studies on birds (Mannan and Meslow 1984, Artman 1990, Hagar et al. 1996) and on big game species (Crouch 1986, Smith and Long 1987), but on few other wildlife groups. However, there are several ongoing studies on the effects of thinning on wildlife habitat in the Pacific Northwest. One research effort in the Oregon Coast Range is examining populations of birds, small mammals, and amphibians in 40-year-old stands pre- and post-thinning (Hayes et al. 1995). In the Oregon Cascade, Coast Range, and Siskiyou Mountains, a retrospective study also is underway which is examining several aspects of biological diversity, including vascular and nonvascular plants, insects, amphibians, birds, and mammals, in stands that were thinned 10-20 years ago (J. Tappeiner, pers. comm.). My study on bat activity was associated with this ongoing, multidisciplinary research effort.

In order to examine the effects of thinning on the use of forests by bats in the western Oregon Coast Range, I compared bat activity in 50- to 100-year-old forest stands that had been thinned to bat activity in stands of the same age that had not been thinned by using automated ultrasonic detectors to record bat calls in these stand types. In addition, I compared bat activity in the young thinned and unthinned stands to bat activity in unmanaged old-growth ( $\geq 200$ -year-old) stands. I expected that bat activity in old-growth stands would be greater than activity in young stands, as was found by Thomas (1988). Because thinning has the potential to create characteristics associated with old forests more rapidly than occurs in unmanaged forests (Tappeiner 1992), I predicted that bat activity in thinned stands would be greater than activity in unthinned stands, thus being intermediate in activity between old-growth and unthinned stands. Finally, I examined habitat structural characteristics of selected stands in order to ascertain to which elements of the forest habitat bats were responding.

## STUDY AREA

I conducted the study in the Oregon Coast Range between 45° 20' north latitude and 43° 30' north latitude, in Tillamook, Yamhill, Polk, Benton, Lane, and Coos counties (Figure 1). The climate in this region is characterized by wet winters and dry summers, with annual precipitation ranging from 150 to 300 cm (Franklin and Dyrness 1984). Temperatures are mild with January low temperatures averaging -1 C and July high temperatures averaging 26 C (Franklin and Dyrness 1984).

Sites were located in the western hemlock (*Tsuga heterophylla*) forest zone (Franklin and Dyrness 1984), at elevations ranging from 200 to 700 m. Overstories in the young stands were dominated by Douglas-fir, with western hemlock, western red cedar (*Thuja plicata*) and true firs (*Abies* spp.) present in some stands. Overstories in the old-growth stands generally were a mix of Douglas-fir and western hemlock. Common understory shrubs included salal (*Gaultheria shallon*), dwarf Oregon-grape (*Berberis nervosa*), and vine maple (*Acer circinatum*).

The young stands regenerated naturally in the early to mid-1900s following cutting and burning, often associated with railroad logging (Bailey 1996). They were composed primarily of one age cohort, with few large trees or snags remaining from the previous stand. The old-growth stands in my study had little or no evidence of human disturbance and displayed structural characteristics typically associated with old-growth, including large diameter trees, a multi-layered canopy, and abundant large snags (Franklin and Spies 1991).

Most sites were located on federal lands managed by the Salem and Eugene Districts of the Bureau of Land Management. One site was located in the Elliot State Forest (Oregon Department of Forestry); two others were located on Willamette Industries land.

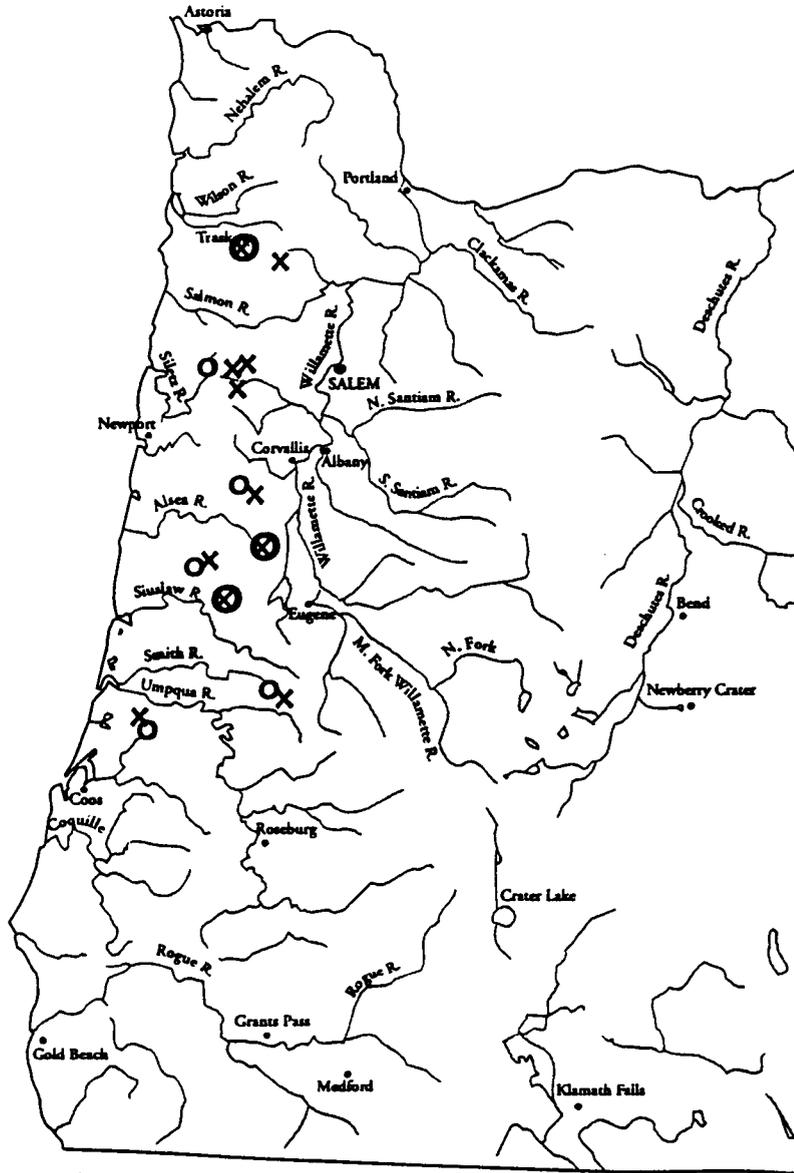


Figure 1. Map of Oregon, showing locations of 11 study sites in the Oregon Coast Range. x = thinned/unthinned pair; o = old-growth.

## METHODS

### *Site selection*

I nonrandomly selected 11 sites for this study which were within commuting distance from Corvallis, Oregon. Each site consisted of a thinned stand and an adjacent unthinned stand of the same age, between 50 and 100 years old. Each thinned/unthinned pair had been considered one stand prior to thinning. A portion of this stand had undergone an operational thinning or salvage between 1970 and 1985; a range of thinning intensities was represented at the 11 sites. The remainder of the original stand was similar in slope and aspect, but had not been thinned, and was used as the unthinned stand in this study. In addition, I selected old-growth stands ( $\geq 200$ -years-old) located near 9 of the sites. There were no unique, old-growth stands near two of the sites (Adams Siding and Bald Mountain), and 1 old-growth stand was sampled for 1 site in 1994 and for a different site in 1995. A total of 8 old-growth stands were sampled. All 3 stand types were at least 10 ha in size, though most were 20 ha in size or greater (Bailey 1996). (Tables 2 and 3). Nine of the sites were chosen from among 15 sites in the Oregon Coast Range which Bailey (1996) had previously selected for a retrospective study on the effects of thinning on young Douglas-fir stands.

### *Sampling design*

I used a randomized block design in which all 3 stand types within a site were sampled simultaneously over a 2-night sampling period. This design was chosen to increase the efficiency of the sampling effort (Hayes, in press). The sampling period was chosen for logistic reasons and also to buffer variability in bat activity that might occur from one night to the next. In 1994, 7 sites were sampled 4 times between June and September. In 1995, 2 of the sites sampled during 1994 and 4 additional sites were sampled 4 times between May and September (Table 2).

Table 2. Ages, site indices, time of thinning, tree densities, and stand sizes for 11 pairs of forest stands in the Oregon Coast Range, 1994 and 1995.

Site	Age	Site index <sup>a</sup>	Year sampled	Thinned					Unthinned		
				Year thinned	%volume removed	Trees/ha	Relative density <sup>b</sup>	Stand size (ha)	Trees/ha	Relative density <sup>b</sup>	Stand size (ha)
Adams Siding	75	124	1995	1976	Unknown	191	0.52	28	459	0.71	63
Bald Mountain <sup>c</sup>	70	120	1994	1976	33	166	0.60	38	255	0.75	20
Bear Creek <sup>c</sup>	100	134	1994	1972	27	141	0.50	16	250	0.84	20
Beaver Flat	50	130	1994-5	1974	51	212	0.42	21	490	0.77	10
Black Rock	70	112	1995	1974	Unknown	236	0.56	22	442	0.53	73
Dline <sup>c</sup>	60	121	1994	1972	12	173	0.44	34	267	0.63	40
Elliot	100	131	1995	1973	54	115	0.36	29	206	0.53	57
Gnome	60	120	1994-5	1983	43	265	0.41	10	591	0.65	40
Highpass <sup>c</sup>	90	114	1994	1971	20	128	0.51	18	153	0.47	10
North Ward	50	130	1995	1985	50	139	0.29	46	373	0.51	17
Sand Creek <sup>c</sup>	70	128	1994	1971	32	348	0.62	40	430	0.84	40

<sup>a</sup>Site Index = height (in feet) of the dominant and codominant trees at 50 years of age (King 1966).

<sup>b</sup>Relative density is a function of the number of trees per acre and the diameter of the trees in inches, and is calculated by the following formula: trees/ac ÷ antilog (10.03 - 1.605 \* ln (d.b.h. in inches)) (Curtis 1982).

<sup>c</sup>Data from Bailey (1996).

Table 3. Tree densities and stand sizes for 8 old-growth stands (associated with pairs of young stands) in the Oregon Coast Range, 1994 and 1995.

Site	Year sampled	Trees/ha	Relative density <sup>a</sup>	Size (ha)
Bear Creek <sup>b</sup>	1994	81	0.63	10
Corvallis Watershed (Beaver Flat)	1994-5	122	0.76	60
Valley of the Giants (Black Rock, Sand Creek)	1994-5	162	0.70	19
Dline <sup>b</sup>	1994	77	0.46	10
Elliot	1995	191	0.75	40
Big Iron (Gnome)	1994-5	134	0.48	45
Highpass <sup>b</sup>	1994	49	0.39	28
North Ward	1995	114	0.46	22

<sup>a</sup> Relative density is a function of the number of trees per acre and the diameter of the trees in inches, and is calculated by the following formula:  $\text{trees/ac} \div \text{antilog}(10.03 - 1.605 * \ln(\text{d.b.h. in inches}))$  (Curtis 1982).

<sup>b</sup> Data from Bailey (1996).

### ***Bat activity***

I used Anabat II bat detectors (Titley Electronics, Ballina, N.S.W., Australia), broad-band divide-by-n automated ultrasonic detectors, coupled with delay switches (Titley Electronics, Ballina, N.S.W., Australia) and tape recorders (Radio Shack, Model VSC-2002) to record bat echolocation calls throughout the night within the study stands. This method is described more fully in Hayes and Hounihan (1994).

