AN ABSTRACT OF THE THESIS OF

Julia L. Boland for the degree of Master of Science in Forest Science presented on July 26, 2007.

Title: Distribution of Bats in Southeast Alaska and Selection of Day-roosts in Trees by Keen's Myotis on Prince of Wales Island, Southeast Alaska.

Abstract approved:

John P. Hayes

We conducted capture and acoustic surveys for bats in six areas along a latitudinal gradient in Southeast Alaska from mid-May to September in 2005 and we continued surveys on Prince of Wales Island from mid-May to September in 2006. We determined the level of effort required to catch each species and documented ranges in morphology and periods of reproduction. We captured little brown myotis, *Myotis lucifugus*; California myotis, *M. californicus*; long-legged myotis, *M. volans*; and Keen's myotis, *M. keenii*, and we acoustically detected and sighted the silver-haired bat, *Lasionycteris noctivagans*. Capture success varied by species, year, and type of capture site. Our surveys support prior research suggesting that the little brown myotis is the most abundant species in the region, although densities appear to be low relative to other parts of its range. California myotis and Keen's myotis were captured as far north as Juneau. The long-legged myotis was captured on Wrangell and Prince of Wales Islands and the silver-haired bat was detected on Prince of Wales Island. Prince of Wales Island is the

southernmost area we sampled and was the only area where all species were detected. Given low rates of detection, all species appear to occur in low densities in Southeast Alaska. Better understanding of population status and trends and examination of habitat ecology and response to forest management in the region is needed to prioritize conservation strategies.

The Keen's myotis is rare and has one of the most limited distributions of any bat species in North America. Understanding gender-specific roosting ecologies of bats at relevant spatial scales is necessary to effectively evaluate the impact of habitat alteration and prioritize conservation efforts for bats in temperate forests. We examined selection of day-roosts in trees by Keen's myotis from mid-May to September, 2006 on Prince of Wales Island, Southeast Alaska. Our objectives were to 1) examine relationships between and determine relative importance of habitat characteristics on selection of day-roosts at three spatial scales and 2) determine if habitat associations for males and females differed at each scale. We tracked 13 females to 62 roosts in trees and 6 males to 24 roosts in trees. Features at each spatial scale appeared to influence selection of day-roosts by female Keen's myotis, but associations were strongest at the tree scale and trees used as roosts were primarily large in diameter with structural defects and located in old-growth forests. Trees in plots around roosts of females had large mean diameters and these plots had a high abundance of roost-like trees. Roosts were generally located near to roads and streams and surrounded by landscapes with a high abundance of old-growth and riparian habitat. Associations were evident for male Keen's myotis at each spatial scale, but associations at the landscape scale were strongest. Male Keen's myotis exhibited flexibility with the types of roosts they chose, but tree roosts were primarily snags in

early to intermediate decay surrounded by a high relative abundance of roost-like trees that were closer to roads and further from riparian habitat. Habitat associations differed between males and females at each spatial scale and differences are likely a reflection of higher energetic constraints associated with reproduction for females. Energetic benefits gained from optimal roosting habitat may be critical for successful reproduction by females. Females primarily roosted in old-growth habitat and we suggest that maintaining structural components characteristic of old growth will promote conservation of Keen's myotis in Southeast Alaska.

Distribution of Bats in Southeast Alaska and Selection of Day-roosts in Trees by Keen's myotis on Prince of Wales Island, Southeast Alaska

by
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CONTRIBUTION OF AUTHORS

Dr. John P. Hayes contributed to writing the proposal, study design, interpretation of data, and writing of Chapters 2 and 3. Dr. Winston P. Smith contributed to writing of the proposal, study design, and critiqued material in Chapters 2 and 3. Manuela Huso assisted with study design, interpretation of data, and critique of Chapters 2 and 3.

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Distribution of Bats in Southeast Alaska and Selection of Day-roosts in Trees by Keen's
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by
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CHAPTER 1: INTRODUCTION

In many areas of North America, the focus of forest management is beginning to shift from primarily intensive timber harvest and production to sustainable harvest with maintenance of ecosystem health and biodiversity (Simberloff 1999, Hobbs et al. 2002). Consequently, there has been increased awareness by forest managers of the ecological roles of wildlife in forest ecosystems. However, bats are one of the most understudied groups of forest-dwelling vertebrates. There are approximately 1100 species of bats, constituting a quarter of all mammalian species; almost half of all bat species are considered by the International Union for the Conservation of Nature and Natural Resources (IUCN) to be threatened or near threatened at a global level (Hutson et al. 2001). The small size, nocturnality, and volancy of forest-dwelling bats in temperate regions create significant challenges to assessment of their biology and ecology. These traits also make it difficult to extrapolate from models of conservation for other taxa (Racey and Entwistle 2003). Timber harvest without mitigation for critical habitat may be detrimental to populations of forest-dwelling bats. However, limited information regarding distribution and habitat associations inhibits our ability to mitigate for potential negative impacts of forest management activities on bat populations (Christy and West 1993, Racey and Entwistle 2003) and lack of information on population status and trends hampers prioritization of mitigating efforts.

Little is known regarding the current distribution and population status of bats in Southeast Alaska. Five species of bat have been reported to occur in the region and Southeast Alaska is thought to be the northern limit of the distributional range for four of them (Parker et al. 1997). The conservation status and region-specific ecology of bats in

Alaska is unclear, but some species that occur in Alaska are primarily associated with forests in other parts of their range (Nagorsen and Brigham 1993, Hayes 2003). The coastal temperate rainforest of Southeast Alaska is rapidly being altered by timber harvest (Iverson et al. 1996, DeGange 1996, USDA Forest Service 1996). In Chapter 2 we assess the presence, distribution, and relative abundance of bats in Southeast Alaska. We document biological characteristics and elements of natural history as well as effective detection methodologies specific to each species. The information we acquired can be used by managers and ecologists to establish a framework for future monitoring efforts of bats in Southeast Alaska.

Keen's myotis has the most limited distribution of any species of bat in North America (Nagorsen and Brigham 1993, Parker and Cook 1996, COSEWIC 2003). A handful of anecdotal observations have been reported in British Columbia regarding roosting habits of Keen's myotis (Burles 2000, COSEWIC 2003), but rigorous examination of habitat associations has not been conducted and nothing is known of their habitat requirements in Southeast Alaska. The Keen's myotis appears to be rare throughout its range, but without appropriate knowledge regarding critical habitat requirements, effective conservation strategies cannot be developed. Suitable day-roost habitat is critical for populations of forest-dwelling bats (Kunz and Lumsden 2003) and dependence of bats on trees for day-roosting may make populations of forest-dwelling bats vulnerable to decline due to timber harvest (Hayes 2003, Hayes and Loeb 2007).

In Chapter 3 we address the influence of tree and landscape characteristics on selection of day-roosts by Keen's myotis on Prince of Wales Island. We focused our efforts on roosting requirements of Keen's myotis given their apparent rarity and the lack

of available information regarding their habitat associations. We hypothesized that male and female Keen's myotis have different roost requirements (as suggested by Broders and Forbes 2004, Barclay and Kurta 2007). We proposed that selection of roosts by Keen's myotis may be influenced by multiple factors operating at different spatial scales and requirements at one scale may affect and potentially constrain selection at broader or finer scales (Weins 1989, Gorressen et al. 2005, Barclay and Kurta 2007).

Racey and Entwistle (2003) suggest that effective conservation of bats requires understanding of population abundance and trends, distribution, critical habitat areas, and potential threats to population persistence. In the following chapters we attempt to address each of these topics for bats in Southeast Alaska. We contribute information regarding relative abundance and distribution of bats in Southeast Alaska and critical roosting habitat of the Keen's myotis. Given our findings we offer insight into potential impacts of habitat alteration on persistence of populations of Keen's myotis. We hope this information can be used by managers and ecologists to develop effective management plans and conservation strategies for forest-dwelling bats in Southeast Alaska.

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CHAPTER 2: DISTRIBUTION OF BATS IN SOUTHEAST ALASKA

ABSTRACT

We conducted capture and acoustic surveys for bats in six areas along a latitudinal gradient in Southeast Alaska from mid-May to September in 2005 and we continued surveys on Prince of Wales Island from mid-May to September 2006. We determined the level of effort required to catch each species and documented ranges in morphology and periods of reproduction. We captured little brown myotis, *Myotis lucifugus*; California myotis, *M. californicus*; long-legged myotis, *M. volans*; and Keen's myotis, *M. keenii*, and we acoustically detected and sighted the silver-haired bat, *Lasionycteris noctivagans*. Capture success varied by species, year, and type of capture site. Our surveys support prior research suggesting that the little brown myotis is the most abundant species in the region, although densities appear to be low relative to other parts of its range. California myotis and Keen's myotis were captured as far north as Juneau. The long-legged myotis was captured on Wrangell and Prince of Wales Islands and the silver-haired bat was detected on Prince of Wales Island. Prince of Wales Island is the southernmost area we sampled and was the only area where all species were detected. Given low rates of detection, all species appear to occur in low densities in Southeast Alaska. Better understanding of population status and trends and examination of habitat ecology and response to forest management in the region is needed to prioritize conservation strategies.

INTRODUCTION

Existing data are limited regarding the presence, distribution, and natural history of bats in Southeast Alaska (MacDonald and Cook 1996, Parker and Cook 1996, Parker et al. 1997). Bats comprise the second largest order of mammals after rodents, but the challenges associated with observing volant, nocturnal animals have contributed to the deficiency of information on their general biology and ecology worldwide. These general difficulties are compounded in the temperate rainforest of Southeast Alaska by the rugged terrain, wet climate, and low densities of bats.

Five species of bat have been documented in Southeast Alaska (little brown myotis, *Myotis lucifugus*; California myotis, *M. californicus*; long-legged myotis, *M. volans*; Keen's myotis, *M. keenii*, and the silver-haired bat, *Lasionycteris noctivagans*). Southeast Alaska is thought to be the northern distributional limit for all species of bat that occur there except the little brown myotis, which is found in the interior of Alaska (Parker et al. 1997).

Estimates of extinction and turnover rates often are higher at the edge relative to the interior of a species range (Doherty et al. 2003). Brown et al. (1995) propose that a species is less abundant at the edge of its range because individuals are suboptimally adapted to these areas and dependent on immigration from populations in the interior of its range. Alternatively, Channell and Lomolino (2000) suggest that populations at the periphery of a species range may persist longest if they are more isolated from and therefore less impacted by extinction factors. Due to the limited availability of data, it is not certain whether the apparent rarity of bats in Southeast Alaska is a result of the species occurring at their distributional limits, some other ecological factor, or an artifact

of inadequate investigation. Each species of bat that occurs in Southeast Alaska is thought to be rare in this region except the little brown myotis, which is suspected to be widespread but in low densities.

The California myotis has been documented in Alaska from 5 specimens found on and around Prince of Wales Island (ca. 54-56° N latitude) (Parker et al. 1997). This species occurs throughout western United States and Canada to Central Mexico and inhabits a variety of habitats from arid grassland to montane forests (Nagorsen and Brigham 1993, Simpson 1993). Roosting habits of California myotis are not known in Alaska, but in other parts of its range they have been observed roosting in rock crevices, tree cavities, mines, bridges, buildings, and under loose bark (Nagorsen and Brigham 1993, Simpson 1993, Brigham et al. 1997). There are no records of reproductive events for the California myotis in Alaska and knowledge is limited in nearby British Columbia, but pregnant females have been found in the interior of Canada from early to late-June (Nagorsen and Brigham 1993).

The Keen's myotis may have the most restricted range of any species of bat in North America and occurs within a narrow strip of coastal coniferous forest from Southeast Alaska through southwestern British Columbia and northwestern Washington (van Zyll de Jong 1979, van Zyll de Jong and Nagorsen 1994, Parker and Cook 1996). Due to its rarity, it was listed as a species of special concern in 1988 by Canada's Ministry of Environment, but has since been down-listed to 'Data Deficient' by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) due to difficulties distinguishing it morphologically and genetically from *M. evotis* and insufficient data regarding population status and trends and basic natural history

(COSEWIC 2003). NatureServe© ranks Keen's myotis as globally imperiled (high risk of extinction due to extreme rarity and restricted range) and in Alaska their status ranges from critically imperiled to vulnerable (www.natureserve.org, accessed June 2007).

Only two specimens of Keen's myotis exist from Southeast Alaska; one found on Wrangell Island in 1887 and one from northern Prince of Wales Island in 1993 (Parker et al. 1997). A third specimen, collected in 1994 from a maternity roost of little brown myotis on Chichagof Island (Parker and Cook 1996), was later confirmed through genetic analysis to be a little brown myotis (Tanya Dewey, personal communication). Keen's myotis are thought to be a forest-dwelling species, but have been captured while flying in estuaries, riparian habitats, and urban environments (Parker and Cook 1996, Davis et al. 2000, COSEWIC 2003). Recent evidence suggests female Keen's myotis on Prince of Wales Island in Southeast Alaska roost primarily in hollows, cracks, or under loose bark of western redcedar (*Thuja plicata*) and western hemlock (*Tsuga heterophylla*; Chapter 3). Male Keen's myotis appear to be less selective and were found to roost by day in cracks, hollows, and under loose bark of trees or stumps, under loose rocks, and in rock crevices (Chapter 3). Male Keen's myotis have also been observed night roosting under bridges (J. Boland, personal observation). In British Columbia, Keen's myotis roost under boulders and in rock crevices and caves (Burles 2000, COSEWIC 2003). The only reproductive information for this species was collected from a maternity roost on Gandl K'in, an island in Haida Gwaii (Queen Charlotte Islands), British Columbia where parturition occurred during early July and young were volant by early August (Burles 2000, COSEWIC 2003).