I placed detectors on wooden frames approximately 1 m above the ground,  $\geq 25$  m from the stand edge (usually  $\geq 50$  m). The microphones on the detectors were oriented upwards at a 30-degree angle and were faced toward the stand interior and away from stand edges, water, or prominent trails. In order to control for potential differences within stands such as proximity to an unknown roosting or foraging area, I placed detectors at a different random location during each sampling period.

In 1994, one detector was placed in each stand type at a site during a sampling period. In 1995, 2 detectors were placed at different random locations in each stand at a site during the sampling period. Doubling the sampling effort in 1995 allowed for a better estimate of the activity within a stand.

During both seasons, ambient temperature was recorded continuously at each detector location using external sensor data loggers (HOBO-XT, Onset Instruments, Pocasset, MA). In 1995, relative humidity also was monitored at each detector location (HOBO-RH, Onset Instruments, Pocasset, MA).

### ***Roads***

At Adams Siding, I set detectors along roads within the thinned and unthinned stands each time the site was monitored. These roads ended within the stands and had little or no traffic.

### *Call analysis*

Taped echolocation calls were analyzed using a Zero-Crossing Interface Module (ZCAIM, Titley Electronics, Ballina, N.S.W., Australia) along with Anabat signal processing software (version 5.1). Feeding activity was distinguished from other activity by presence of high repetition rate feeding buzzes.

### *Species identification*

Bat passes were classified into 5 species groups based on the minimum frequency and duration of calls from identified species in this region (Table 4). These categorizations were based on information compiled from several sources in the Pacific Northwest, including the Washington Cascades (Erickson 1993), the Oregon Coast Range (J.P. Hayes, Oregon State University, unpublished data), and southwestern Oregon (S.P. Cross, Southern Oregon State College, unpublished data).

I used the typical minimum frequencies used by each species in this region to characterize a species group. However, the entire range of minimum frequencies used by individuals of most *Myotis* species in the Pacific Northwest varies considerably, and most species may use frequencies between 37 and 47 kHz (J.P. Hayes and S.P. Cross, unpublished data). For this reason, the *Mysp* group is inclusive of all *Myotis* species except the fringed myotis, although regional information suggests that the minimum frequency range of this group would be typical only for the little brown bat. The other species groups are assumed to be exclusive, including only calls from the species represented, although the groups do not necessarily contain all of the calls detected from those species.

Calls with low minimum frequencies and a narrowband FM component were included in the *Eptes/Las* group. Many of the call sequences were brief and could not

Table 4. Minimum frequency and duration of echolocation calls in 5 bat species groups from western Oregon.

Group	Species included	Minimum frequency (kHz)	Duration (milliseconds)
<i>Eptes/Las</i>	<i>Eptesicus fuscus</i> <i>Lasionycteris noctivagans</i> <i>Lasiurus cinereus</i>	< 30	> 5 narrowband FM <sup>a</sup>
<i>MythCory</i>	<i>Myotis thysanodes</i> <i>Corynorhinus townsendii</i>	< 30	3 - 7
<i>Myev/vo</i>	<i>Myotis evotis</i> <i>Myotis volans</i>	$30 \leq x \leq 36.5$	< 7
<i>Mysp</i>	<i>Myotis californicus</i> <i>Myotis evotis</i> <i>Myotis lucifugus</i> <i>Myotis volans</i> <i>Myotis yumanensis</i>	$37 \leq x \leq 47$	< 5
<i>Myyu/ca</i>	<i>Myotis californicus</i> <i>Myotis yumanensis</i>	$\geq 47.5$	< 5

<sup>a</sup> The *Eptes/Las* group is characterized by narrowband FM calls; the *Myotis* groups are characterized by broadband FM calls.

further be identified to species. The echolocation call of Townsend's big-eared bat is low intensity and difficult to detect (Kunz and Martin 1982), and for this reason probably represents a very low percentage of the calls in the *MythCory* group.

### ***Vegetation sampling***

At each detector location within each stand in 1995, I measured habitat characteristics within a 0.79-ha (50-m radius) circular plot centered on the detector location (Figure 2; Table 5). I recorded the size and decay class of all snags  $\geq 28$  cm in diameter and  $\geq 2$  m in height within this plot, following the decay classes defined by Cline et al. (1980), and noted the distance and position of each snag relative to the detector. I also estimated the size of canopy gaps and recorded the distance and position of gaps relative to the bat detector. One 0.03-ha (10-m radius) circular satellite plot was centered 25 m from the detector in the direction the detector microphone pointed and at every subsequent 90 degree direction. Within the 0.03-ha plots, I measured diameters of all trees that were  $\geq 28$  cm d.b.h. using a logger's tape, and I estimated tree height after using a clinometer or Relaskop to measure the height of the tallest tree in the plot. I visually estimated cover by shrubs  $\geq 1$  m tall and crown closure in a 0.01-ha (5-m radius) circular subplot centered in each satellite plot.

### ***Data analysis***

I used 31 observations for the analysis: one for each stand type within each site (9 sites with 3 stands each and 2 sites with 2 stands each). For each stand within each site, I summed the number of bat passes over the 2-night sampling period, then calculated a mean number of bat passes from the 4 sampling periods. In 1995, I averaged the number of bat passes between the 2 sampling points when more than one detector was placed in a stand during the same sampling period before calculating a mean from the 4 sampling periods.

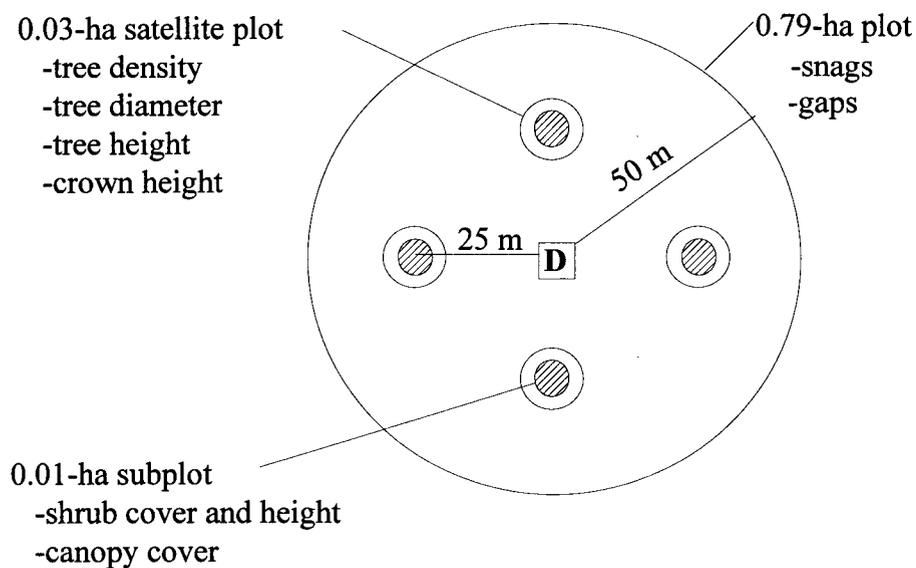


Figure 2. Schematic of vegetation sampling design at bat detector locations in the Oregon Coast Range in 1995. Snag and gap characteristics were measured in 0.79-ha plots centered on each detector location (**D**) within stands. One 0.03-ha circular satellite plot was centered 25 m from the detector in each of 4 directions, and tree diameters and densities were recorded within these plots. A 0.01-ha subplot was centered in each satellite plot for measuring shrub and canopy cover. Drawing is not to scale.

Table 5. Habitat variables measured in 0.79-, 0.03-, and 0.01-ha plots centered on each bat detector location within a stand in the Oregon Coast Range in 1995.

Variable	Category <sup>a</sup>	Description
<b>0.79-ha plots:</b>		
#snags/ha	S	Total number of dead trees and remnant trees $\geq 28$ cm d.b.h. and $\geq 2$ m in height per hectare
remnants	S	Number of live trees which are remnants from a previous stand
snag d.b.h.	S	Average diameter at breast height (1.5 m) of all snags and remnants (cm)
snag height	S	Average height of all snags and remnants (m)
snag distance	S	Average distance between detector and snags (m)
forward snags	S	Number of snags $\leq 50$ m in front of detector microphone
forward d.b.h.	S	Average d.b.h. of forward snags (cm)
decay class 1-2	S	Number of snags in decay classes 1 and 2 (by Cline et al. 1980)
decay class 3	S	Number of snags in decay class 3 (Cline et al. 1980)
decay class 4-5	S	Number of snags in decay class 4 and 5 (Cline et al. 1980)
small snags	S	Number of snags 28 - 50.9 cm d.b.h.
medium snags	S	Number of snags 51 - 75.9 cm d.b.h.
large snags	S	Number of snags $\geq 76$ cm d.b.h.
snags $\leq 5$ meters	S	Number of snags $\leq 5$ m of the detector
snags $\leq 10$ meters	S	Number of snags $\leq 10$ m of the detector
gaps	G	Presence (1) or absence (0) of a break in the overstory canopy $\geq 3$ m x 6 m
forward gap	G	Presence (1) or absence (0) of a gap $\leq 50$ m in front of detector microphone
forward gap distance	G	Average distance between detector and forward gaps (m)
gaps $\leq 10$ m	G	Presence (1) or absence (0) of a gap $\leq 10$ m of the detector
gaps $\leq 5$ m	G	Presence (1) or absence (0) of a gap $\leq 5$ m of the detector
large gaps	G	Presence (1) or absence (0) of a gap $\geq 12$ m x 18 m in size

<sup>a</sup> Each variable was placed in a category based on whether it described snag characteristics (S), gap characteristics (G), or stand density (D).

Table 5. Continued.

Variable	Category	Description
<b>0.03 ha-satellite plots</b>		
#trees/ha	D	Total number of all trees $\geq 28$ cm d.b.h.
d.b.h.	D	Average diameter at breast height of all trees (cm)
relative density	D	Trees/ac $\div$ antilog (10.03 - 1.605 * ln (d.b.h. in inches))
height	D	Average height of all trees (m)
crown height	D	Average distance from ground to lowest part of overstory crown (m)
hardwood density	D	Number of hardwood trees/hectare
hardwood d.b.h.	D	Average diameter of all hardwood trees (cm)
<b>0.01-ha subplots</b>		
shrub cover	D	Percent cover of all shrubs
shrub height	D	Average height of all shrubs (m)
canopy cover	D	Percent cover of all overstory trees $\geq 28$ cm d.b.h.

For this analysis, bat activity is defined as the number of bat passes per 2 nights, based on the number of bat passes per 9 hours, the average night length while monitoring. A bat pass was defined as the sequence of  $\geq 1$  echolocation pulses emitted by a bat as it passed through the air space sampled by the detector microphone, with  $\geq 2$  seconds between sequential pulses. To compare overall bat activity and activity by species group among stand types, I used a general linear models procedure (PROC GLM, SAS Institute 1989a) with site as a block and bat passes/2 nights as the response variable. I set the significance level at 0.10 for all analyses.

In order to meet the assumptions of normality and constant variance for this analysis, I log-transformed the number of bat passes/2 nights for overall bat activity and for the *Myev/vo*, *Mysp* and *Myyu/ca* groups. None of the transformations I tried adequately distributed the data in the *Eptes/Las* and *MythCory* groups to meet the assumptions for the analysis, so I ranked the data from these two groups for the analysis. Medians reported are back-transformed from log values.

Because there were 2 degrees of freedom available from the analysis of stand type, 2 orthogonal contrasts were possible. Therefore, I compared bat activity in old-growth stands with activity in the young stands combined, and I compared the number of bat passes in the thinned stands with the number of bat passes in the unthinned stands. A two-sided t-test (PROC TTEST, SAS Institute 1989b) was used to compare bat activity along roads versus activity within stands at the Adams Siding site.

Power for nonsignificant results was calculated using the randomized block ANOVA model in PASS software (Hintze 1991). The number of blocks used depended on the analysis -- for both years, I calculated power with 11 blocks; for 1994, I used 7 blocks; and for 1995, I used 6 blocks. I used an effect size of 0.30, based on variability reported by Hayes (in press). I set the significance level at 0.10.

To compare vegetative characteristics among stand types, I calculated a mean value for each characteristic in each stand sampled ( $n = 17$ ). For the discrete variables associated with gaps, I calculated a mean as a relative index of gap occurrence in stands. I then used a general linear models procedure (PROC GLM, SAS Institute 1989a), with site as a block, to compare each variable among the stand types. For calculating power

using the randomized block ANOVA model in PASS software, I used 6 blocks, an effect size of 1.0, based on variability reported by Bailey (1996), and set the significance level at 0.10.

Pearson's product-moment correlation (PROC CORR, SAS Institute 1990) was used to examine the relationship of bat activity, overall and by group, to characteristics of stand structure. I also performed a multiple linear regression analysis (PROC MIXED, SAS Institute 1996), with site as a block, on the structural variables. For this analysis, I grouped all the structural variables into three categories: those describing stand density, those describing snag characteristics, and those describing gap characteristics (Table 5). I ran the regression analysis on each structural variable separately, to determine which variables from each category had the strongest relationship with bat activity for each species group. I then performed the multiple regression analysis for each species group using the 3 variables representing stand density, snags, and gaps which were most strongly related to bat activity in each category.

Hardwoods, remnants, decay class 3 snags, and snags  $\leq 5$  m from the detector did not occur in  $\geq 20\%$  of the stands. The resulting variables of hardwood density, hardwood d.b.h., number of remnants, number of decay class 3 snags, and number of snags  $\leq 5$  m from the detector did not meet the assumptions for the analysis and were excluded from the analysis. Because no echolocation calls from the *MythCory* and *Eptes/Las* groups were recorded in  $\geq 50\%$  of the stands, I did not examine the relationships between structural characteristics and bat activity in these groups. Pearson's correlation (PROC CORR, SAS Institute 1990) was also used to investigate correlations between bat activity and temperature and relative humidity.

## RESULTS

Over 3,900 sampling hours over two seasons yielded 6,410 bat passes and 43 feeding buzzes. The total sampling effort and a summary of the data collected by stand type are given in Table 6.

### *Bat activity in 1994*

In 1994, I monitored 160 detector-nights in old-growth, thinned, and unthinned stands combined, totaling 1,470 sampling hours. I failed to record any data on 14 of the nights due to mechanical problems with the equipment or extraneous sources of ultrasound (e.g., noise from rain or insects). The mean number of bat passes detected per 2-night sampling period was 45.97 (SE = 6.78). The detectors registered no activity during 1% of the sampling periods, and recorded  $\leq 5$  bat passes during 20% of the sampling periods.

In 1994 alone, I did not detect a difference in bat activity among stand types ( $F = 0.61$ ;  $P = 0.56$ ;  $1-\beta = 0.23$ ). Closer examination of the data revealed that the Bear Creek site in particular had a trend different from the other sites, which strongly influenced this result. When this site was excluded from the analysis, I was able to detect a difference among stand types ( $F = 3.81$ ;  $P = 0.06$ ). Bats exhibited the most activity in old-growth stands, followed by thinned and unthinned stands (Figure 3a). There was more activity in old-growth than in young stands ( $F = 5.1$ ;  $P = 0.05$ ); however, I was not able to detect a difference in activity between thinned and unthinned stands ( $F = 2.5$ ;  $P = 0.15$ ;  $1-\beta = 0.21$ ).

Table 6. Sampling effort, total number of bat passes and feeding buzzes, and mean and maximum number of bat passes and feeding buzzes per 2-night sampling period by stand type at 11 sites in the Oregon Coast Range in 1994 and 1995.

Year	Stand	Hours sampled	Number of bat passes	Number of buzzes	Passes/sampling period		Buzzes/sampling period	
					(mean)	(max)	(mean)	(max)
1994	Old growth	428	1340	17	63.24	261	.810	15.0
	Thinned	519	932	3	38.08	215	.125	1.0
	Unthinned	523	938	6	38.39	155	.261	6.0
	Total	1470	3210	26	45.97	261	.382	15.0
1995	Old growth	688	1169	4	38.67	152	.148	2.0
	Thinned	845	1237	11	32.35	182	.297	5.0
	Unthinned	847	667	1	17.24	66	.029	1.0
	Roads	119	127	1	13.39	36	.056	1.0
	Total	2499	3200	17	28.87	183	.163	5.0

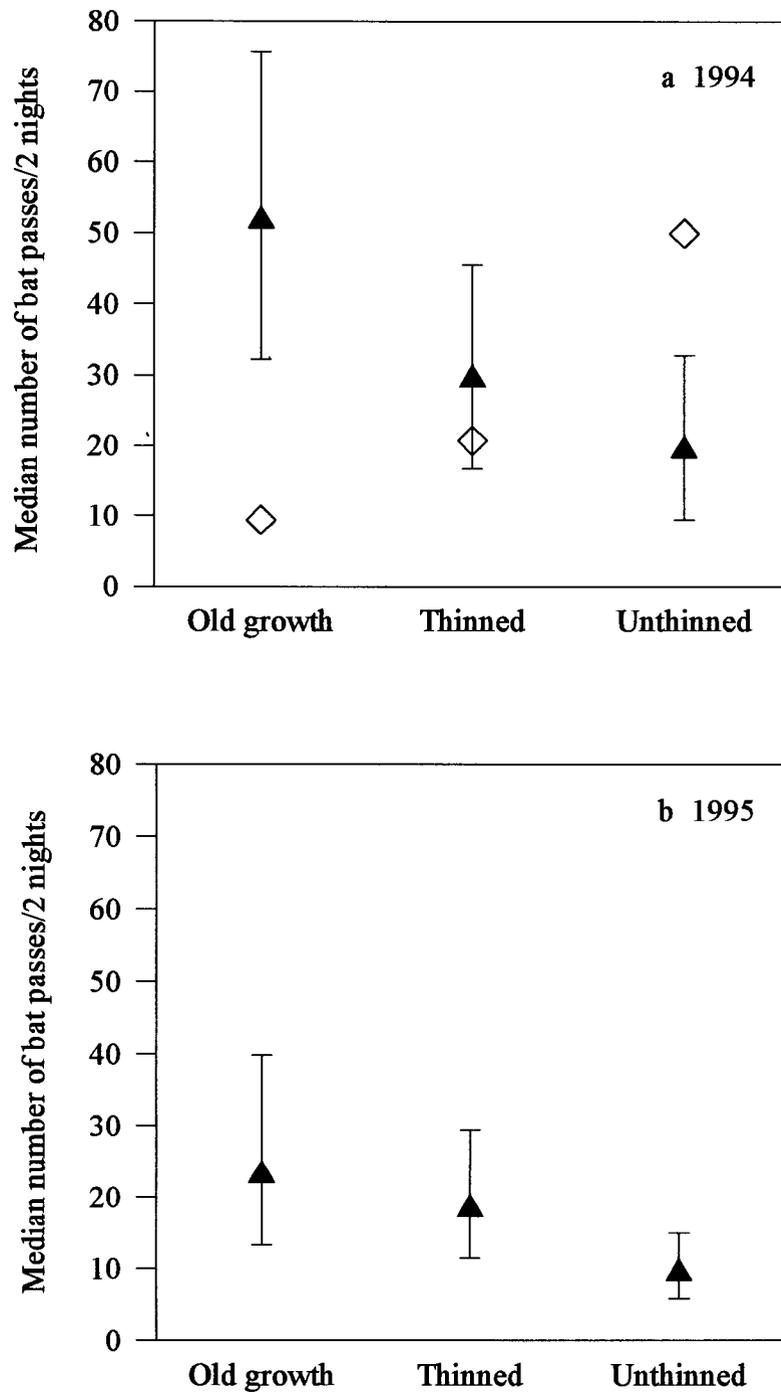


Figure 3. Median number of bat passes per 2 nights and 95% confidence limits in 3 stand types at 11 sites in the Oregon Coast Range in 1994, excluding Bear Creek (a); and in 1995 (b). Diamonds are medians for the Bear Creek site alone. Medians were generated from back-transformation of log values.

### ***Bat activity in 1995***

In 1995, I monitored 264 detector-nights in old-growth, thinned, and unthinned stands combined, totaling 2,380 sampling hours. I failed to record any data on 41 (16%) of the 264 detector-nights because of equipment malfunction or extraneous ultrasound. The average number of bat passes per sampling period in 1995 was 28.87 (SE = 3.33). The detectors registered no activity during 4% of the sampling periods, and recorded  $\leq 5$  bat passes during 26% of the sampling periods.

In 1995 alone, bat activity differed among stand types ( $F = 4.6$ ;  $P = 0.04$ ), with bat activity being highest in old-growth stands (Figure 3b). I detected a significant difference in activity levels between thinned and unthinned stand types ( $F = 5.2$ ;  $P = 0.05$ ) and a difference in activity levels between old growth and young stands ( $F = 4.0$ ;  $P = 0.08$ ).

### ***Bat activity over both seasons***

When data from all sites and both seasons were pooled, bat activity differed among old-growth, thinned, and unthinned stand types ( $F = 3.53$ ;  $P = 0.05$ ; Figure 4a). Median bat activity was 1.5 times higher in old-growth than in young stands ( $F = 3.44$ ;  $P = 0.08$ ) and 1.6 times higher in thinned than in unthinned stand types ( $F = 3.63$ ;  $P = 0.07$ ). When the Bear Creek site was removed from this analysis, the same trends were evident, and the resulting significance levels were lower ( $F = 11.33$ ;  $P = 0.001$ ; Figure 4b). Median bat activity was 1.9 times higher in old-growth than in young stands ( $P = 0.003$ ) and 1.8 times higher in thinned than in unthinned stands ( $P = 0.006$ ).