The little brown myotis is common throughout Canada, the United States, and Mexico, appears to be the most abundant species of bat in Alaska (Parker et al. 1997), and has been recorded as far north as Fort Yukon (Hall 1981) and Fairbanks (Fenton and Barclay 1980, Parker et al. 1997). This species appears to be resident in Alaska throughout the year and has been found wintering on Kodiak Island and in caves in the southeast region (Parker et al. 1996, 1997). The little brown myotis is known to occur in a wide range of habitats and elevations (Fenton and Barclay 1980) and to roost in tree cavities, loose bark, rock crevices, buildings, bridges, and caves (Nagorsen and Brigham 1993). In Southeast Alaska, the little brown myotis has been found roosting in buildings, under bridges, and in cavities and under loose bark of trees (J. Boland, personal observation). Reproductive data are limited in Southeast Alaska, but pregnant females have been found in mid-June, lactating individuals in mid-June and early August, and juveniles in mid-August (Parker et al. 1996). In British Columbia, little brown myotis give birth between mid-June and mid-July after a 50-60 day period of gestation, although it is speculated that populations occurring in higher latitudes and elevations give birth to young later (Fenton et al. 1980, Nagorsen and Brigham 1993).

The long-legged myotis occurs throughout western North America to central Mexico (Warner and Czaplewski 1984). Five specimens are recorded from locations in Southeast Alaska; the northernmost location being Admiralty Island (ca. 57.5° N latitude, Parker et al. 1996). It has also been located as far north as Atlin (ca. 59.5° N latitude) in British Columbia, which is at the same latitude and approximately 100 km east of Skagway at the northeast end of Southeast Alaska. Long-legged myotis primarily inhabit coniferous forest, but may also be found in arid environments (Warner and Czaplewski

1984, Nagorsen and Brigham 1993, Hayes 2003). The only reproductive information

available for this species in Alaska is one lactating female found in late July (Parker et al.

1996), but pregnant females have been documented in British Columbia from 23 May to

18 July and lactating females from 25 June to 8 August (Nagorsen and Brigham 1993).

The silver-haired bat ranges from Southeast Alaska and southern Canada, to

northern Mexico (Kunz 1982). Four specimens have been collected as far north as

Juneau in Southeast Alaska (Parker et al. 1996). In British Columbia, the silver-haired

bat is thought to be primarily a forest-dwelling species and has been found roosting under

loose bark, in cracks and hollows of trees, and in abandoned bird nests and cavities

(Nagorsen and Brigham 1993). One pregnant female was collected in British Columbia

on 18 June and parturition is thought to occur in late June or early July (Nagorsen and

Brigham 1993).

The conservation status of bats in Alaska is unclear due to the lack of information

pertaining to their population status and trends and region-specific ecology. The coastal

temperate rainforest of the Pacific Northwest is rapidly being altered by timber harvest

(Iverson et al. 1996, DeGange 1996, USDA Forest Service 1996). Many questions

regarding ecological requirements of bats within this system need to be addressed. The

temperate rainforests of the Pacific Northwest comprise a unique biome in North

America and caution should be taken when making extrapolations of ecology from other

parts of a species' range. We examined presence and distribution of bats using capture

and acoustic techniques along a latitudinal gradient in Southeast Alaska. We documented

biological characteristics and elements of natural history for each species and, using

multiple techniques in a variety of habitat types, we determined how and where to

effectively detect each species. The information we acquired can be used by managers and ecologists to establish a framework for future monitoring efforts of bats in Southeast Alaska.

METHODS

Study Area

Southeast Alaska consists of the Alexander Archipelago and a narrow strip of mainland adjacent to British Columbia and extends from approximately 54° to 60° N latitude. The landscape is mountainous with coastal coniferous rainforest, muskeg bogs, marshlands, alpine areas, and glaciers with their associated outwash plains and ice fields. The glaciated St. Elias and Fairweather mountain ranges essentially isolate the region from south-central Alaska (Anthony and Tunley 1976). The region is approximately 22.9 million acres in size and 48% is classified as forest (Fig. 2.1, van Hees 2003). The classification of 'forest' includes a mix of old growth, even- and uneven-aged second growth, muskeg, alpine, and grass flats (van Hees 2003). Dominant forest types are western hemlock (*Tsuga heterophylla*), western hemlock-Sitka spruce (*T. heterophylla-Picea sitchensis*), and mixed conifer (van Hees 2003). The climate is maritime with cool summers and mild winters, high humidity, and high precipitation. Monthly average temperatures from May to September range from approximately 6-13 °C and monthly average precipitation ranges from 2.5-29.7 cm (National Oceanic and Atmospheric Administration, www.noaa.gov, accessed June 2007).

Captures

We captured bats and recorded their echolocation calls from 13 May to 31 August 2005 to assess their presence and distribution across a broad range of habitats in six areas along a latitudinal gradient in Southeast Alaska. We captured bats in Yakutat, Juneau, Chichagof Island, Mitkof Island, Wrangell Island, and Prince of Wales Island and we continued survey efforts with emphasis on Keen's myotis on Prince of Wales Island from 20 May to16 Aug 2006.

We verified presence of bats at potential capture sites by passively recording their echolocation calls through the night using echolocation detectors (Anabat II detectors- Titley Electronics, Ballina NSW, Australia). We recorded activity for at least one night prior to selecting a site. Most capture sites were located in riparian and over aquatic habitats (i.e., rivers, creeks, ponds). Aquatic environments are important areas of bat activity because they provide drinking water and relatively high abundance of insect prey (Thomas 1988, Grindal et al. 1999, Hayes 2003) and bats often use these areas more often than upland habitats (Parker et al. 1996, Grindal et al. 1999). We also attempted captures on roads and trails within forests that were potentially used by bats as flyways. We contacted the public through flyers, newspaper classifieds, and other forms of community outreach to acquire knowledge of locations of bat activity and buildings with known or suspected roosts. Buildings and structures were suspected of being roosts if bats had been observed or guano was found in or around the structure. We prioritized captures at sites with bat activity (as determined by detectors, sightings, and guano), but in an attempt to diversify the habitats sampled we did not necessarily always attempt captures at sites with the highest level of activity.

We used several techniques separately and simultaneously to increase likelihood of captures and detection of each species. We captured bats using mistnets (Kunz and Kurta 1988) and four-banked harp traps (G5 Bat Trap, Bat Conservation and Management, Inc., Carlisle, PA; Francis 1989) suspended outside roosts and over water and flyways. At selected locations, mistnets were also mounted on pulley systems from 20-30 ft stacked steel poles (Tom O'Shea and Dan Neubaum, personal communication). In 2006 we focused effort on capturing Keen's myotis and most capture attempts were made with mistnets placed over water or trails where entire corridors could be closed off. In an attempt to detect bats that were not captured, we also acoustically monitored bats using Anabat II detectors in the area where captures were conducted.

Capture Effort

In 2005 we attempted to broadly survey bats to ascertain the prevalence and distribution of each species across the region. In 2006 our main focus was to capture Keen's myotis on Prince of Wales Island for telemetry studies (Chapter 3), although we captured and collected data on other species as well. Analyses of capture success and effort were restricted to capture attempts with mistnets, including stacked mistnets, throughout the region. Captures at roosts were excluded from analyses of effort.

We measured capture effort in units of nethours. We calculated nethours by summing the total area of mistnets opened each night multiplied by the number of hours the nets were open (m^2 net * hours). Capture per unit effort was determined by the number of bats captured in mistnets divided by number of nethours staged (capture/ unit effort = #bats / (m^2 net * hours)). We determined the effort required to capture each species in each area sampled and at each type of site. Types of sites included rivers,

creeks, ponds, roads, and trails. Rivers were distinguished as flowing waterways greater than 12 m wide with variable depths. Creeks were generally less than 12 m wide and less than 1 m deep.

Morphology and Reproduction

We identified species based on morphological characteristics and pelage (Nagorsen and Brigham 1993). For each bat, we recorded age, sex, reproductive status, and lengths of ear, tragus, thumb, foot, and forearm. We measured lengths of ear and tragus from the inside base notch to tip, thumb from base of joint to base of nail, and foot from base of toenails to start of ankle. To confirm identifications made in the field, we collected a tissue biopsy with a 2 mm biopsy punch from the wing of each individual identified as Keen's myotis and a subset of individuals identified as little brown myotis for DNA analyses. We sent biopsies to Tanya Dewey at the University of Michigan for analyses. Character data for DNA analyses of Keen's myotis were taken from double-stranded mitochondrial sequences of the cytochrome *b* gene and character data for the little brown myotis were taken from single-stranded sequences (Dewey 2006).

We classified reproductive status of female bats into 5 categories: pregnant, lactating, post-lactating, parous (evidence of reproduction at some point in the past, but not currently pregnant or lactating), and nulliparous (no evidence of previous reproduction). Pregnancy was determined by gently palpating the abdomen to detect the presence of a fetus. Females in early stages of pregnancy before the fetus is large enough to feel were likely misdiagnosed as not pregnant. A bat was identified as lactating if skin around nipples was bare and the nipple was either noticeably swollen or milk was expressed by gently rubbing or squeezing it (Anthony 1988). Post-lactating females have

enlarged, keratinized nipples and the area around the nipple is bare. The nipples of parous females are dark and keratinized, but with slight hair growth in the area around them. The nipples of nulliparous females are small, undeveloped, and almost concealed by hair (Anthony 1988). Males were identified as reproductive if testicles were enlarged and descended and non-reproductive if otherwise. We distinguished juveniles from adults by transilluminating the wing and examining finger bones for the presence of cartilaginous epiphyseal plates (Anthony 1988).

RESULTS

Captures

We caught 308 bats comprising four of the five species that were previously known to occur in the region (little brown myotis, California myotis, long-legged myotis, and Keen's myotis; Table 2.1) and we sighted and acoustically detected the silver-haired bat. We captured 226 bats with mistnets during 118 nights and, in addition, 61 little brown myotis were captured from roosts in buildings and one little brown myotis was captured as it exited a Keen's myotis maternity roost in a tree. Nineteen Keen's myotis were captured from the maternity roost in a tree.

The little brown myotis was the most frequently captured species, comprising 87% of mistnet captures throughout the region in 2005 and is likely the most abundant species of bat in Southeast Alaska (Table 2.2). In 2006, when surveys were conducted exclusively on Prince of Wales Island and our efforts were focused on captures of Keen's myotis, little brown myotis comprised 34% of total captures (Fig. 2.2). We also captured 59 little brown myotis from 5 day-roosts in buildings in Yakutat (3), Juneau (1), and Petersburg (1). Little brown myotis were present in each area sampled and were the only

bats captured in Yakutat and on Chichagof Island (Fig. 2.3). Fifty-five percent of little brown myotis captured in mistnets were captured over creeks and 29% were captured over rivers (Table 2.3). The little brown myotis was the only species of bat captured from roosts in buildings or mistnetted in urban environments.

We found Keen's myotis in each area except Chichagof Island and Yakutat. Although we captured Keen's myotis throughout much of the region, captures were relatively rare in 2005 (ca. 6% of mistnet captures). In 2006 we captured 34 Keen's myotis on Prince of Wales Island; 19 female Keen's myotis (plus one male little brown myotis) were captured as they exited from a roost in a tree, 1 was captured over a pond, and the remaining 14 were captured while flying under bridges or along trails when the entire flight corridor was blocked with mistnests. Seventy-one percent of Keen's myotis captured in mistnets in 2005 and 2006 were captured over creeks.

California myotis were found in Juneau and on Mitkof and Prince of Wales Islands. In 2005 only 6% of mistnet captures were of California myotis, but in 2006 California myotis comprised 30% of all captures on Prince of Wales Island. Sixty-two percent of captures of California myotis from 2005 and 2006 were on creeks.

We captured two long-legged myotis in 2005 on Wrangell and Prince of Wales Islands, comprising only 1% of mistnet captures for that year. Eight individuals were captured on Prince of Wales Island in 2006 (13% of all 2006 captures). All but one long-legged myotis were netted over creeks.

On Prince of Wales Island a silver-haired bat flew in several circles approximately 1.5 m from the observer (J. Boland) and its calls were concurrently recorded with a detector placed approximately 2.5 m away. This bat was seen 25 min

before sunset. We recorded echolocation calls with frequencies and shape characteristic

of silver-haired bats (Fig. 2.4) on two occasions in Juneau, four occasions on Prince of

Wales Island, and two occasions on Wrangell Island, but positive identifications of these

calls cannot be confirmed. We can say with confidence that they were not calls from

Myotis spp., but echolocation calls of big brown bats (*Eptesicus fuscus*) have similar

structure, length, and frequency as calls of silver-haired bats (Betts 1998).