### ***Roads***

In 1995, 16 detector-nights were monitored along roads at Adams Siding in addition to the monitoring within forest stands, accounting for 119 sampling hours. Bat

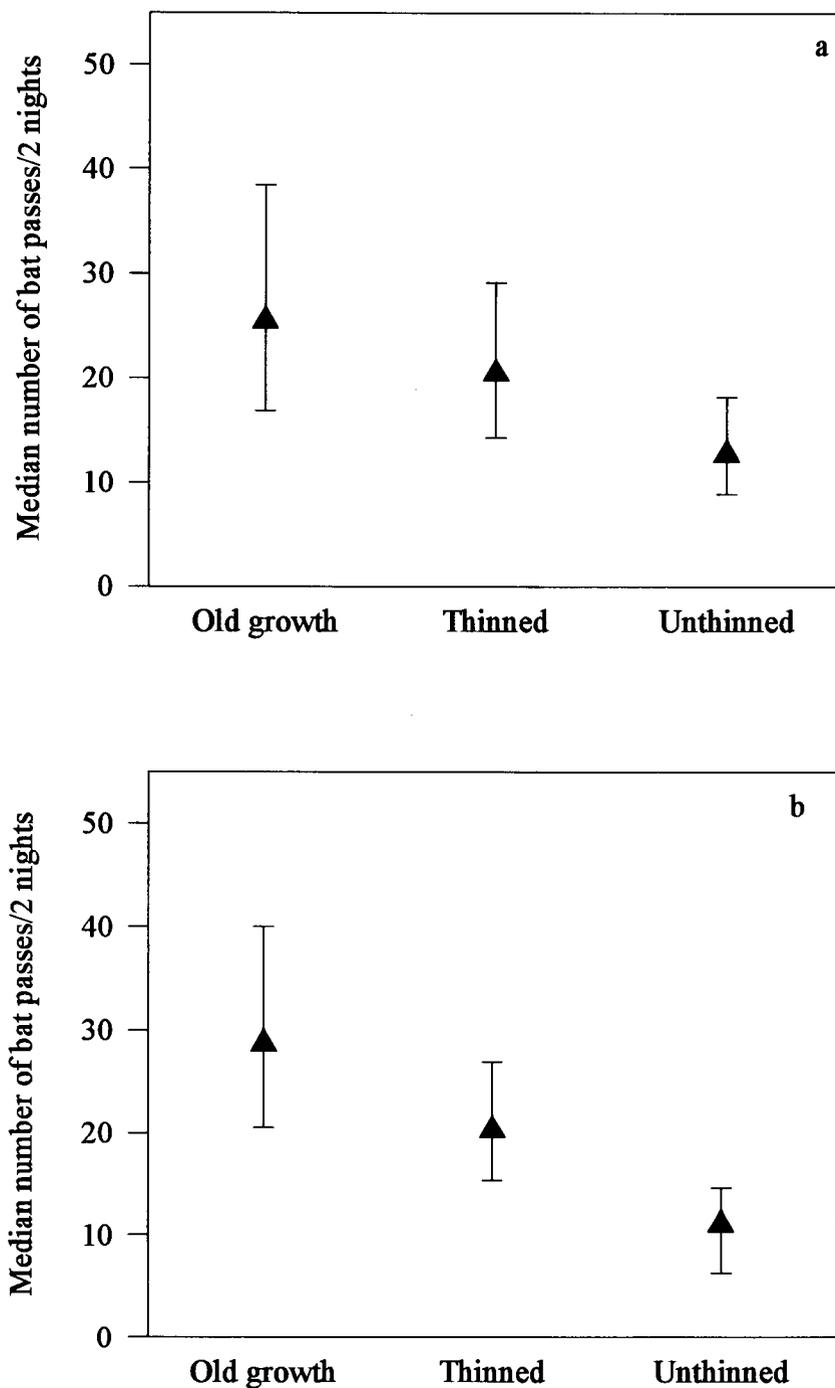


Figure 4. Median number of bat passes per 2 nights and 95% confidence limits in 3 stand types at 11 sites in the Oregon Coast Range in 1994 and 1995, including all sites (a); and excluding Bear Creek site (b). Medians are back-transformed from log values.

activity was higher along roads ( $\bar{x} = 8.4$ , 95% confidence interval: 5.3 - 13.5) than from within stands ( $\bar{x} = 4.4$ , 95% confidence interval: 3.2 - 6.1) at this site ( $t = 2.36$ ;  $df = 21$ ;  $P = 0.03$ ). Ninety-nine percent of the identifiable calls were of *Myotis* species.

### *Activity by species groups*

Of 6,410 calls analyzed, I was able to classify 62% into one of the 5 species groups. The remainder of the calls were not distinct enough to identify, and I classified these as unknown. Ninety-eight percent of all identifiable calls fit the characteristics of calls from *Myotis* species. The *Mysp* group was the most common group in all stand types, comprising 57% of the total identifiable calls (Table 7). I classified an additional 23% of the total identifiable calls as belonging in the *Myyu/ca* group, 16% as belonging in the *Myev/vo* group, and 2% as belonging in the *Eptes/Las* group (Table 7). Only 1% of the total identifiable calls fit characteristics of the *MythCory* group.

I did not detect a difference in the proportion of the total number of bat passes which were classified as unknown among the 3 stand types ( $F = 0.3$ ;  $P = 0.77$ ;  $1-\beta = 0.32$ ). I analyzed activity of the species groups with the assumption that the proportion of unidentified calls in each stand type was the same even though the statistical power to detect a difference in these proportions was low.

I detected a difference in the activity of bats in the *Mysp* group among stand types ( $F = 3.3$ ,  $P = 0.06$ ; Figure 5). As with overall bat activity, activity of this group was higher in old-growth stands than in young stands ( $F = 3.5$ ,  $P = 0.08$ ) and activity in thinned stands was higher than activity in unthinned stands ( $F = 3.2$ ,  $P = 0.09$ ). I also detected a difference in activity of bats in the *MythCory* group ( $F = 2.6$ ,  $P = 0.10$ ; Figure 6). Bat activity of this species group was higher in old-growth than in young stands ( $F = 4.6$ ,  $P = 0.05$ ), but no difference was detected in activity between thinned and unthinned stands ( $F = 0.62$ ,  $P = 0.44$ ;  $1-\beta = 0.32$ ).

Table 7. Distribution of bat calls among 5 species groups in 3 habitat types in the Oregon Coast Range in 1994 and 1995.

Species group	Old-growth	Thinned	Unthinned	Total
<i>Eptes/Las</i>	45	25	21	91
<i>Myev/vo</i>	178	247	217	642
<i>Mysp</i>	1057	718	501	2276
<i>MythCory</i>	32	16	8	56
<i>Myyu/ca</i>	340	310	260	910

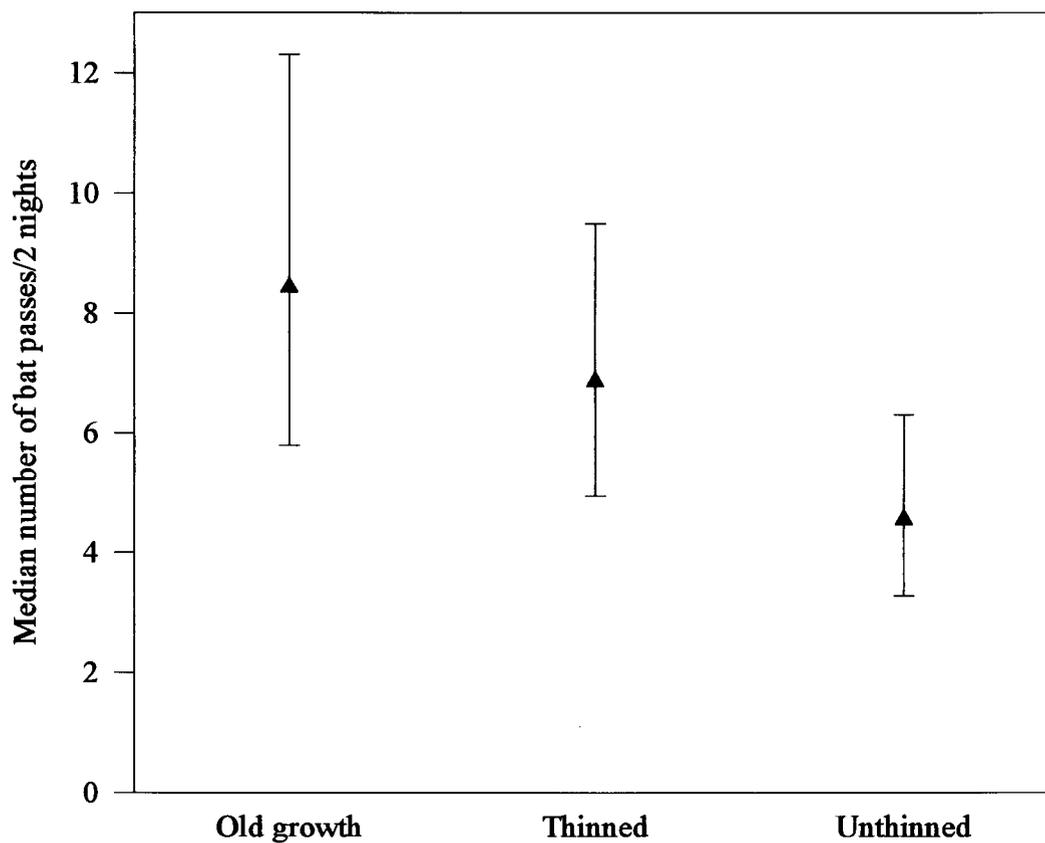


Figure 5. Bat activity in 3 stand types at 11 sites in the Oregon Coast Range in 1994 and 1995. Median number of bat passes per 2 nights and 95% confidence limits for the *Mysp* group. Medians are back-transformed from log-transformed data.

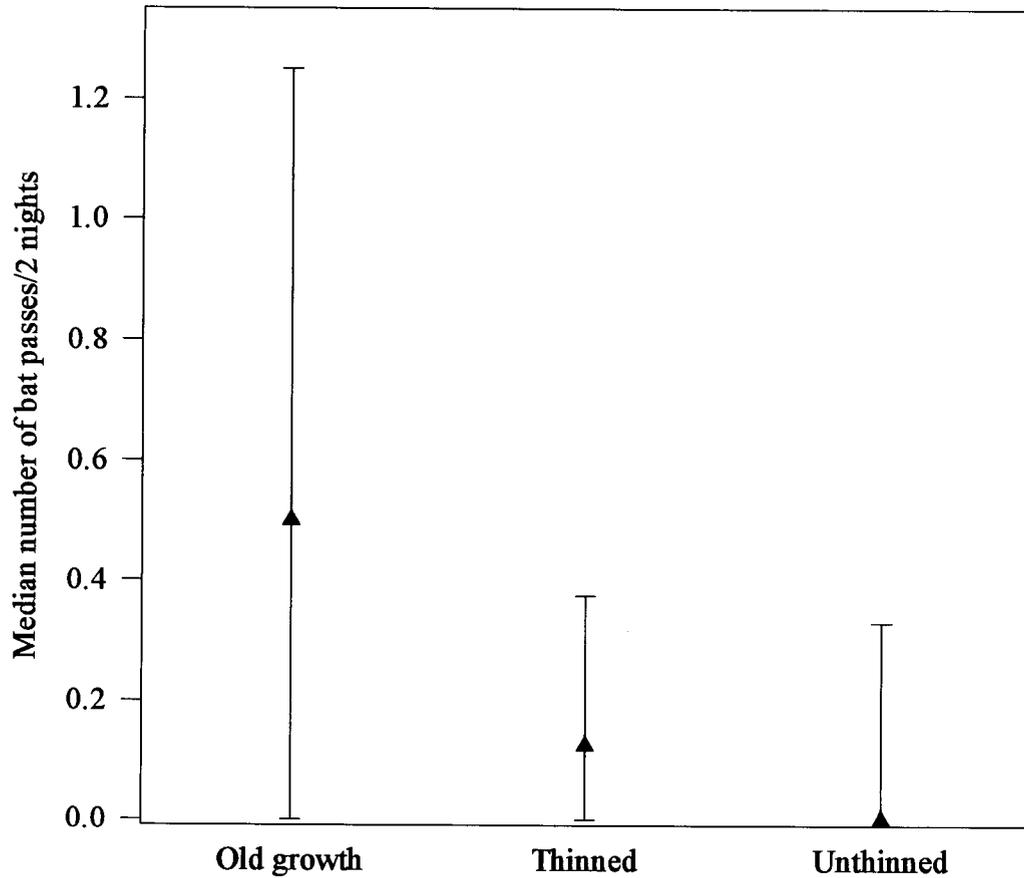


Figure 6. Bat activity in 3 stand types at 11 sites in the Oregon Coast Range in 1994 and 1995. Median number of bat passes per 2 nights and upper and lower 25% quartiles for the *MythCory* group.

I did not detect any differences in activity among stand types in the other 3 species groups, although the trends of the *Eptes/Las* and *Myyu/ca* groups were in the same direction as the trends of the *Mysp* and *MythCory* groups. The trend of the *Myev/vo* group, however, differed from the other groups, with more passes recorded in the thinned and unthinned stand types than in the old-growth (Table 7). The statistical power to detect differences among groups was 0.32.

### ***Vegetation structure among stand types***

Vegetation structure varied between old-growth and young stands and between thinned and unthinned stands. Old-growth stands had fewer trees/ha, larger tree diameters and heights, higher relative densities, greater percentage of shrub cover, and taller shrub heights than young stands (Table 8). Compared to unthinned stands, thinned stands had fewer trees/ha, larger tree diameters, lower relative densities, higher shrub cover, lower canopy cover, and lower crown heights than unthinned stands (Table 9). The old-growth stands averaged 11 snags per hectare (SE = 2.8), the thinned stands 5.2 (SE = 2.5), and the unthinned stands 6.7 (SE = 2.5); however, I did not detect any differences among stand types with respect to snag density ( $1-\beta = 0.89$ ). I did not detect any differences among stand types with respect to other snag or gap characteristics listed in Table 5.

### ***Bat activity and vegetation structure***

Snag diameter, shrub cover, and the presence of gaps  $\leq 10$  m from the detector were significantly correlated with overall bat activity (Table 10; Figure 7). Activity of the *Mysp* group was significantly positively correlated with snag diameter and with snag height (Table 10; Figure 8). The *Myyu/ca* group was positively associated with shrub cover, snag diameter, and the presence of gaps  $\leq 5$  m from the detector, and negatively correlated with the distance from the detector to a gap (Table 10; Figure 9). There was a

Table 8. Structural variables which differed between old-growth and young stands at 5 sites in the Oregon Coast Range in 1995. Means and standard errors are given for old-growth stands and for thinned and unthinned stands combined. F-values are from orthogonal contrasts generated in a general linear models procedure using SITE as a block (SAS Institute 1989b).

Habitat variable	Old growth		Young		F	P
	$\bar{x}$	SE	$\bar{x}$	SE		
trees/hectare	147.52	36.8	301.26	43.6	14.07	0.005
d.b.h. (cm)	78.56	3.8	48.58	3.8	52.71	0.0001
relative density	0.64	0.05	0.55	0.05	5.67	0.04
height (m)	42.19	1.3	38.40	1.0	8.52	0.02
shrub cover (%)	52.86	5.3	27.54	4.7	18.89	0.002
shrub height (m)	3.71	0.3	2.37	0.2	18.98	0.002

Table 9. Structural variables which differed between thinned and unthinned stands at 6 sites in the Oregon Coast Range in 1995. Means and standard errors are given for thinned and unthinned stands. F-values are from orthogonal contrasts generated in a general linear models procedure using SITE as a block (SAS Institute 1989b).

Habitat variable	Thinned		Unthinned		F	P
	$\bar{x}$	SE	$\bar{x}$	SE		
trees/hectare	192.90	32.3	426.80	32.3	26.29	0.0005
d.b.h. (cm)	51.83	3.3	40.41	3.3	5.87	0.03
relative density	0.43	0.04	0.62	0.04	11.42	0.008
shrub cover (%)	34.52	4.6	17.47	4.6	6.85	0.03
canopy cover (%)	55.90	4.2	79.87	4.2	16.26	0.003
crown height (m)	23.33	0.8	26.30	0.8	6.90	0.03

Table 10. Results of correlation analyses of bat activity, overall and by species group, with 26 structural variables from 17 stands in the Oregon Coast Range in 1995. Correlation coefficients (r) and P-values are based on Pearson's correlation analysis (SAS Institute 1990).

Variable		All bats	<i>Myyu/ca</i>	<i>Myev/vo</i>	<i>Mysp</i>
# trees/ha	r	-.30	-.13	-.03	-.19
	P	.24	.63	.90	.47
d.b.h.	r	.38	.22	-.05	.34
	P	.13	.40	.85	.18
relative density	r	.01	-.07	.10	.20
	P	.95	.80	.71	.45
height	r	.17	-.16	.03	.08
	P	.52	.54	.92	.77
shrub cover	r	.44	.57	-.24	.25
	P	.08	.02	.35	.33
shrub height	r	.07	.26	-.49	-.04
	P	.80	.31	.05	.86
canopy cover	r	-.33	-.35	.01	-.14
	P	.20	.17	.97	.58
crown height	r	.20	.03	.26	.29
	P	.44	.92	.31	.26
#snags/ha	r	.17	.11	-.08	.16
	P	.51	.68	.77	.55
snag d.b.h.	r	.52	.52	.19	.55
	P	.03	.03	.47	.02
snag height	r	.36	.28	-.03	.45
	P	.16	.27	.92	.07
snag distance	r	-.10	.11	-.53	-.30
	P	.70	.67	.03	.24
forward snags	r	.01	-.07	-.14	-.06
	P	.96	.79	.58	.82

Table 10. Continued.

Variable		All bats	<i>Myyu/ca</i>	<i>Myev/vo</i>	<i>Mysp</i>
decay 1-2	r	.23	.02	-.11	.27
	P	.38	.93	.68	.30
decay 4-5	r	.16	.14	-.04	.13
	P	.55	.58	.87	.61
small snags	r	-.15	-.41	-.12	-.27
	P	.56	.10	.64	.29
medium snags	r	-.01	.09	-.15	.03
	P	.97	.72	.57	.91
large snags	r	.31	.31	-.01	.34
	P	.22	.22	.98	.19
snags $\leq$ 10 m	r	.31	.16	.11	.37
	P	.23	.54	.67	.15
gaps	r	.13	.21	-.27	.10
	P	.61	.42	.29	.71
forward gap	r	.26	.32	-.09	.23
	P	.32	.20	.73	.37
gap distance	r	-.27	-.58	.16	-.15
	P	.29	.01	.54	.57
gaps $\leq$ 10m	r	.44	.36	.05	.27
	P	.08	.15	.85	.30
gaps $\leq$ 5m	r	.38	.49	-.08	.09
	P	.14	.04	.76	.73
large gaps	r	-.04	.10	-.46	-.08
	P	.89	.70	.06	.76

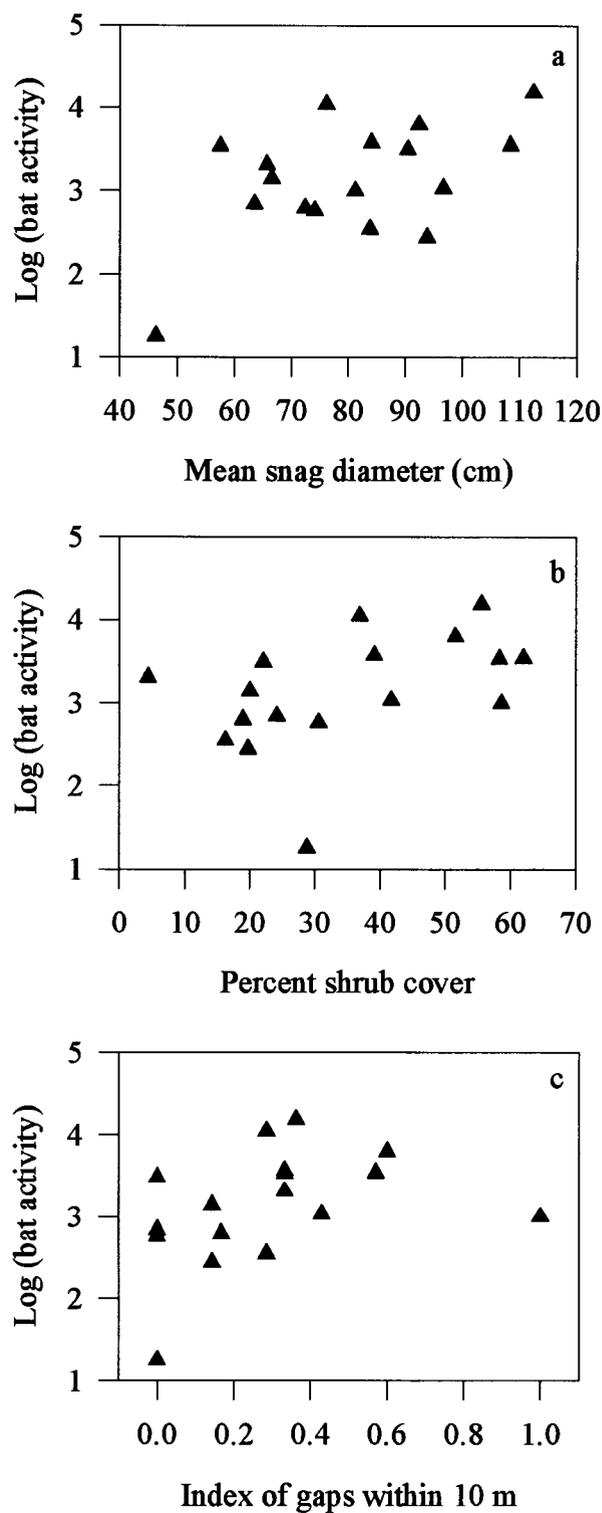


Figure 7. Overall bat activity (number of bat passes per 2 nights) at 11 sites in the Oregon Coast Range in 1995 versus mean snag diameter (a); mean percent shrub cover (b); and relative presence of gaps within 10 m of the detector (c).