Capture Success

Capture success (number of captures per unit effort) was calculated for mistnet

surveys only and captures at roosts were not included in analyses. Number of captures

relative to effort was highest for little brown myotis each year in each area sampled

(Table 2.4) and was highest on rivers in 2005 and creeks in 2006; although capture

success was nearly as high for little brown myotis on ponds in 2006 (Table 2.5). Capture

success was much higher for little brown myotis than for any other species in 2005, but in

2006, when surveys were restricted to Prince of Wales Island and the majority of capture

attempts were focused on sites where entire corridors were closed off with nets, success

of captures between species was more evenly distributed (Table 2.5). In 2005, capture

success for Keen's myotis was highest on Prince of Wales Island and for California

myotis in Juneau. Capture success for Keen's, California, and long-legged myotis was

highest in 2005 on ponds. In 2006 capture success of Keen's, California, and long-

legged myotis was higher on Prince of Wales Island than in any area sampled in 2005 and

it was greatest for Keen's and California myotis on trails and for long-legged myotis on

creeks.

Morphology and Reproduction

We documented the range of morphological measurements of each species (Table 2.6) and verified identifications made in the field of Keen's myotis and little brown myotis with DNA analysis. Identifications for Keen's and little brown myotis from DNA analyses confirmed identifications in the field and all little brown myotis belonged to the subspecies *M. l. alascensis*.

In 2005 and 2006 we captured 12 California myotis, 6 Keen's myotis, and 2 long-legged myotis that were pregnant or post-partum. We found 74 reproductive or post-reproductive female little brown myotis, however 40 of the 74 were from the same maternity colony and observed on the same night in Juneau. No reproductive males were captured in either year. Pregnant bats were found between 4 June and 4 July, lactating bats from 4 June to 12 August, and post-lactating bats from 24 June to 24 August (Table 2.7). Thirty-two juvenile bats were captured (2 California myotis, 2 Keen's myotis, 28 little brown myotis) from 19 June to 25 August.

DISCUSSION

The results of our surveys indicate that little brown myotis are widely distributed through Southeast Alaska. We found Keen's and California myotis as far north as Juneau; almost 300 km further north than previously recorded. We did not capture long-legged myotis north of Prince of Wales and Wrangell Islands but previous records indicate they occur as far north as Admiralty Island (Parker et al. 1997). We did not capture any silver-haired bats, but the sighting of one individual was confirmed by concurrent recordings of its echolocation calls on Prince of Wales Island.

Although big brown bats have not been documented in Southeast Alaska, there is one record of a specimen in the interior of Alaska (Reeder 1965). Our inability to capture silver-haired bats knowing they occur in Southeast Alaska suggests that, if densities are low, species may not be detected in capture surveys. However, big brown bats, like little brown bats, are generalists that frequently are found roosting in man-made structures (Kurta and Baker 1990, Williams and Brittingham 1997, Lausen and Barclay 2006). Big brown bats are also large relative to the other species of bat that occur in Southeast Alaska (Kurta and Baker 1990). If they occurred in the region and roosted in buildings, it is unlikely that big brown bats would go unnoticed. Nonetheless, given the possibility that big brown bats may occur in Southeast Alaska, the only positive identification we can make of echolocation calls belonging to silver-haired bats were the ones recorded on Prince of Wales Island where visual identification occurred. However, it is likely that the distribution of silver-haired bats extends at least as far as Juneau (Barbour and Davis 1969).

The composition of species captured on Prince of Wales Island in 2005 was different than that in 2006. Overall, surveys in 2005 targeted a wide range of species in a variety of habitats, whereas in 2006 the majority of effort was directed at capturing Keen's myotis and different techniques were used to accomplish these goals. In 2005 nets were most frequently set up in aquatic habitats with relatively little vegetative clutter and a relatively high level of bat activity. However, we also attempted captures in aquatic and non-aquatic habitats with varying levels of vegetative clutter and bat activity. By 2006 we realized we had more success capturing Keen's myotis at locations where we could effectively close off flight corridors and we attempted most of our captures at sites

with these conditions. Most often we blocked potential flight corridors under bridges or across trails and small creeks. To effectively block a trail or small creek it needed to be surrounded on each side and above by vegetation or a bridge. In 2006 we caught proportionately fewer little brown myotis and greater proportions of all other species captured on Prince of Wales Island in 2005.

We found that little brown myotis were more likely to be captured over water with relatively low vegetative clutter and capture success for California, Keen's, and long-legged myotis was higher when flight corridors could be completely blocked with nets. The relative success of captures in different types of habitat may be explained by ecomorphology. Ecomorphology can be used to examine the relationship between morphological design and the ability of an organism to exploit its environment (Swartz et al. 2003). Wing morphology and body size influence wing loading and aspect ratio, which in turn affect in-flight maneuverability (Swartz et al. 2003). Kalcounis and Brigham (1995) found that individuals with higher wing loading foraged in less cluttered environments and attribute it to lower maneuverability. Measurements of forearm length and weight for each species captured in this study (Table 2.6, Fenton and Barclay 1980, Warner and Czaplewski 1984, Simpson 1993, Nagorsen and Brigham 2003) suggest wing loading is higher for little brown myotis than California, Keen's and long-legged myotis. Given their morphology and associated wing loading, little brown myotis may be less adept at flying in structurally cluttered environments and are therefore less willing to exploit habitat in relatively small corridors. California, Keen's, and long-legged myotis may be more maneuverable in flight and therefore more capable of exploiting forested environments and better at avoiding nets in open areas.

External morphology of each species in Southeast Alaska was, for the most part, similar to what is found in other parts of their range (Warner and Czaplewski 1984, Nagorsen and Brigham 1993, Simpson 1993). However, the range for adult body mass of California myotis (4.5-7.5 g) and Keen's myotis (5-8 g) in our study appears to be higher than what is reported in other parts of their range (3.3-5.4 g and 3.8-6.7 g, respectively; Hall 1981, Simpson 1993, Nagorsen and Brigham 1993, COSEWIC 2003). Body masses were from individuals that were thought to be not pregnant, but as mentioned previously, some individuals may have been misdiagnosed if the fetus could not be felt with gentle palpations on the abdomen. Length of ear and tragus for Keen's myotis were slightly smaller for bats captured on Prince of Wales Island (15.0-18.0 and 7.5-11.5 mm, respectively) relative to measurements recorded for Keen's myotis in British Columbia (16.0-20.0 and 9.0-12.0 mm), however this is likely explained by differences in measurement techniques. We made ear and tragus measurements in this study from the inside base to tip; measurements made from the outside base of the ear or tragus would be longer.

There were too few observations to determine species-specific periods of reproduction with any confidence, but our observations can supplement future monitoring efforts. The period of gestation for bats fluctuates with temperature, which affects development of young and timing of parturition (Altringham 1996). Climatic conditions associated with latitude in Southeast Alaska may affect timing of reproductive events by determining when bats emerge from hibernation and thus when ovulation and fertilization occur.

Low ambient temperatures and precipitation affect growth and reproduction of bats by delaying parturition, inhibiting milk production, and decreasing insect availability (Racey and Swift 1981, Grindal et al. 1992, Speakman and Thomas 2003). Summer nighttime temperatures in Southeast Alaska are frequently below 8° C and precipitation is high throughout the summer (National Oceanic and Atmospheric Administration, www.noaa.gov, accessed June 2007). Use of torpor by pregnant bats can prolong gestation and low temperatures are associated with delayed growth in young bats (Racey and Swift 1981).

The overall low rate of capture relative to effort for each species captured in this study suggests that bats, regardless of species, occur in low densities in Southeast Alaska. Frequent low temperatures and high levels of precipitation combined with low insect abundance associated with these conditions (Grindal et al. 1992) may be factors keeping population densities low for all species of bat that occur in Southeast Alaska.

SCOPE AND LIMITATIONS

Relative abundance of each species of bat was determined by the number of individuals captured. Success of captures can be influenced by the types of habitats sampled because use of habitats can vary by species of bat. The type of habitat used by a species of bat may be determined by morphology and echolocation ability (Swartz et al. 2003, Lacki et al. 2007). Although we sampled a variety of habitat types, our sampling design was primarily opportunistic and different results of relative abundance may be obtained with different sampling design and capture methodology.

Given overall low numbers of captures per night, one night of relatively high captures could be very influential on calculations of capture success (as indexed by

number of captures per unit effort). For example, in 2006 we captured 19 California myotis on 9 different nights, but on one night captured 5 individuals on a trail. These were the only California myotis captured on a trail in 2006. Although 63% of mistnet captures of California myotis were on creeks and only 23% on one trail, capture success for California myotis was nearly three times higher on trails versus creeks. Capture success was highest for little brown myotis in each area sampled for each year, but was especially high for little brown myotis in Yakutat largely due to one night when 31 bats were netted on the same river at the same site. This site may have been located near to a maternity roost because all bats were caught in nets on the river immediately after sunset and only four of the individuals were male. This particular night was also highly influential in determining that capture success was highest on rivers for little brown myotis in 2005.

Fluctuations in length of night in Southeast Alaska could also influence calculations of capture success. In 2005, we began our surveys in the north in May and progressively moved south as the season advanced. Most capture attempts began at sunset and ended at sunrise, resulting in a greater amount of time spent at capture sites in the southern relative to the northern areas due to changes in day length. Given the dates when pregnant bats were captured, it is likely that most bats are midway through gestation when the nights are shortest. Bats in late stages of pregnancy need to forage longer to maintain energetic demands of fetal development (Altringham 1996); reproductive female bats in Southeast Alaska may need to be active for a greater proportion of the night when the nights are shorter to fulfill those demands.

Consequently, activity could be more concentrated with higher numbers of captures and higher estimates of capture success when nights are shorter.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

We documented the distribution of bats that occur in Southeast Alaska, successful methods and locations of capture, and capture success for each species. Our findings contribute baseline knowledge of biology, distribution, and effective trapping methodology for future monitoring of bat populations in Southeast Alaska.

Southeast Alaska is thought to be the northern limit for the ranges of California myotis, Keen's myotis, long-legged myotis, and silver-haired bats and given low rates of capture during this and previous surveys (Parker et al. 1997), densities for each species appear to be low in the region. Some suggest the abundance of a species is highest in the interior relative to the edge of its range because the environment is more suitable in the interior (Brown et al. 1995). One mechanism that may maintain this pattern is source-sink dynamics; where centralized populations act as the source for peripheral populations due to outward dispersal of individuals from the central population (Pulliam 1988). If this is the case, it can be predicted that extinction rates are higher for populations at the edge of a species range and populations in the interior will persist longer (Brown et al. 1995, Doherty et al. 2003). An alternative view suggests that peripheral populations that are more isolated from the original sources leading to extinction (e.g., habitat degradation and introduced competitors) may persist longest (Lomolino and Channell 1995). In any case, as Keen's myotis has a remarkably small range and all existing populations, regardless of their location, may be critical to persistence of the regional population.

Currently, data are insufficient for conclusive determination of habitat associations for all species of bat in Southeast Alaska, but many of the species are primarily associated with forested habitats in other parts of their range. The long-legged myotis and Keen's myotis are primarily associated with coniferous forests (Warner and Czaplewski 1984, Firman and Barclay 1993, Nagorsen and Brigham 2003, Hayes 2003) and female Keen's myotis on Prince of Wales Island appear to be primarily associated with old-growth forests for day roosting (Chapter 3). Silver-haired bats are generally found in older coniferous or deciduous forests in northwestern North America (Kunz 1982, Barclay et al. 1988, Campbell et al. 1996, Nagorsen and Brigham 2003). Although little brown myotis and California myotis are known to occur in both forested and non-forested habitats (Warner and Czaplewski 1984, Nagorsen and Brigham 1993, Vonhof and Barclay 1996, Hayes 2003), the little brown myotis was the only species captured from roosts in buildings or while foraging in urban environments in this study.

Forests in Southeast Alaska, especially on private land, are being rapidly clearcut (DeGange 1996, Iverson et al. 1996, US Forest Service 1996). Between 1955 and 1995 the USDA Forest Service estimates that about 15% of commercially valuable or "productive" forest in the Tongass National Forest had been harvested and converted to early seral forests (Iverson et al. 1996, USDA Forest Service 1996). It is estimated that 60% of forests conveyed to the State of Alaska or Alaska Native Corporations were harvested by 1996 (USDA Forest Service 1996).

Many factors contribute to species declines and risk of extinction. Intrinsic biological and ecological factors such as low reproductive rate and rarity may exacerbate consequences of extrinsic factors such as habitat loss (Racey and Entwistle 2003). All

bat species have low reproductive rates. In temperate climates, high precipitation and low ambient temperatures are associated with lowered reproductive success due to unsuccessful pregnancies and abstinence from mating (Grindal et al. 1992, Lewis 1993). Therefore, it is likely that the reproductive rate of bats at the northern limits of their distributional range are lower than that those of conspecifics in southern parts of their range (Racey and Entwistle 2003). Some suggest the abundance of a species is lower at the edge of their range because habitats are less suitable relative to the interior of their range (Brown et al. 1995). Southeast Alaska is thought to be the northern distributional limit for all species of bat that occur there except the little brown myotis. It is likely that climatic factors associated with high latitudes in Southeast Alaska impose energetic constraints on bats that keep population densities naturally low in the region.