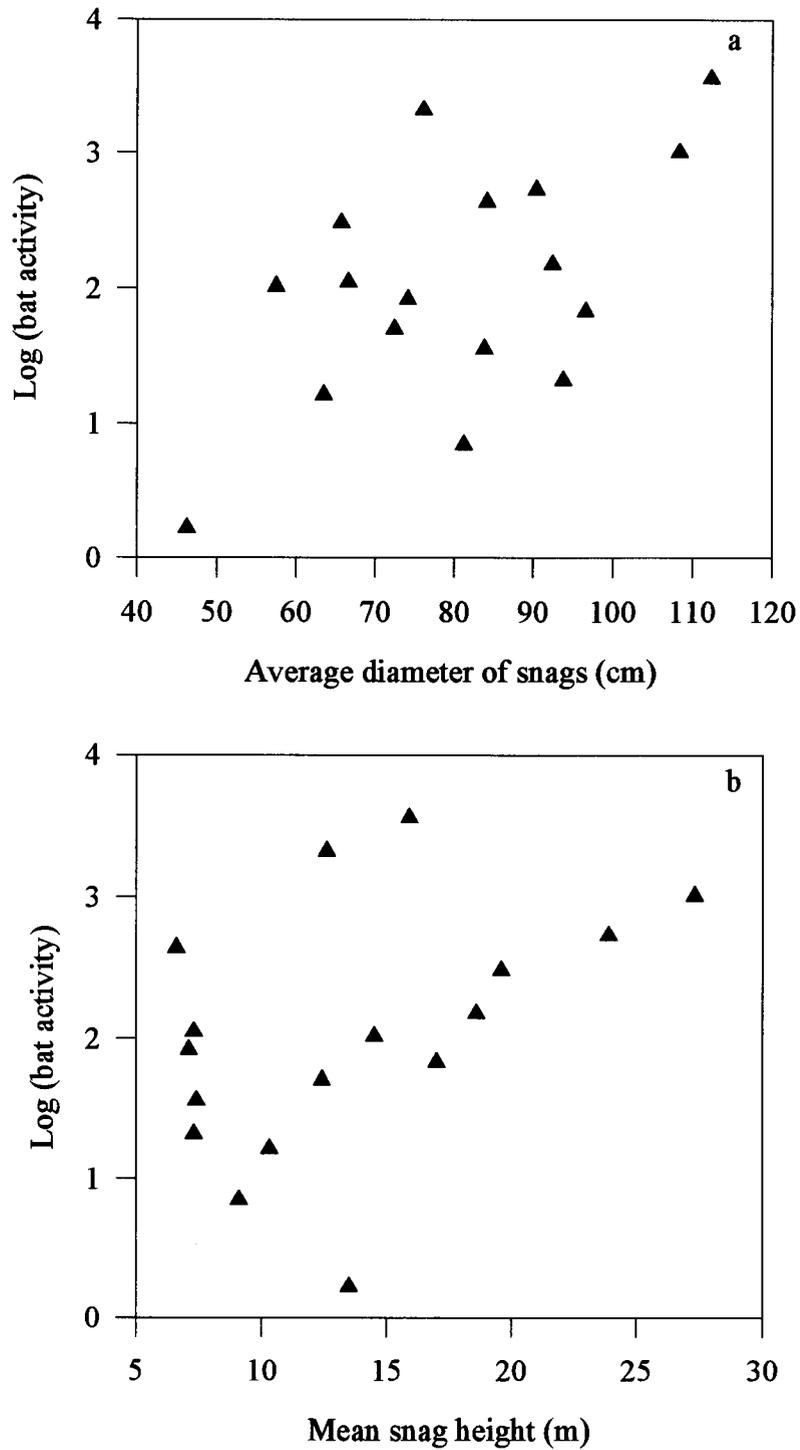


Figure 8. *Mysp* group activity (number of bat passes per 2 nights) at 11 sites in the Oregon Coast Range in 1995 versus mean snag diameter (a); and mean snag height (b).

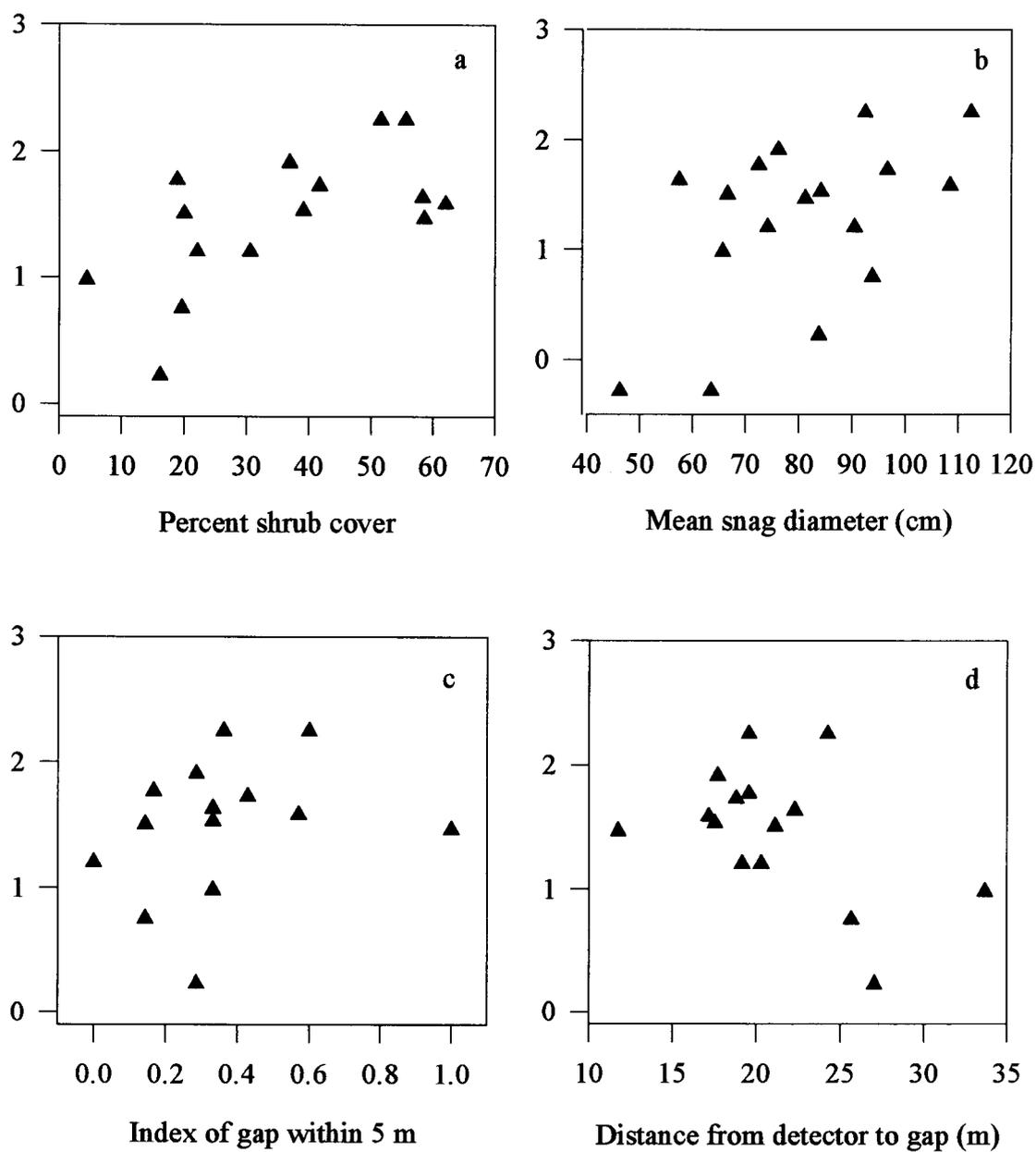


Figure 9. *Myiaca* activity (number of bat passes per 2 nights) in the Oregon Coast Range in 1995 versus mean percent shrub cover (a); mean snag diameter (b); relative presence of gaps within 5 m (c); and mean distance from the detector to a gap (d).

significant correlation between activity of the *Myyu/ca* group and the number of small snags, but this was due to the influence of one outlier. The *Myev/vo* group was negatively correlated with distance from the detector to snags, shrub height, and presence of large gaps (Table 10; Figure 10).

Overall bat activity was best explained by the following linear regression model:  $Y = 0.02 * \text{mean snag diameter} + 1.5$  ( $P = 0.04$ ). Activity of the *Mysp* group was best explained by a similar regression model:  $Y = 0.02 * \text{mean snag diameter} + 0.5$  ( $P = 0.01$ ). Activity of the *Myev/vo* group was best explained by a regression model including distance from the detector to snags:  $Y = -0.08 * \text{snag distance} + 3.2$  ( $P = 0.05$ ). A regression model with percent shrub cover best explained activity of the *Myyu/ca* group:  $Y = 0.02 * \text{shrubs cover} + 0.97$  ( $P = 0.01$ ).

### ***Environmental conditions***

Minimum nightly temperatures at bat detector locations varied from 6 to 19 C. Maximum nightly temperatures ranged from 9 to 26 C. The mean minimum temperatures in 1994 and 1995 were 11.7 C and 11.4 C, respectively. The mean maximum temperatures in 1994 and 1995 were 17.0 C and 15.5 C, respectively. In 1995, the mean minimum nightly humidity was 72% and varied from 28% to 100%. The mean maximum nightly humidity was 87% and varied from 50% to 100%.

Bat activity combined over both seasons was significantly correlated with both temperature and humidity variables (Table 11). In 1994, I measured only maximum and minimum nightly temperatures, and I did not find a significant correlation between bat passes and either minimum or maximum nightly temperature. In 1995, I calculated average nightly temperature in addition to maximum and minimum nightly temperatures, and I also measured maximum, minimum, and average nightly humidity. Bat activity was positively correlated with temperature variables, and negatively correlated with humidity variables (Table 11).

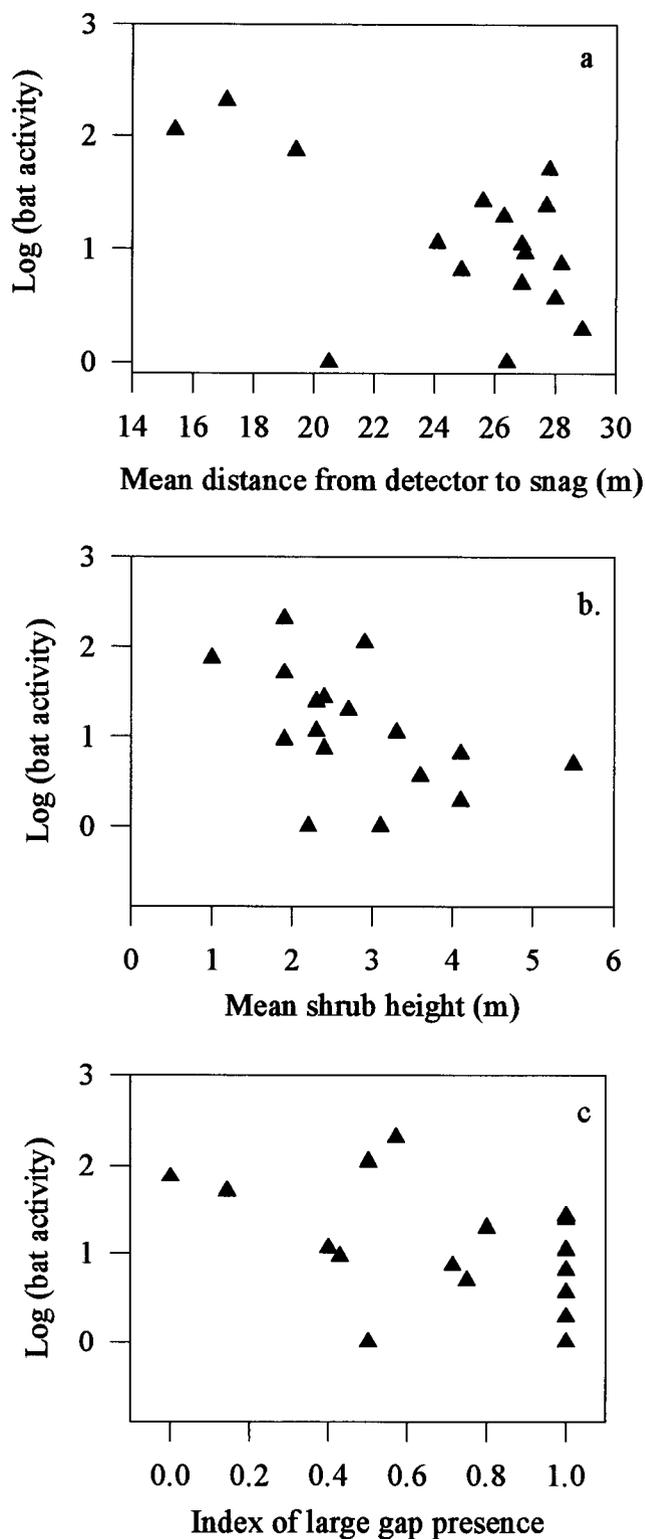


Figure 10. *Myev/vo* activity (number of bat passes per 2 nights) at 11 sites in the Oregon Coast Range in 1995 versus mean distance from detector to snags (a); mean shrub height (b); and relative presence of large gaps (c).

Table 11. Environmental variables which were significantly correlated with bat activity in the Oregon Coast Range in 1994 and 1995. Correlation coefficients (r), number of observations (n), and P values for Pearson's correlation are given.

Variable	Year	n	r	P
Maximum nightly temperature	1995	59	0.57	0.0001
	1994 & 1995	120	0.28	0.0020
Minimum nightly temperature	1995	59	0.36	0.0050
	1994 & 1995	120	0.26	0.0030
Average nightly temperature	1995	59	0.48	0.0001
Maximum nightly humidity	1995	54	-0.31	0.0200
Minimum nightly humidity	1995	54	-0.40	0.0030
Average nightly humidity	1995	54	-0.36	0.0080

When I examined the stand types separately, I found a positive correlation between bat activity and minimum temperature in old-growth stands in 1994 and a positive correlation between bat activity and minimum and maximum nightly temperature in the old-growth and thinned stands over both years and in 1995 alone (Table 12). However, I was not able to find significant correlations between bat activity and temperature in unthinned stands (Table 12).

Table 12. Environmental variables which were significantly correlated with bat activity by stand type in the Oregon Coast Range in 1994 and 1995. Correlation coefficients (r), number of observations (n), and P values for Pearson's correlation are given.

Variable	Stand type	Year	n	r	P
Maximum nightly temperature	Old growth	1995	18	0.50	0.04
	Old growth	1994 & 1995	35	0.37	0.03
	Thinned	1995	22	0.60	0.003
	Thinned	1994 & 1995	42	0.34	0.003
Minimum nightly temperature	Old growth	1994	21	0.63	0.002
	Old growth	1994 & 1995	39	0.35	0.03
	Thinned	1995	22	0.62	0.002
	Thinned	1994 & 1995	46	0.35	0.02
Average nightly temperature	Thinned	1995	22	0.66	0.001
Maximum nightly humidity	Thinned	1995	20	-0.41	0.07
Minimum nightly humidity	Old growth	1995	16	-0.46	0.07
	Thinned	1995	20	-0.45	0.05
Average nightly humidity	Thinned	1995	20	-0.45	0.05

## DISCUSSION

### *Effects of thinning*

Historically, commercial thinning has been used to increase the economic yield of a stand through harvest of some merchantable trees in order to increase growth and resulting yield from the remaining trees. Thinning also holds promise as a technique for altering vegetative structure in order to produce desired wildlife habitat conditions (Tappeiner 1992, Bailey 1996, Hagar et al. 1996, Barbour et al. in press). Thinning alters stand structure by reducing tree densities, opening up the canopy, increasing tree diameter growth rates, accelerating crown development, and enhancing understory development (Tappeiner 1992, Bailey 1996).

In my study, tree density, canopy cover, tree diameters, crown height, and shrub cover differed between thinned and unthinned stands (Table 9). In tree density, tree diameter and height, percent tall shrub cover, and shrub height, the thinned stands were intermediate between old-growth stands and unthinned stands. These conditions are consistent with studies suggesting that thinning may be a way to enhance the development of these structural characteristics in young stands (Newton and Cole 1987, Bailey 1996, Barbour et al. in press).

Bat activity also varied among stand types. Overall bat activity was approximately 1.5 times higher in old-growth stands than in young stands in my study. This is consistent with Thomas and West (1991), who reported higher detection rates of *Myotis* bats in old growth than in young forests in the Oregon Coast Range, although the magnitude of the differences they found (2.5 to 4.4 times higher) was greater than that found in my study. Other studies have reported increasing bat activity with increasing stand age. Erickson (1993) found higher bat activity in 51- to 62-year-old managed forest stands than in 10- to 13-year-old sapling-pole sites in Washington. Krusic et al. (1996) reported higher bat activity in hardwood stands  $\geq 119$  years old than in stands 10- to 119-years old in the White Mountains of New Hampshire.

In my study, bat activity was higher in thinned stands than in the adjacent unthinned stands. This suggests that elements other than stand age alone are influencing the activity of bats in forest stands; bats seem to be sensitive to stand structure. Similarly, Hagar et al. (1996) reported different abundances of some bird species in thinned and unthinned forests that seemed to be related to differences in stand structure caused by thinning.

Activity of bats in thinned stands was intermediate between activity in unthinned young stands and that in unmanaged old-growth stands. There was one notable exception to this trend. At the Bear Creek site, which was sampled in 1994, the most bat activity occurred in the unthinned stand, followed by the thinned stand, with the least amount of activity in the old-growth stand. Data from Bear Creek were sufficiently extreme to change the results of the overall analysis which included the other 6 sites sampled that year. Similarly, in 1995, the greatest amount of bat activity at the Elliot site occurred in the unthinned stand, with less activity in both the old-growth and thinned stands. However, the results of the overall analysis with all 6 sites in 1995 were statistically significant even when the Elliot site was included.

The Bear Creek and Elliot thinned/unthinned pairs were 100-year-old stands, the oldest of the young stands in my study, and each had been thinned at 80 years of age. In addition, stands at both sites were very productive, having two of the highest site indices at 134 and 131, respectively (Table 2). In the absence of management, developing forest stands which reach a critical density will thin themselves naturally, as competition among trees causes mortality in suppressed and intermediate trees (Oliver and Larson 1990). The unthinned stands at Bear Creek and Elliot had thinned themselves significantly by 80 years of age, making them more similar in structure to thinned stands than were younger, less productive, unthinned stands which had not reached this stage. In his study of these and other stands, Bailey (1996) noted that structural differences between thinned and unthinned stands were smaller on productive, older sites, particularly because the thinnings that had occurred at these sites were less intense.

Although structural differences caused by self-thinning may explain why unthinned stands had higher levels of bat activity at Bear Creek and Elliot, it is not clear

why levels of activity in the old-growth stands were lower at these two sites. One potential explanation is the particular isolation of these two old-growth stands relative to other stands >100-years-old in the surrounding landscape. However, I do not have information quantifying isolation. In addition, other old-growth stands in the Oregon Coast Range are also relatively isolated, including others sampled in my study which had relatively high levels of bat activity. Another distinction of the Bear Creek old-growth stand was that it was a very small stand (10 ha). This feature, in addition to isolation, may have made Bear Creek old growth less suitable habitat for species normally associated with old forest, potentially explaining the low levels of bat activity there.

When bat activity was examined by species group, there were more bat passes in old growth, followed by thinned and unthinned, for 4 of the 5 species groups (Table 7). Only the *Mysp* group and the *MythCory* group were statistically different among stand types. It is likely that activity of the *Mysp* group had the most influence on overall bat activity because it was the most common group in my study. However, I cannot determine which species within this group has the most influence on the activity pattern.

The pattern of the *MythCory* group likely reflects the activity of the fringed myotis because the calls of Townsend's big-eared bat are low intensity and difficult to detect (Kunz and Martin 1982), and for this reason probably represents a very low percentage of the calls in the *MythCory* group. Virtually nothing is known of the ecology of the fringed myotis in the Oregon Coast Range, where it is a rare species. In the Southern Oregon Cascades and Siskiyou, day roost sites have been located primarily in snags, under bark, and in rock crevices in forested areas (S.P. Cross, Southern Oregon State College, unpublished data). My data indicate that in the Oregon Coast Range, the fringed myotis may occur more frequently in old-growth forest than in younger forest.

In contrast to the other species groups, the *Myev/vo* group was represented by the most bat passes in thinned stands, followed by unthinned stands, and the lowest number in old-growth stands. This trend does not necessarily represent the trend of both the long-eared myotis and the long-legged myotis, but probably does reflect the trend of least one of these species. What little is known of the ecology of these species in the Pacific Northwest suggests that the long-eared myotis roosts during the day in trees, rock

crevices, stump, and logs, sometimes in forest and sometimes in cleared areas (D. Waldien, Oregon State University, unpublished data); whereas, the long-legged myotis has primarily been found roosting in snags and trees, but never in stumps or logs, and mostly associated with forested areas (Ormsbee 1996). The long-legged myotis is a relatively common inhabitant of Pacific Northwest forests, and the long-eared myotis is believed to be less abundant (Barbour and Davis 1969, Maser et al. 1981). My data on the number of bat passes recorded in each stand type do not allow me to make inferences on habitat associations for individual species, but they do suggest directions for future study.

### ***Bat activity and vegetation structure***

In order to explore reasons why bat activity varied among stand types, I measured those structural variables which I thought might influence bat activity, based on what is currently known of the foraging and roosting habits of bats. For example, larger trees with more deeply furrowed bark and snags potentially provide roosting sites, tree density and crown height might influence the ability of bats to maneuver in a forested environment, gaps are potential foraging habitat, and shrubs and tree crowns are potential substrate for insect prey.

Examination of the scatter plots (Figures 7 - 10) revealed a great deal of variability in bat activity associated with structural variables. In some cases, one or two points seemed to be establishing the direction of the relationship. Therefore, these results should not be viewed as definitive relationships, but may be indicators of possible associations and directions for further study.

Most variables significantly correlated with overall bat activity or activity by species groups exhibited trends consistent with current understanding of bat life history. Overall bat activity, activity of the *Mysp* group, and activity of the *Myyu/ca* group were all positively correlated with the mean diameter of snags. This relationship may be due to an increase in potential roosting sites available in larger snags. The *Mysp* group also showed a positive linear relationship with snag height, which also would fit the

hypothesis of improved roost site availability as snags increase in size. Consistently, activity of the *Myev/vo* group tended to decrease with increasing distance between the detector and snags. No significant relationship emerged between bat activity and snag density. Some stands that had very few snags exhibited a great deal of bat activity, which suggests that habitat elements other than snags may be significant in determining levels of bat activity.