The conservation status of bat populations in Southeast Alaska is undetermined. The species of bat that inhabit Southeast Alaska are long-lived with naturally low reproductive rates (Fenton and Barclay 1980, Kunz 1982, Warner and Czaplewski 1984, Nagorsen and Brigham 1993, Simpson 1993). Low densities in conjunction with life history traits and region-specific ecologies may make populations of forest-dwelling bats in Southeast Alaska vulnerable to decline due to loss of habitat. To understand how the increasing rate of habitat loss and alteration affect population status and distribution of bats in Southeast Alaska, the current status and future trends of populations and habitat associations for each species across multiple spatial scales is required.

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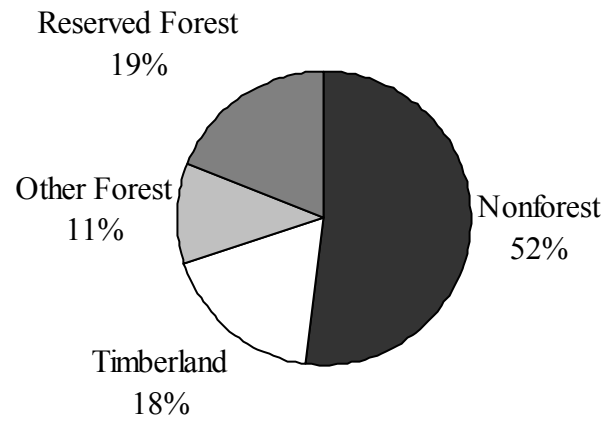
Figure 2.1. The percent area by land class for Southeast Alaska (from van Hees 2003).

little brown
myotis
87%

Keen's myotis
6%

California
myotis
6%

long-legged
myotis
1%

2005

long-legged
myotis 13%

California
myotis 30%

little brown
myotis 34%

Keen's myotis
23%
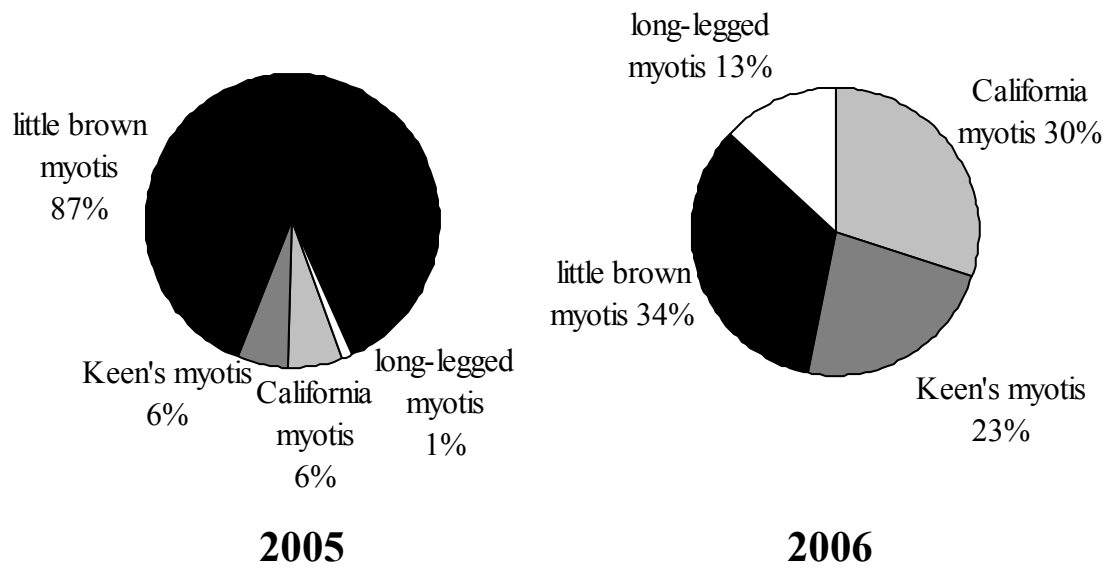
2006

Figure 2.2. Proportion of mistnet captures of each species of bat captured throughout Southeast Alaska in 2005 and proportion of mistnet captures of each species of bat captured on Prince of Wales Island in 2006.
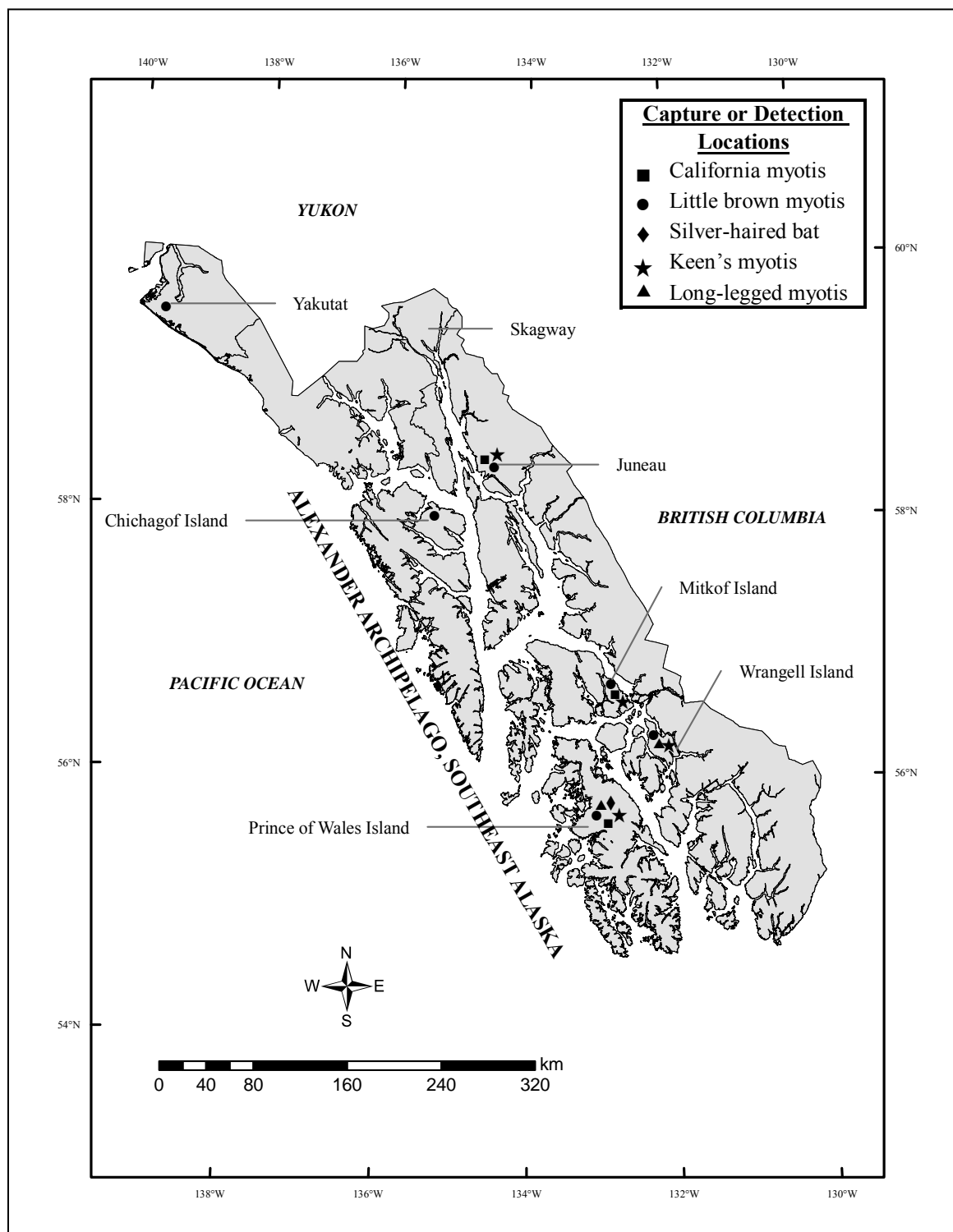
Figure 2.3. Map of Southeast Alaska and areas where species of bat were captured or detected during surveys, 2005 and 2006.
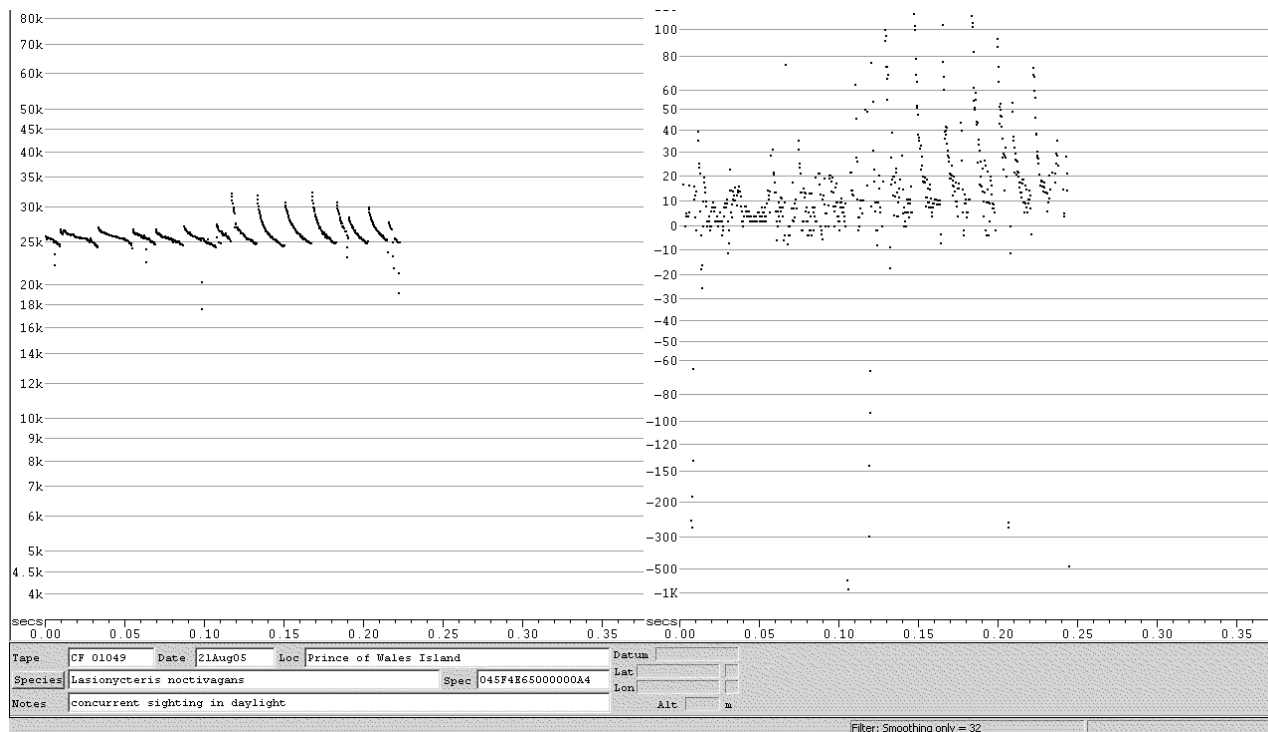
Figure 2.4. Spectrograph of echolocation call of a silver-haired bat recorded with an Anabat II detector. Y-axis is frequency in kHz and x-axis is time in milliseconds. Left-hand screen displays echolocation pulses; right-hand screen displays associated slopes of pulses. Recorded by J. Boland, Prince of Wales Island, 2005 by passive monitoring.

Table 2.1. Number of bats captured in mistnets and, in parentheses, number of bats captured from roosts in Southeast Alaska, 2005 and 2006. Captures in 2006 were exclusively on Prince of Wales Island.

Area	California myotis	Keen's myotis	little brown myotis	long-legged myotis	Total
Yakutat			40 (19)		40 (19)
Chichagof Island			28		28
Juneau	4	2	19 (40)		25 (40)
Mitkof Island	1	2	8 (3)		11 (3)
Wrangell Island		1	25	1	27
Prince of Wales Island					
2005	5	4	21	1	31
2006	19	15(19)	22 (1)	8	64 (20)
Total	29	24 (19)	163 (63)	10	245 (63)

Table 2.2.   Proportion of mistnet captures (excluding captures at roosts) of each species of bat captured in Southeast Alaska in 2005 and 2006.

Species	2005	2006
California myotis	0.06	0.30
Keen's myotis	0.06	0.23
little brown myotis	0.87	0.34
long-legged myotis	0.01	0.13

Table 2.3. The proportion of individuals of each species and the proportion of all bats captured at each site type in 2005 and 2006, Southeast Alaska.

Site Type	California myotis	Keen's myotis	little brown myotis	long-legged myotis	*All bats*
Creek	0.62	0.71	0.55	0.90	0.59
Pond	0.14	0.13	0.14	0.10	0.14
River	0.03	0.00	0.29	0.00	0.22
Road	0.03	0.04	0.01	0.00	0.01
Trail	0.17	0.13	0.01	0.00	0.04

Table 2.4. Number of bat captures per unit effort for all species by site type in 2005 and 2006, Southeast Alaska. Effort = area of net*hours.