Variables associated with gaps and with shrub cover and shrub height were significantly related to the overall activity of bats, as well as with the activity of the *Myyu/ca* group and the *Myev/vo* group. Canopy gaps and shrub growth are related in that gaps allow more light to reach the forest floor, enhancing growth of the understory. Activity of bats generally was positively correlated with increasing shrub cover and with the proximity of gaps. One potential explanation for more frequent detections of bats in areas with gaps and high shrub cover is that these areas may support concentrations of insects that either attract more bats or cause bats to spend more time in those areas searching for prey. However, few feeding buzzes were recorded in these areas, leaving this relationship unclear. Other potential explanations are that bats spend more time in openings because maneuverability is easier, or that bats are more easily detected in these openings.

The *Myev/vo* group had a significant negative correlation with the height of shrubs. One potential explanation for this relationship is that bats foraging or traveling above the shrub layer would be further from the bat detector when the shrub layer was higher, thus being more difficult to detect.

A comparison of the structural characteristics correlated with bat activity with the structural characteristics which differed among stand types (Tables 8 and 9), indicates which characteristics may be influencing bat activity among stand types. Greater bat activity in old-growth stands compared to young stands may be related to the higher shrub cover associated with old-growth stands. Similarly, greater bat activity in thinned stands compared to unthinned stands may be the result of higher shrub cover and lower canopy cover associated with thinned stands. These relationships are inconclusive, and warrant further study.

### ***Bat activity and environmental conditions***

The activity of bats in my study increased with increasing temperature between 6 and 26 C, as is reflected in positive correlations of bat activity with both minimum nightly temperature and maximum nightly temperature (Table 11). This result is consistent with other studies which have reported greater activity by bats at higher temperatures (Kunz 1973, Lacki 1984, Rydell 1991, Maier 1992, Hayes In Press). When I examined stand types separately, bat activity in old-growth and in thinned stands had a significant positive correlation with temperature (Table 12), but I was not able to detect a relationship between temperature and bat activity in the unthinned stands.

There was also a negative relationship between bat activity and relative humidity. Bat activity decreased as the humidity increased in 1995. This relationship was evident in the old-growth and thinned stands, but I was not able to detect a relationship in the unthinned stands. This result may be a reflection of the absence of bat activity in rainy weather. In general, humidity is high in these coastal forests, and I would expect humidity to have less of an effect on bat activity than other factors.

### ***Distribution of bat species groups***

Of the calls that I was able to classify, almost all were *Myotis* species. Seven of the 11 bat species which occur in the western Oregon Coast Range are in this genus. Thomas (1988) classified 88% of calls recorded in unmanaged stands in the Oregon Coast range as *Myotis* species. Erickson (1993) reported 99% of identified calls in managed forest in the Washington Cascades as *Myotis*.

Many species of *Myotis* bats have been associated with forests. *Myotis* bats in the Pacific Northwest have broad wings, are capable of maneuverable flight, and use short, broad band echolocation calls (Aldridge and Rautenbach 1987). These characteristics are suitable for flight in the relatively cluttered conditions in forests (Aldridge and Rautenbach 1987; Fenton 1990). In contrast, hoary bats, silver-haired bats, and big

brown bats commonly, though not exclusively, forage in open areas (Kunz 1982, Shump and Shump 1982, Barclay 1985, Kurta and Baker 1990). They use lower frequency, narrowband calls which can detect prey at longer distances (Fenton 1990). Hoary bats, in particular, are morphologically adapted for fast flight and capturing prey in open areas (Barclay 1985, Nagorsen and Brigham 1993).

Low detection rates of non-*Myotis* species in forested habitats also may be the result of species altering their calls in different environments (Obrist 1995). The structure of echolocation calls emitted by bats in cluttered, forested areas may be different from the structure of calls emitted by the same bats in open areas. If this is the case, basing call classification on reference calls recorded in open habitats may have resulted in misidentification of calls recorded in closed habitats.

### *Identification of bat calls*

Others claim to distinguish most non-*Myotis* bats from each other by their calls (Erickson 1993, Thomas 1988). In this study, I did not feel confident in differentiating between all hoary bats, silver-haired bats, and big brown bats, because of the brevity of most of the call sequences recorded.

Other studies have categorized *Myotis* species into groups. Thomas (1988) distinguished long-legged myotis from other *Myotis* species, grouped the little brown bat with the Yuma myotis, and had a separate group for the California myotis and the long-eared myotis. Erickson (1993) distinguished the Yuma myotis from the other *Myotis*. In my study, the groups were based on characteristics of reference calls from Oregon and Washington (Erickson 1993, J. P. Hayes, Oregon State University, unpublished data, S.P. Cross, Southern Oregon State College, unpublished data). With this information, I did not feel I could confidently distinguish between the long-eared myotis and the long-legged myotis most of the time; however, I could separate these species from other *Myotis* based on the minimum frequency of the call. I also could separate the Yuma myotis and the California myotis from other *Myotis* but not from each other, based on the

minimum frequency. Calls of the fringed myotis were distinguishable from those of other *Myotis*, but not necessarily from those of Townsend's big-eared bat. I was less confident in being able to distinguish the little brown bat from other *Myotis* species, because many species have ranges of minimum frequency which overlap the frequency range of the little brown bat.

### ***Roads***

Although the number of bat passes was very low at the Adams Siding site where roads were sampled, the trend for more activity along the roads is consistent with other studies which have reported concentrations of bat activity along forest edges, trails, and other linear landscape elements (Grindal 1995, Krusic et al. 1996). All but one of the bat passes identified to species was of a *Myotis* bat, so apparently these roads were not attracting the more open-adapted species such as big brown and hoary bats. Roads in forest stands may be serving as corridors for *Myotis* bats for traveling and/or feeding.

### ***Feeding activity***

The low number of feeding buzzes relative to general echolocation calls in all stands also is consistent with results from other studies (Thomas 1988, Erickson 1993, Krusic et al. 1996). The fact that feeding buzzes are recorded in forest stands suggests that bats do hunt and feed in forest stands. They may be feeding opportunistically while traveling from one roost or feeding area to another, or hunting and feeding may be the primary activity of bats in these stands. Low numbers of feeding buzzes in forest stands do not necessarily indicate that they are not using these stands for feeding, but may indicate that feeding activity is more diffuse in forest stands than in more defined areas such as forest edges and riparian corridors. Some species of bats foraging in closed habitats rely on prey-generated sounds or visual cues to locate prey and use echolocation primarily to collect information about their surroundings (Fenton 1990). If this is the

case for some of the bat species using forested stands in Oregon, then more feeding may be occurring in these stands than is evident from the number of feeding buzzes.

### *Scope and limitations*

The scope of this study was limited to forest stands in the Oregon Coast Range. Although the stands sampled in this study ranged throughout much of the region, they were not randomly selected and therefore caution should be used in applying the results to the entire region. The scope of the study also is limited to stands between 50 and 100 years old and to unmanaged stands  $\geq 200$  years old. My data suggest that the results apply to young stands  $< 100$  years old but may not apply to older, productive stands, such as Bear Creek and Elliot. Because most of the same species occur in the Oregon Cascades, the results may be used to make predictions about activity in the lower elevations of the Cascades.

The automated bat detector survey method allowed me to record the calls of bats as they flew through the space sampled by the microphone. Because it was automated and sampled a fixed unit of space, an automated bat detector avoided many of the biases of other bat survey methods (Thomas and West 1989). However, there are several limitations associated with this method. Bat activity is not a direct measure of bat abundance. Detectors are unable to distinguish between multiple passes by a single bat and single passes by several bats. However, bat detectors can provide a survey of relative bat activity in different habitat types (Thomas and West 1989).

Another limitation is that bat detectors do not detect all species equally. Bats with higher intensity calls are likely to be recorded at further distances than species with lower intensity calls. In addition, bat detectors may not detect bats equally in all habitat types. Denser, more cluttered environments may impede reception or transmission of bat calls. However, because all habitats sampled in my study were forested, I believe this potential source of variability was minimal.

The Anabat II system has been used in several studies of bat activity (Erickson 1993, Conole and Baverstock 1995, Kutt 1995, Lance et al. 1995, Krusic et al. 1996, Hayes in press), and the ability to accurately classify bats to species on the basis of the call parameters available with this system is being evaluated. Two of the limitations in trying to accurately identify species from field data are the variability in call characteristics within a species and the brevity of call sequences recorded in the field (Thomas et al. 1987, Brigham et al. 1989, Erickson 1993). There is a great deal of variability among the calls from a single species, and consequent overlap in call characteristics among different species.

Interpretation of my results with regard to species groups is limited because the groupings are based on call characteristics rather than ecological similarity of the species. However, the *Myotis* groups consist of species adapted for foraging in closed environments, and the *Eptes/Las* group consists of species whose calls seem better adapted for foraging in more open environments. The trends in bat activity of the species groups do not necessarily represent the trends of all species included in the group, but probably do reflect the trends of at least one of those species. These data do not allow for making inferences on habitat associations for individual species, but they suggest directions for future study.

### ***Management implications and research needs***

My results are consistent with results from similar studies: bat activity is higher in old-growth stands than in young stands (Thomas 1988, Krusic et al. 1996). If bat activity is representative of bat population abundance in an area, then maintaining old-growth ecosystems would be beneficial to bat populations.

In contrast to the predictions of Thomas and West (1991), I did not find managed stands to be devoid of bats, even when the stands contained few or no damaged trees and snags. My results show that bat activity is generally higher in thinned than in unthinned young stands, suggesting that bats are sensitive to stand structure. Thinning young stands

shortens the stem exclusion stage of forest development (i.e., high stem density and low species diversity; Oliver and Larson 1990). This in turn may benefit bats by creating habitat structure in these young stands that bats are able to use more effectively. If managers are able to use thinning to create old-growth structure more quickly than would occur naturally, this would likely benefit bat populations.

The effects of thinning vary depending on variables such as stand age, site productivity, and the intensity of thinning (Tappeiner 1992, Bailey 1996). As self-thinning occurs in older, unthinned stands, they become more similar in structure to thinned stands, as was evident at the Bear Creek site. My results suggest that thinning stands younger than 80 years old would be beneficial to bats. Enhancing characteristics associated with old-growth structure through thinning may be most effective on some sites and stages of stand development and at certain thinning intensities (Bailey 1996, Barbour et al. in press).

My data suggest potential relationships, but do not establish to which elements of stand structure bats are responding. My results suggest that bat activity is related to the presence of gaps and to increased understory cover. If this is the case, high thinning intensities would benefit bats more than low thinning intensities. In addition, other silvicultural systems, such as individual or group selection harvest, also may be beneficial to bat populations.

Although my results did not indicate that bats were responding to snag density, bat activity was positively correlated with snag diameter. Other studies have indicated that bats roost in snags (Betts 1995, Chung-MacCoubrey 1995, Crampton and Barclay 1995, Vonhof 1995, Ormsbee 1996). Large snags seem to be habitat elements used by several species of bats and need to be included in habitat management for this taxa.

More conclusive information is needed on the specific habitat elements in forest stands to which bats are responding. My results suggest that not all species show the same patterns with respect to habitat type, and knowledge of the habitat requirements and behavior of individual bat species would facilitate understanding how to manage the forest to benefit each species. The identification of species from calls recorded by the Anabat system needs to be refined in order to study these relationships.

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