2005	Total effort (net hours)	California myotis/ effort	Keen's myotis/ effort	little brown myotis/ effort	long-legged myotis/ effort	All bat captures/effort
Creek	36995	0.00016	0.00019	0.00195	0.00003	0.00232
Pond	9005	0.00044	0.00022	0.00222	0.00011	0.00300
River	8806	0	0	0.00545	0	0.00545
Road	683	0	0	0.00147	0	0.00147
Trail	187	0	0	0	0	0
Total	*55676*	*0.00018*	*0.00016*	*0.00253*	*0.00004*	*0.00291*
2006						
Creek	17082	0.00070	0.00064	0.00100	0.00047	0.00281
Pond	3073	0	0.00033	0.00098	0	0.00130
River	936	0.00107	0	0	0	0.00107
Road	858	0.00117	0	0	0	0.00117
Trail	2328	0.00215	0.00129	0.00086	0	0.00429
Total	*24278*	*0.00078*	*0.00062*	*0.00091*	*0.00033*	*0.00264*

Table 2.5. Number of bat captures per unit effort for all species by area in 2005 and 2006, Southeast Alaska. Unit effort= area of net*hours

2005	Total effort (net hours)	California myotis/ effort	Keen's myotis/ effort	little brown myotis/ effort	long-legged myotis/ effort	*All bat captures/effort*
Yakutat	6700	0	0	0.00597	0	0.00597
Chichagof Island	9383	0	0	0.00298	0	0.00298
Juneau	6934	0.00058	0.00029	0.00274	0	0.00361
Mitkof Island	10253	0.00010	0.00020	0.00078	0	0.00107
Wrangell Island	11634	0	0.00009	0.00215	0.00009	0.00232
Prince of Wales Island						
2005	10772	0.00046	0.00037	0.00195	0.00009	0.00288
2006	24278	0.00078	0.00062	0.00091	0.00033	0.00264

Table 2.6. Mean morphological measurements (range and sample sizes) of bats captured in Southeast Alaska in 2005 and 2006.

Species	Ear (mm)	Tragus (mm)	Thumb (mm)	Foot (mm)	Forearm (mm)	Weight* (g)
California myotis	12.2 (11-14) n=25	5.6 (5-7) n=25	4.4 (4-5) n=21	5.5 (5-7) n=25	33.4 (31.2-34.8) n=25	6.0 (4.5-7.5) n=20
Keen's myotis	16.8 (15-18) n=41	9.0 (7.5-11) n=41	6.0 (5-6) n=21	7.5 (5-9) n=22	36.4 (34.6-39.8) n=41	6.1 (5-8) n=37
little brown myotis	12.6 (9-15) n=177	6 (5-7) n=148	5.6 (5-7) n=53	8.0 (6-10) n=100	37.2 (34.2-39.8) n=147	7.7 (5.5-11) n=147
long-legged myotis	11.3 (9-12) n=8	5.8 (5-6) n=8	5.7 (5-6) N=8	7.0 (5-8) n=8	38.2 (37-38.8) n=8	7.0 (7-8.25) n=7

* weight calculations do not include data from pregnant bats

Table 2.7. Dates when reproductive, post-reproductive, and juvenile bats were captured in Southeast Alaska in 2005 and 2006.

	Pregnant	Lactating	Post-lactating	Juvenile
California myotis	Jun 19-28	13 Jun- 12 Aug	12-15 Aug	6-12 Aug
Keen's myotis	4 Jul	7 Jul- 7 Aug	14 Aug	24 Jul- 7 Aug
little brown myotis	4 Jun- 2 Jul	4 Jun- 8 Aug	24 Jun- 24 Aug	19 Jun- 25 Aug
long-legged myotis	26 Jun	24 Jul	*	*

* No bats captured

CHAPTER 3: SELECTION OF DAY-ROOSTS IN TREES BY KEEN'S MYOTIS AT FOUR SPATIAL SCALES ON PRINCE OF WALES ISLAND, SOUTHEAST ALASKA

ABSTRACT

The Keen's myotis (*Myotis keenii*) is rare and has one of the most limited distributions of any species of bat in North America. Understanding gender-specific roosting ecologies of bats at relevant spatial scales is necessary to effectively evaluate the impact of habitat alteration and prioritize conservation efforts for bats in temperate forests. From May to September 2006 we examined selection of day-roosts in trees by Keen's myotis on Prince of Wales Island, Southeast Alaska. Our objectives were to 1) examine relationships between and determine relative importance of habitat characteristics on selection of day-roosts at three spatial scales: the tree, tree plot, and landscape, and 2) determine if habitat associations for males and females differed at each scale. We tracked 13 females to 62 roosts in trees and 6 males to 24 roosts in trees. Characteristics measured at each spatial scale appear to influence selection of day-roosts by female Keen's myotis, but characteristics of trees were more influential than those measured at other scales and trees used as roosts were primarily large in diameter with structural defects. Trees surrounding roosts of female Keen's myotis had large mean diameters and there was a high abundance of roost-like trees in plots surrounding roosts. Roosts were generally located closer to riparian habitat and in landscapes with more old-growth. Associations were evident for male Keen's myotis at the tree and plot scales, but characteristics at the landscape scale were most influential. Male Keen's myotis exhibited flexibility in the types of roosts they chose, but tree roosts were primarily snags in early to intermediate decay that were surrounded by a high relative abundance of roost-

like trees, closer to roads, and further from riparian habitat than were randomly selected trees. Habitat associations differed between males and females at each spatial scale and differences are likely a reflection of higher energetic constraints associated with reproduction for females. Energetic benefits gained from optimal roosting habitat may be critical for successful reproduction by females. Females primarily roosted in old-growth habitat and we suggest that maintaining structural components characteristic of old growth will promote conservation of Keen's myotis in Southeast Alaska.

INTRODUCTION

Animals respond to their environment at multiple spatial scales and habitat associations at one scale may influence and ultimately constrain relationships at broader or finer scales (Weins 1989, Orians and Wittenberger 1991, Gorresen et al. 2005). The spatial scales at which habitat characteristics influence selection of day roosts by forest-dwelling bats can range from several squared centimeters (e.g., the entrance to a roost; Sedgeley and O'Donnell 2004, Psyllakis and Brigham 2005) to hundreds of hectares (e.g., the area encompassing potential foraging areas and roost sites; Brigham 1989, Brigham et al. 1997, Waldien and Hayes 2001, Broders et al. 2006, Miles et al. 2006).

Day-roosts can provide shelter from inclement weather, protection from predators, and a place to rear young (Kunz and Lumsden 2003, Barclay and Kurta 2007). Habitat characteristics that influence selection of day-roosts by bats may vary by sex (Broders and Forbes 2004), age, and reproductive status (Tuttle 1976). Roost habitat may limit populations of forest-dwelling bats (Lunney et al. 1985, Crampton and Barclay 1998) and dependence of bats on the availability and abundance of suitable roosts and suitable habitat surrounding roosts may magnify sensitivity to structural alteration created

by forest management (Hayes 2003, Hayes and Loeb 2007). Understanding the gender-specific roosting ecology of bats at all relevant spatial scales is fundamental to evaluation of the impacts of habitat alteration and effective prioritization of conservation efforts (Racey and Entwistle 2003, Broders et al. 2006, Barclay and Kurta 2007).

Little is known about the habitat associations and roosting ecology of Keen's myotis (*Myotis keenii*; Nagorsen and Brigham 1993, van Zyll de Jong and Nagorsen 1994). The Keen's myotis was listed as a species of special concern in 1988 by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), but has since been down-listed to 'data deficient' due to insufficient knowledge regarding population status, habitat ecology, and basic natural history (COSWIC 2003). The distribution of Keen's myotis is one of the smallest known for bats in North America. This species appears to be restricted to low elevation coastal coniferous forests of western Washington, southern British Columbia, and Southeast Alaska (Nagorsen and Brigham 1993, van Zyll de Jong and Nagorsen 1994). Although Keen's myotis are reported to roost in caves, rock crevices, and under boulders in British Columbia (Firman and Barclay 1993, Burles 2000), knowledge of the structural characteristics of natural roosts or habitat surrounding roosts is minimal and nothing is known about the roost requirements of Keen's myotis in Southeast Alaska.

Research Approach

Our objectives were to determine the influences of habitat characteristics on selection of day-roosts by adult male and female Keen's myotis on Prince of Wales Island and to determine at which spatial scale relationships between habitat characteristics and use of roosts are strongest. We hypothesized that male and female

Keen's myotis constitute two ecologically distinct groups based on energetic

requirements (as suggested by Altringham and Senior 2005, Broders et al. 2006) and that

their selection of summer day-roosts in trees is influenced by multiple factors operating at

multiple spatial scales. We proposed that bats may simultaneously respond to several

factors at different spatial scales and requirements at one scale may affect and constrain

selection at broader or finer scales. We developed hypotheses to explain mechanisms

that influence selection of day-roosts in trees by adult male and female Keen's myotis at

three spatial scales: the tree, immediate vicinity around the tree (tree plot), and the

landscape. For each scale, we created models with variables predicted to be influential

given existing knowledge of roosting ecology of forest-dwelling bats.

Tree

Bats in temperate coniferous forests frequently roost in cracks, cavities, and under

sloughing bark of live trees and snags (Campbell et al. 1996, Vonhof and Barclay 1996,

Brigham et al. 1997, Hayes 2003, Barclay and Kurta 2007). Low temperatures and

precipitation are associated with low aerial insect availability (Racey et al.1987) and

increased costs of homeothermy for bats (Tuttle and Stevenson 1982). The climate in

Southeast Alaska is cool and wet throughout the summer and bats need to maintain

energetic balance in frequently inhospitable weather. Bats can spend more than half of

each 24-hour period in roosts and more during inclement weather and roosts can provide

protection from wind and rain and a thermally stable environment when ambient

temperatures are low (Kunz 1982). Suitable cavities and crevices in trees can provide

roosts where bats can further reduce costs of thermoregulation by clustering (Kurta 1985)

and Keen's myotis have been documented roosting colonially in British Columbia

(Burles 2000). Cracks and cavities in large diameter trees may provide more insulation from temperature fluctuations (Wiebe 2001, Kunz and Lumsden 2003) and larger spaces for clusters of bats (Brigham et al. 1997) than do smaller trees. Bats also often roost in trees that are taller than surrounding vegetation (Campbell et al. 1996, Vonhof and Barclay 1996, Weller and Zabel 2001, Watrous et al. 2006). Tall trees with high entrances to cavities or cracks and located on relatively steep slopes may provide roost sites that are easier to locate, enter, and exit by bats. We hypothesized that Keen's myotis select roosts in trees that are easy to locate and provide insulation from ambient temperatures and space where bats can cluster. We predicted the odds that a tree is used for roosting increase with the presence of defects (cavities, cracks, and/or broken tops) and sloughing bark, diameter, and increased height relative to surrounding canopy.

Tree plot

Bats select day roosts in areas with an abundance of trees with similar size and decay characteristics as the roost tree (Campbell et al. 1996, Waldien et al. 2000, Weller and Zabel 2001, Erickson and West 2003). This may indicate a preference for roosts that are surrounded by an abundance of potential roost sites, but suitable roost habitat may have an upper threshold to the density of surrounding trees regardless of roost potential (Hayes and Loeb 2007). Stem density is often associated with use of habitat by forest-dwelling bats (Vohhof and Barclay 1996, Brigham et al. 1997, Humes et al. 1999, Erickson and West 2003, Loeb and O'Keefe 2006, Psyllakis and Brigham 2006) and may be attributed to flight limitations imposed by structural clutter (Brigham et al. 1997, Hayes and Loeb 2007). We hypothesized that availability of trees of similar size and decay as those used for roosting, stem density, and average tree size in the immediate

vicinity of the roost tree is associated with selection of roosts by Keen's myotis. We predicted that the odds a tree is selected by Keen's myotis increase with abundance of roost-like trees, increasing mean diameter of canopy trees, and decreasing density of canopy trees in plots surrounding roosts.

Landscape

Habitat associations at one spatial scale may not be apparent at larger or smaller scales (Gorressen et al. 2005). The composition and configuration of the landscape can influence the use of roosts by determining the proximity of roosts to activity areas (Tuttle 1976, Ormbee and McComb 1998, Miles et al. 2006, Broders et al. 2006), the abundance and quality of potential roosts (Waldien et al. 2000), the quality of activity areas (sites used for foraging and drinking; Hayes 2003), and the suitability of habitat through which bats commute between roosts and activity areas (Verboom and Huitema 1997, Hayes 2003).

Habitat selection by bats is sometimes associated with distance to streams (Ormsbee and McComb 1998, Waldien and Hayes 2001) and roads (Loeb and O'Keefe 2006). Roads and streams are used by bats for commuting and foraging and it may be energetically advantageous for bats to select roosts near to foraging areas and flight corridors if suitable roosts are available (Tuttle 1976). We hypothesized that selection of roosts by Keen's myotis is associated with distance to commuting corridors and foraging areas and we predicted the odds a roost occurs in an area increase with decreasing distance to roads and riparian areas.

Some studies suggest forest-dwelling bats select roosts in old forests more frequently than young forests (Grindal 1998, Psyllakis and Brigham 2006, Perry et al.

2007). Others have documented no strong association between roost selection and forest age (Ormsbee and McComb 1998). The preference for old forests by some bats may be related to the abundance of potential roosts (Thomas 1988). We hypothesized that selection of day roosts by Keen's myotis is influenced by the composition of forest types in the surrounding landscape due to structural limitations to flight and abundance of potential roosts and we predicted that the odds a roost occurs in a landscape increase with proportion of old-growth forest.

Bats sometimes may avoid large, open spaces while commuting and foraging due to risk of predation, exposure to weather, and low insect availability (Verboom and Huitema 1997, Hayes 2003). Forest-dwelling bats may also avoid landscapes with a high proportion of open area because there is limited availability of suitable roosts. We proposed that Keen's myotis primarily forage and roost in forests and limit exposure to predators and wind by avoiding open areas. We hypothesized the area of recently clearcut stands in the landscape is negatively associated with selection of day roosts by Keen's myotis and predicted that the odds a roost occurs in a landscape decrease with increasing area of clearcut.

Gender-specific selection

Male and female bats often select for different characteristics of roosts, which may be due to differences in energetic and behavioral requirements (Thomas 1988, Campbell et al. 1996, Broders and Forbes 2004, Altringham and Senior 2005, Barclay and Kurta 2007). Female tree-roosting bats often roost colonially in well-insulated tree cavities (Sedgeley 2001, Kunz and Lumsden 2003, Smith and Racey 2005, Barclay and Kurta 2007), whereas males generally roost solitarily in poorly insulated roosts under

loose bark or in cavities of trees (Kunz and Lumsden 2003, Turbill 2006, Barclay and Kurta 2007). Males and females may also roost in different areas within the landscape and roosting and foraging areas may differ in size depending on availability of suitable roost sites (Broders and Forbes 2004, Broders et al. 2006). Given different energetic requirements and strategies of energy conservation of male and female bats, we hypothesized they select for different characteristics of roosts and landscape surrounding roosts.

METHODS

Study Area

Prince of Wales Island is the largest island in the Alexander Archipelago of Southeast Alaska and spans from 54°41' to 56°22' N latitude (Fig. 3.1). It is approximately 215 km long, 72 km wide, and has an area of 700,224 ha. The climate is maritime with cool summers and mild winters, high humidity, and high precipitation. From May to September, the average monthly temperatures are between 8 and 14° C and average monthly precipitation is between 17.8 and 29.7 cm (www.noaa.gov, 2007). We considered Prince of Wales Island the most suitable area for radio-tracking Keen's myotis in Southeast Alaska due to the extensive road system, diversity of habitats, and apparent abundance of Keen's myotis relative to other areas in the region (Chapter 2). The landscape is mountainous with a mosaic of coastal coniferous old-growth rainforest, muskeg bogs, peatland mixed-conifer forest, alpine areas, and managed landscapes (van Hees 2003). Productive old-growth forests in Southeast Alaska typically contain a dense and structurally diverse understory, and an uneven-aged, vertically stratified canopy dominated by western hemlock (*Tsuga heterophylla*), Sitka spruce (*Picea sitchensis*), and

to a lesser extent western redcedar (*Thuja plicata*) and yellow cedar (*Chamaecyparis nootkatensis*) (Alaback 1982, van Hees 2003). Red alder (*Alnus rubus*) is often found in riparian areas and disturbed habitats throughout the island. Clearcuts <25 years old are comprised primarily of remaining slash, regenerating conifers, and a dense shrubby layer of *Vaccinium spp*. Peatland mixed-conifer forests are well-drained, gently sloping, and interspersed with patches of muskeg bog (DeMeo et al. 1992, Smith et al. 2004). Canopy species in peatland mixed-conifer forests include western hemlock, yellow cedar, western redcedar, mountain hemlock (*Tsuga mertensiana*), and lodgepole pine (*Pinus contorta*).

Captures and Species Identification

Location of sites where bats are captured can influence results of studies examining their habitat relationships (Waldien et al. 2000). To minimize biasing results of our evaluation, we conducted captures in a variety of habitats in landscapes with varying management histories. However, due to logistical constraints, we limited sites to those that were within 0.5 km of a road. We verified presence of bats at potential capture sites by echolocation monitoring (Anabat II detectors-Titley Electronics, Ballina NSW, Australia) for at least one night prior to selecting a site. At each capture site we set up mistnets at least 30 min before sunset. Most capture attempts were in aquatic and riparian areas because these are important areas for foraging and drinking (Thomas 1988, Waldien and Hayes 2001) and bats often use these areas more than upland habitats (Parker et al. 1996, Grindal et al. 1999). We captured bats in mistnets suspended over creeks, rivers, and ponds and across roads and trails within forests. Our greatest success capturing Keen's myotis occurred when we completely blocked a corridor with mistnets. We recorded location of each capture site with a global positioning system (GPSMAP

60CS, Garmin International, Inc., Kansas, USA) and imported coordinates into a geographical information system (GIS, ArcMap, Environmental Systems Research Institute, Redlands, California, USA).

We identified species based on morphological and pelage characteristics (Nagorsen and Brigham 1993). To confirm identifications made in the field we collected a tissue biopsy with a 2 mm biopsy punch from the wing of each individual identified as Keen's myotis for DNA analysis. Character data for Keen's myotis DNA analyses were taken from double-stranded mitochondrial sequences of the cytochrome *b* gene (Dewey 2006). Identifications based on DNA analyses agreed with identifications made in the field. For each bat we captured we recorded age, sex, reproductive status, and length of ear, tragus, thumb, foot, and forearm. We distinguished juveniles from adults by transilluminating the wing and examining finger bones for the presence of cartilaginous epiphyseal plates (Anthony 1988). Reproductive status of females was classified to 5 categories: pregnant, lactating, post-lactating, parous (reproductive at some point in the past, but not currently), and nulliparous (never reproductive) (Anthony 1988). Pregnancy was determined by gently palpating the abdomen to detect the presence of an embryo (Anthony 1988). Females in early stages of pregnancy were likely misdiagnosed as not pregnant.

Telemetry

We attached 0.27g (Blackburn Transmitters) or 0.36 g (LB-2N, Holohil System, Carp, Ontario, Canada) radiotransmitters to adult Keen's myotis that weighed 5-8 g (mean, 6.3g). Transmitters comprised 3-7% of body weight. We did not tag bats in late stages of pregnancy, although we may have inadvertently tagged bats in early stages of

pregnancy if the fetus could not be detected. We clipped a small amount of fur between the scapulae and attached the transmitter with a non-toxic, non-irritant surgical adhesive (Torbot Bonding Cement, Torbot Group, Inc. RI, USA). Bats were wrapped in a cloth and held for 30 minutes while the adhesive dried.

We used PLL synthesized tracking receivers (model TRX-1000S, Wildlife Materials, Int. IL, USA) and hand-held 3- and 6-element yagi antennas to track bats to roosts. We tracked bats every day for 14 days unless equipment failed, the battery in the transmitter died, or the transmitter was shed by the bat. If at any point the signal could not be located, we continued to search for it every day until the 12th day after the transmitter had been activated. Most roosts were independently located by two observers. If the two observers did not agree on the exact location of the roost, they continued scanning the area until a definitive, joint decision was reached.

Roost and Available Trees

All measurements at roost structures were made during days when tagged bats were not present at that structure to avoid disturbing roosting bats. For each roost tree we noted presence of cracks, hollows, and broken top and measured height (m), slope (%), and diameter at breast height (dbh; cm). Height and slope were measured with a clinometer and slope was measured by standing on the downhill side of the roost or available tree and 10 m from the tree. At 10 m, a 10% slope is equivalent to approximately 1 m of vertical height. Slope affects the relative height of trees and trees located upslope project above trees that occur downslope. For example, on a 10% grade, a tree that occurs upslope will appear 1 m taller than a tree of equal height that occurs 10 m away and downslope. Therefore, slope-height (m) was calculated for each tree by

adding 1 m of height for every 10% of slope. For each roost and available tree we measured the distance to the nearest tree of equal or greater height in four cardinal directions and calculated the mean distance. Percent bark remaining on the stem was estimated by 2 or 3 observers and averaged. Trees (>3 m in height) were classified into one of 4 decay stages (Table 3.1; modified from Cline et al. 1980). Six species categories were identified for roost or available trees: hemlock, cedar, spruce, unknown, alder, and pine. Although there are two species of cedar on Prince of Wales Island (yellow cedar and western redcedar), they are morphologically very similar except for the shape and color of needle sprays and these are absent from many dead trees; therefore we grouped the two species together. Trees were labeled "unknown" if they could not be identified to species due to advanced decay (i.e., no bark or branches).

For each roost we randomly selected 2 available trees within 200 m and in the same forest type. We measured the same characteristics on available structures as were measured for roosts. We defined available trees as conifers with diameters equal to or greater than 20 cm. Our analyses and interpretations do not depend on the assumption that available trees were not used by bats. Location of each roost and available tree was recorded with a global positioning system (Garmin GPS Map 60CS, Garmin International, Inc. Kansas, USA) and imported into a geographical information system (GIS, ArcMap, Environmental Systems Research Institute, California USA).

Tree Plot

We recorded species and decay stage and measured dbh for every tree within a 0.1 ha circular plot (tree plot) centered on roost and available trees and from these measurements calculated a range of variables describing characteristics of vegetation

(Table 3.2). We calculated plot density as the number of canopy trees (≥20 cm dbh) per

plot (density). We calculated the quadratic mean diameter (QMD) of canopy trees to

determine the average size of canopy trees within each plot. From the total basal area of

canopy trees within each plot, we calculated the proportion of basal area from trees with

roost-like characteristics as an index of the relative abundance of potential roosts.

Characteristics of roost-like trees were determined post-hoc according to observations of

trees used as roosts by bats in this study. Roost-like trees were defined as those with

diameters ≥20 cm dbh and in decay stages 2 or 3 for females (Female-PR) and decay

stages 3 or 4 for males (Male-PR). Definitions were similar to those of potential roosts in

other studies (e.g., Campbell et al. 1996, Weller and Zabel 2001).

Landscape Unit

We determined the mean of maximum distances between two roosts used by an

individual bat for males and females and used these values as diameters for defining the

area of the landscape unit (Miles et al. 2006). We performed analyses of landscape

characteristics with ArcGIS© geographic information system (GIS; Environmental

Systems Research Institute, Redlands, California) using digital maps of terrestrial

ecosystems, roads (The Nature Conservancy, Terrestrial Ecosystems; Albert and Schoen

2006), and streams (USDA Forest Service, 2006) on Prince of Wales Island. Landscape

units were centered on roost and random points and random points were generated using

ArcGIS©. As capture locations during this study were located within 0.5 km of a road,

and all roosts were within 2.7 km of the capture sites, we restricted the creation of

random points to those within 3.2 km of a road throughout the island. Within each unit

we measured the distances to road, stream, and nearest hard edge (edge of forest and

opening, not including roads and streams) and we calculated the total length of hard

edges, roads, and streams within each unit. We calculated proportions of old-growth

forest (never cut), young forest (previously cut and >25 years old), clearcut (<25 years

old), naturally open-vegetated areas (wetlands, muskegs, and slide zones), and peatland-

mixed conifer forest in each unit.

Statistical Analyses

We conducted preliminary univariate analyses to test for differences between

characteristics of used and available habitats for males and females at all scales and

differences between characteristics of habitats used by males and females. We used

Fisher's exact test to determine relative use of structures characterized by discrete values.

We calculated estimates of odds ratios with exact 95% confidence limits given a case-

control method and 2x2 contingency table (PROC FREQ, SAS Institute, 2003). Odds

ratios for univariate analyses of categorical variables were only calculated for discrete

variables with two categories (presence/ absence). Odds ratios indicate the odds a tree

with a given characteristic is used as a roost relative to the odds that a tree without that

characteristic is used. For each roost tree we sampled two available trees within the same

stand. To account for random effects of sampling, we blocked the two available trees

with the roost tree from which they were chosen and determined differences in means

(PROC MIXED, SAS Institute, 2003) between roost and available/ random points and

between female roosts and male roosts. Constant variance was assessed with graphical

displays of observed versus expected values (PROC UNIVARIATE, SAS Institute, 2003)

and equality of variance was assessed with F-tests (PROC TTEST, SAS Institute 2003).

Non-normal data were ln-transformed and we reported means and medians with 95%

confidence intervals for untransformed and backtransformed estimates, respectively.

We used prior knowledge of habitat associations of other species of forest-

dwelling bats to select variables predicted to be influential on roost-site selection by adult

male and female Keen's myotis for analyses using logistic regression and model

selection. We evaluated dbh, defects, bark, and slope-height at the tree scale; Female-PR

or Male-PR, density, and QMD at the tree plot scale; and proportions of old-growth forest

and clearcut habitat and distance to nearest road and to nearest stream at the landscape

scale (Table 3.2). We developed a set of candidate models with all possible additive

combinations of predictor variables at each spatial scale. To control for spurious effects

and maintain parsimony and precision of estimators, we limited the number of candidate

models by restricting the number of predictor variables within each scale to ≤4 (Burnham

and Anderson 2002). We used logistic regression to examine relationships between

predictor variables and use of roosts by Keen's myotis and we used Akaike's Information

Criterion adjusted for small sample sizes and overdispersed data (QAIC$_c$; Burnham and

Anderson 2002) to rank models according to their ability to differentiate between used

and available roosts and surrounding habitats. To determine the relative level of

empirical support for each model, we calculated the difference between the minimum

QAIC$_c$ value and the QAIC$_c$ value for that model (Δ_i; Burnham and Anderson 2002).

Models with Δ_i <2 were considered strongly competing and models with Δ_i >10 have

essentially no support so we reported results for models with Δ_i <7. We calculated

Akaike weights (w_i) for each model as an index of the weight of evidence in favor of

model i being the actual best model given the candidate set of models (Burnham and

Anderson 2002). Model fitting with logistic regression is sensitive to multicollinearity

among independent variables in the model (Hosmer and Lemeshow 2000). Therefore,

prior to including variables in models we tested for linear correlations using Pearson's

product-moment correlation (PROC CORR, SAS Institute 2003) and all variables

included in the same model had correlation values less than 0.55. We calculated the

model-averaged estimate of effect for each variable weighted by the sum of Akaike

weights ($\sum w_i$) from the subset of models that included that variable (Burnham and

Anderson 2002). Model-averaged coefficient estimates often have reduced bias and

better precision than estimates from the selected best model (Burnham and Anderson

2002). We used the model-averaged estimates of coefficients for each variable to

calculate odds ratios with 95% confidence intervals (Burnham and Anderson 2002). We

reported $\sum w_i$ as an indicator of the relative importance of each variable within each scale

(Burnham and Anderson 2002). We reported a generalization of the coefficient of

determination (R^2_G) as an index of the ability of the model to predict whether the

sampling unit is used by Keen's myotis (Nagelkerke 1991). This value generalizes the

concept of R^2 to generalized linear models and can be roughly interpreted as similar to R^2

in classic regression models (Nagelkerke 1991). Given the limited knowledge of the

roosting requirements of Keen's myotis, we did not rule out the possibility that some or

all of our hypotheses and associated models excluded potentially influential variables so

we examined additional variables with univariate statistics to determine where future

research may be warranted.

We removed 7 available trees and their associated plots from all analyses because

those species of tree were never used as roosts by Keen's myotis and because their

structural dissimilarity would have made comparisons using these trees uninformative. We removed 3 roost trees used by females from model selection analyses because we did not have associated data for characteristics of the tree plot and validity and interpretability of model selection using AIC is dependent on analysis of a fixed dataset (Burnham and Anderson 2002). Our final dataset for model selection procedures included 24 used and 49 available samples for males and 59 used and 114 available samples for females across all spatial scales. The dataset used for univariate analyses contained an additional three roost trees for female Keen's myotis.

RESULTS

Bats

We attached transmitters to 13 adult female and 6 adult male Keen's myotis. We tracked females to 62 roosts in trees and 1 in a house and we tracked males to 24 trees (n=6 bats), 6 stumps (n=2 bats), the space under 3 loose rocks in a quarry (n=1 bat), and 1 rock crevice (n=1 bat). Four females were captured as they emerged from a roost where two previously tagged females had been tracked earlier that day. With the exception of those four individuals, all bats were captured in-flight over creeks or along trails. On two occasions, two females were captured on the same night at the same site. Five trees were used on different occasions by different tagged female bats and on six occasions, multiple tagged female bats (2-4) were found roosting in the same tree on the same day. If the tree was used by different bats on different days it was assumed their decision to use that tree was made independently and the tree was counted once for each day it was used by a different bat. If multiple bats were found using the same tree on the same day, it was

assumed their decision to use that tree was not made independently and the tree was counted only once.

We tracked female Keen's myotis for a mean of 11.5 days (range 7-17, SD=2.6) and males for a mean of 10.8 days (range 5-19, SD=4.7). Including all non-tree roosts and roosts shared by multiple bats, each female used an average of 6.0 (range 4-8, SD=1.5) different roosts and males used an average of 5.7 (range 4-7, SD=1.5) different roosts during the period they were tracked. One female was excluded from these calculations because she was only tracked for two days due to equipment failure. Most bats switched roosts daily and appeared to cycle through a suite of roosts. Male and female bats often returned to previously used roosts after several days of roosting elsewhere (females: n=12 occasions, males: n=6 occasions). The mean number of consecutive days spent in a single roost for individuals was similar for females and males ($\bar{x}$=1.4 days, range=1-6, SD=0.87 and $\bar{x}$=1.1, range 1-5, SD=0.68, respectively). Day roosts for females were located between 94 and 1125 m ($\bar{x}$=350, SD=302, n=13) from capture sites and the distance between roosts used on consecutive days ranged from 7 to 215 m ($\bar{x}$=104, SD=52, n=66) apart. Day roosts for males were between 39 and 2282 m ($\bar{x}$=631, SD=835, n=6) from point of capture and the distance between roosts used on consecutive days ranged from 8 to 536 m ($\bar{x}$=144, SD=200, n=33) apart.

Tree Characteristics

Females

Female Keen's myotis only roosted in cedar and hemlock and used cedar significantly more than hemlock and more than expected given their availability (Fig. 3.2). Cedars comprised 87% of roosts used by females. Females were never found

roosting in a live tree without defects although the vast majority of available trees (70%) were in this category. Fifty-six percent of trees used by females were live with defects, 37% were snags in early decay, and 6% were snags in intermediate decay (Fig. 3.3). Female Keen's myotis roosted in trees with defects significantly more than expected given their availability (Fig. 3.4). For females, the odds a tree was a roost increased by 5.4 times (Exact 95% CI 2.3, 12.9) if it had a broken top, 18.5 times (Exact 95% CI 7.8, 46) if it had a crack in the stem, and 24.2 times (Exact 95% CI 7.6, 99.21) if there was a cavity in the stem (Table 3.3). Mean diameter, height, slope-height, and slope of trees used as roosts by female Keen's myotis were significantly greater and percent bark remaining on roost trees was significantly less than available trees. There was no significant difference between the mean of average distance to nearest tree for used and available trees (Table 3.4).

The model with the lowest $QAIC_c$ included all four variables, but a closely competing model ($\Delta = 0.50$) contained all variables except slope-height (Table 3.5). The null model was not a competing model ($\Delta = 106.79$). Calculations of cumulative Akaike weights ($\sum w_i$) for model-averaged coefficient estimates and odds ratios indicate that dbh, defects, and bark are nearly equal in relative importance followed by slope-height (Table 3.6). The odds that a tree was a roost for female Keen's myotis increased 1.32 (95% CI 1.15, 1.52) times for every 10 cm increase in diameter at breast height. For every 10% decrease in bark, the odds of a tree being a roost site for female Keen's myotis increased by 1.41 (95% CI 1.14, 1.62) times. However, only 12% of trees used as roosts had less than 20% bark cover, indicating there may be a lower threshold for the amount of bark preferred on roost trees used by female Keen's myotis. Odds that a tree was a roost for

female Keen's myotis increased 1.24 (95% CI 1.07, 1.43) times for every 5 m increase in

slope-height, but the strength of evidence for this effect was relatively weak ($\sum w_i = 0.56$).

Model-averaged odds ratios can not be accurately determined for categorical variables.

Therefore, we calculated the odds a tree was a roost given presence of defects using

estimates of relative risk from 2x2 contingency tables. The odds of a tree being used as a

roost by female Keen's myotis increased by 38.32 (Exact 95% CI 12.02, 148.82) times if

the tree had at least one defect (cavity, crack, or broken top).

Males

Male Keen's myotis roosted primarily in cedar and hemlock snags (Fig. 3.5) in

intermediate and late stages of decay (Fig. 3.6) with cracks, cavities, broken tops, and

sloughing bark (Fig. 3.7). The odds that a tree was a roost increased by 8.3 times (Exact

95% CI 2.4, 30.5) if there was a crack in the stem, but Fisher's exact p-values for

frequency distributions of used and available trees with cavities and broken tops were

non-significant and 95% confidence intervals for odds ratios included 1, indicating there

was no significant effect of cavities and broken tops on use of trees by male Keen's

myotis (Table 3.3). The mean percent bark remaining on trees used as roosts by male

Keen's myotis was significantly less than available trees, but there were no statistically

significant differences in means of other variables (Table 3.4).

The best model for male Keen's myotis at the tree scale included defects, bark,

and slope-height and no competing model had $\Delta < 2$ (Table 3.7). The null model had $\Delta =$

23.155. At the tree scale, calculations of cumulative Akaike weights at the tree scale

ranked bark as the most influential variable on selection of roost trees by male Keen's

myotis followed by slope-height, defects, and dbh (Table 3.8). There was a negative

relationship between use of trees and amount of bark remaining on the stem and the odds of a tree being used as a roost increased 1.41 (95% CI 1.15, 1.73) times with every 10% decrease in the amount of bark remaining. Trees used as roosts by male Keen's myotis did not appear to have a minimum threshold for the amount of bark given the high proportion of roost trees with less than 20% bark (42%). There was a positive relationship between slope-height and use of trees by male Keen's myotis and the odds a tree was a roost increased by 1.52 (95% CI 1.14, 2.04) times for every 5 m increase in slope-height. As discussed above, the odds ratio for the presence of defects on roost trees was calculated with relative risk estimates from 2x2 contingency tables. A tree with at least one defect was 6 times (Exact 95% CI 1.74, 23.52) more likely to be used as a roost by male Keen's myotis than a tree without defects. Confidence limits of coefficient estimates for dbh included zero and therefore suggest there was no effect of dbh on selection of trees as roosts by male Keen's myotis.

Females vs. males

Female Keen's myotis roosted more frequently in cedar and live trees with defects than did males and males roosted more frequently in hemlock snags in early and intermediate stages of decay more frequently than did females. There was no significant difference in frequency of use for types of defects present on roost trees used by male and female Keen's myotis (Table 3.3). Mean diameter, height, and slope-height were significantly greater for roost trees of females than males and mean percent bark remaining was significantly less on trees used by males (Table 3.4).

Tree Plot Characteristics

Females

The mean proportion of basal area of canopy trees that were live or in early stages of decay (Female-PR) was significantly greater in the plots surrounding roost trees relative to available trees (Table 3.9). Mean QMD was significantly greater in the plots around roost trees used by female Keen's myotis, but there was no difference in mean stem density between used and available plots.

The best model at the tree plot scale for female Keen's myotis contained the variables Female-PR, and QMD and no competing models had Δ<2 (Table 3.5). The null model had $\Delta = 31.03$. The sum of Akaike weights for the subset of models within which each variable occurred ($\sum w_i$) indicates strong evidence for the effects of Female-PR and QMD on selection of roost sites by female Keen's myotis (Table 3.6). The odds that a tree was used as a roost by female Keen's myotis increased 1.92 (95% CI 1.46, 2.53) times for every 10% increase in the relative abundance of potential roosts. The odds of a plot being used for roosting by female Keen's myotis increased 1.42 (95% CI 1.08, 1.49) times with every 5 cm increase in QMD. There was no significant effect of density as indicated by the inclusion of zero in 95% confidence intervals for model-averaged coefficient estimates and low cumulative Akaike weight (0.25).

Males

The mean proportion of basal area of canopy trees that were dead and in early or late stages of decay (Male-PR) were significantly greater in plots around roost trees of male Keen's myotis than plots around available trees (Table 3.10). Measurements of

mean stem density and QMD in roost plots of male Keen's myotis were not significantly different from available plots.

At the tree plot scale for male Keen's myotis, the model with the lowest QAIC$_c$ value included Male-PR and there were no competing models with $\Delta<2$ (Table 3.7). The null model had $\Delta = 11.67$. The relative importance of variables as determined by $\sum w_i$ suggests the relative abundance of potential roosts was most influential on selection of roost sites by male Keen's myotis (Table 3.8). The odds of a tree being used as a roost by male Keen's myotis increased 2.52 (95% CI 2.32, 4.48) times for every 10% increase in the relative abundance of potential roosts. Density and QMD had no detectable effect on selection of roosts by male Keen's myotis, as indicated by the inclusion of zero in 95% confidence intervals for model-averaged coefficient estimates and relatively low cumulative Akaike weights.

Females vs. males

The relative abundance of roost-like trees for females was significantly greater in plots surrounding tree roosts of females and the relative abundance of roost-like trees for males was significantly greater in plots surrounding tree roosts of males (Table 3.9). Mean density in tree plots containing roost trees of male Keen's myotis was statistically similar to that of plots surrounding roost trees of females. The mean QMD was significantly greater in tree plots used by female Keen's myotis than in tree plots used by males.

Landscape Characteristics

Females

The mean maximum distance between roosts for females was approximately 1104 m and the size of the landscape unit was 96 ha. The mean distance from roosts used by female Keen's myotis to nearest hard edge was not significantly different from that for random points. The mean distances to nearest road and to a stream were significantly shorter from roosts than from random points (Table 3.10). The mean proportions of clearcut and peatland-mixed conifer forests were significantly less and the proportion of productive old-growth forest was significantly greater in landscape units centered on roosts used by female Keen's myotis than in units centered on random points. There was no significant difference in mean proportions of second-growth forest or naturally open-vegetated habitats in used and random units. The mean length of hard edge was significantly less and the mean length of stream was significantly greater within landscapes centered on roosts of female Keen's myotis than in landscapes centered on random points.

At the landscape scale, two competing models had Δ<2, but the top model had >72% chance of it being the best approximating model from the set of candidate models for female Keen's myotis (Table 3.5). The null model had Δ = 88.16. The top model included all four variables and values of $\sum w_i$ suggest substantial support for the influence of each variable on selection of roosts by female Keen's myotis (Table 3.6). For every 10% increase in the proportion of old-growth in the landscape, the odds of a tree being used as a roost by female Keen's myotis increased 1.71 times. A 10% decrease in proportion of area that was clearcut in the surrounding landscape resulted in a 46% increase in the odds a tree was used as a roost by female Keen's myotis. For every 20 m

decrease in distance from roost or random point to nearest road or stream, the odds of a tree being used as a roost increased by 1.11 and 1.16 times, respectively.

Males

The mean maximum distance between roosts for males was approximately 1108 m and the area of the landscape unit was 96 ha. The mean distance to nearest road from roosts used by male Keen's myotis (180 m) was significantly less than distances to road from random points (854 m). Distances to nearest hard edge or stream did not statistically differ between used and random units (Table 3.10). The mean proportion of area containing young forest (0.11) was significantly greater in landscape units centered on roosts used by male Keen's myotis than in units centered on random points (0.21). There were no statistically significant differences in mean proportions of other habitat classifications between landscape units surrounding roost trees of male Keen's myotis and randomly generated points.

At the landscape scale, three models from the candidate set had $\Delta<2$ and were considered to be strongly competing (Table 3.7). Combined, these models represented measurements of the distance to road and stream and proportion of old growth in the landscape. Distance to road ($\sum w_i = 1$) and stream ($\sum w_i = 0.99$) were most influential on selection of roosts by male Keen's myotis at the landscape scale as indicated by the sum of Akaike weights (Table 3.8). The proportion of clearcut forest in the surrounding landscape had no detectable effect on roost selection by male Keen's myotis at the landscape scale, as indicated by the inclusion of zero in the 95% confidence intervals for the model-averaged coefficient estimate. The odds of a tree being used as a roost by male Keen's myotis increased 1.13 times with every 20 m decrease in distance to the

nearest road and odds increased 1.09 times with every 20 m increase in distance to the

nearest stream. For every 10% increase in proportion of old-growth forest, the odds of a

tree being used as a roost by male Keen's myotis increased 1.20 times, but $\sum w_i$ was 0.36,

indicating the relative influence of old growth on selection of roosts by male Keen's

myotis at this scale is low.

Females vs. males

The mean distance to nearest stream was significantly less in landscapes

surrounding roosts used by females (102 m) than males (219 m), but there was no

difference between distance to nearest road or edge (Table 3.10). The mean proportion of

old-growth forest (females, 0.73; males, 0.38) and total distance of stream (females, 2882

m; males, 2066 m) was significantly greater in landscapes surrounding roosts of female

Keen's myotis than landscapes surrounding roosts of males. The mean proportions of

clearcut (females, 0.05; males, 0.18) and young forest (females, 0.07; males, 0.21) and

total distance of edge (females, 1560 m; males, 2758 m) were significantly less in

landscapes surrounding roosts of females relative to males.

Multi-scale Comparisons

Females

We compared all models across spatial scales to determine at which spatial scale

relationships between habitat characteristics and use of roosts by female Keen's myotis

are strongest (Table 3.12). The top two, highly competitive models were from the tree

scale and contained the variables: dbh, defects, bark, and slope-height. For the top two

models from the tree scale, $\sum w_i = 1$, indicating there was nearly a 100% chance that one

of the tree scale models was the best approximating model from all models and scales

considered. Results of model selection across all scales suggest characteristics at the tree

scale are most influential on selection of roosts by female Keen's myotis.

Males

Four competing models from the landscape and tree scales had Δ<2 (Table 3.13).

The top three models represented the landscape scale and their combined w_i values

indicated there was a 90% chance that one model from that scale was the best overall

model. The characteristics that appear to be most influential on selection of roosts by

male Keen's myotis are the distance to the nearest road and stream and the proportion of

productive old-growth at the landscape scale.

DISCUSSION

We found that habitat characteristics at multiple spatial scales were associated

with selection of day-roosts by Keen's myotis on Prince of Wales Island. The habitat

characteristics that appear to influence selection of day-roosts by females differed from

those of males and associations were strongest for females at the tree scale whereas

associations for males were strongest at the tree and landscape scales

Females

Our data indicate that selection of roosts in trees by female Keen's myotis is most

strongly influenced by characteristics of the tree and female Keen's myotis primarily

roosted in live or recently dead, large diameter trees with structural defects. The

energetic requirements of bats likely influence the selection of roosts in the cool, wet

climate of Southeast Alaska. Bats can enter torpor during inclement weather to conserve

energy, but use of torpor delays fetal development, inhibits milk production, and slows growth in juveniles (Tuttle 1976, Racey and Swift 1981). The use of torpor by reproductive females and juveniles in Southeast Alaska is likely a costly option because the growing season is short and bats need time to build fat reserves before hibernation (Barclay and Kurta 2007, Solick and Barclay 2007). Insufficient accumulation of fat by bats prior to hibernation may cause higher mortality of juveniles over winter (Grindal et al. 1992, Kunz et al. 1998) and lower fecundity for species at higher latitudes (Kunz et al. 1998). Warm tree cavities with stable microclimates are often selected by female bats for day-roosting, which may reduce the metabolic demands of thermoregulation and facilitate fetal development and growth of juveniles by allowing reproductive females to avoid the use of torpor (Sedgeley 2001, Kunz and Lumsden 2003, Barclay and Kurta 2007).

The insulating properties of a tree increase with thickness and water content in tree walls (Maeda 1974, Kurta 1985, Nicolai 1986), so larger diameter trees have greater potential to provide insulated roost-sites. Larger diameter trees also may provide larger cavities and crevices where bats can cluster to further reduce costs of thermoregulation (Kurta 1985, Kurta 1986, Brigham et al. 1997, Barclay and Kurta 2007). Tall trees may be easier to locate and receive higher levels of solar radiation (Vonhof and Barclay 1996, Brigham et al. 1997). We hypothesized Keen's myotis would differentially select roost trees that are relatively easy to locate, provide stable microclimates, and contain cavities and crevices where bats can cluster. The selection for tall, large-diameter, live and recently dead trees with defects by female Keen's myotis supports this hypothesis and

suggests that selection of day-roosts by female Keen's myotis may be driven by energetics of the species.

The type of tree preferentially selected for roosting by female Keen's myotis was found in higher proportions in the immediate vicinity of roosts. Plots with larger trees and more trees with characteristics similar to those of preferred roost trees may be selected by female Keen's myotis because they have a greater abundance of potential roosts. Our results are consistent with other studies that found greater availability of trees in certain stages of decay (Waldien et al. 2000, Erickson and West 2003) or above certain diameter thresholds (Weller and Zabel 2001, Campbell et al. 1996) in plots surrounding roost trees. Our findings suggest that forest patches with greater availability of large-diameter, live or recently dead trees with defects are important in selection of roosts by female Keen's myotis on Prince of Wales Island.

The effect of stem density on habitat selection by bats has been attributed to structural limitations imposed on flight (Brigham et al. 1997, Humes et al. 1999). Lack of relationships with tree density in plots surrounding roosts in our study may reflect the fact that Keen's myotis is a small bat with low wing loading, and presumably is highly maneuverable in flight (Saunders and Barclay 1992, Brigham et al. 1997, Swartz et al. 2003) and adept at flying in forested environments. Alternatively, plots surrounding roosts and randomly selected structures may not have exhibited adequate variation for us to detect influences of tree density on roost use. Available trees and plots were selected within 200 m and in the same habitat type as each roost tree. Given that all roosts of female Keen's myotis were found in old-growth forest, our sampling design prohibited detection of relatively large differences in tree densities such as those that may occur

between old and young forests. Several studies have found that bat activity in young

forest is low relative to that in older forests (Parker et al. 1996, Humes et al. 1999, Law

and Chidel 2002, Erickson and West 2003, Lloyd et al. 2006) and our results suggest

these forest types may not be used for roosting by female Keen's myotis.

Our results suggest female Keen's myotis on Prince of Wales Island select roosts

in trees that are closer to roads and streams than available trees. Weller and Zabel (2001)

found a relationship between roost selection by bats and distance to nearest stream and

suggest this relationship may be attributed to use of these habitats by bats for foraging

and commuting. Riparian corridors and roads may be high quality flyways for

commuting between roosts and activity areas because they provide protection from wind

and predators (Verboom and Huitema 1997), but are structurally open relative to the

interior of the forest (Grindal 1998, Law and Chidel 2002, Lloyd et al. 2005). Flight is

energetically costly and female Keen's myotis may conserve energy by roosting near

commuting corridors and foraging areas (Tuttle 1976). However, stream habitat is

abundant on Prince of Wales Island and the energetic costs of commuting from roosts to

flight corridors and foraging areas may be trivial in relation to the long distances bats

may travel each night (Barclay and Kurta 2007).

In addition to providing corridors for commuting, riparian areas provide important

foraging habitat for many species of bats (Thomas 1988, Parker et al. 1996, Grindal et al.

1999, Waldien and Hayes 2001, Broders et al. 2006). The importance of riparian areas

for foraging may be attributed to greater availability of insect prey (Thomas 1988,

Barclay 1991, Grindal et al. 1999, Ober 2007). The relationship between use of roosts by

bats and total area of preferred foraging habitat in the landscape surrounding roost sites

has been well documented (Tuttle 1976, Broders et al. 2006, Miles et al. 2006) and we propose the abundance of total stream habitat in the landscape surrounding roosts indicates the importance of riparian areas as activity areas for female Keen's myotis on Prince of Wales Island.

The proportionate abundance of old-growth forest in landscapes surrounding day roosts of female Keen's myotis may be attributed to greater abundance of potential roosts. The ability to select from an abundance of potential roosts in the landscape may give bats the advantage of selecting roosts that are surrounded by optimal landscape features (Miles et al. 2006) or that have a range of thermal characteristics suitable for variable weather conditions (Kunz and Lumsden 2003, Barclay and Kurta 2007). We hypothesized that Keen's myotis prefer roosting in landscapes with an abundance of potential roosts and we found that female Keen's myotis primarily roosted in types of trees (i.e., large diameter conifers with defects) that are more abundant in older forests. Humes et al. (1999) suggest that structural characteristics of the forest and not necessarily stand age, influence use by bats. Young forests are generally characterized by even-aged, small-diameter stands with high stem density and little vertical stratification with high levels of structural clutter and few to no roost-like trees. Older forests typically have multi-layered canopies with larger diameter trees and lower stem density, which may provide more roosting potential and habitat that is structurally more effectively used by flying bats. However these structural characteristics may also be present in mature stands that have been silviculturally thinned (Humes et al. 1999). It is possible that thinned forests with large-diameter trees in varying levels of decay would be suitable for roosting by Keen's myotis. However, industrial harvesting of forests on Prince of Wales Island

began in the 1940's and stands in the temperate rainforests of Southeast Alaska do not

reach maturity until they are approximately 150 years-old (Iverson et al. 1996).

Therefore, it is unlikely that regenerating second-growth forests on Prince of Wales

Island are structurally suited to provide suitable roosting habitat for bats at this time.

The landscape on Prince of Wales Island is a diverse mosaic of forested, naturally

open, managed, and unmanaged habitats and the area of clearcut was not highly

correlated with the area of old-growth forest in our sampling units. Therefore, the

negative effect of proportional abundance of clearcut on selection of roosts by female

Keen's myotis may be attributed to something other than a lower abundance of potential

roosts associated with a higher abundance of clearcut habitat. In Southeast Alaska, wind

is one of the most predominant disturbance agents (Nowacki and Kramer 1998) and owls

have been observed preying on bats in several areas of the region (J. Boland, personal

observation). We hypothesize that selection of roosts in landscapes with less clearcut

area may be due to behavioral strategies aimed at reducing exposure to predators and

wind (as suggested by Verboom and Huitema 1997).

Males

At the tree scale, selection of day-roosts in trees by male Keen's myotis appears

to be associated with the amount of bark remaining on the stem, relative height of the

tree, and presence of defects. Male Keen's myotis were also found roosting solitarily in

stumps, rock crevices, and under loose rocks. Males may be more flexible than females

in selection of roost sites, which may be related to differences in energetic requirements

(Thomas 1988, Campbell et al. 1996, Broders and Forbes 2004). Male bats are not

limited by the energetic constraints of birth and lactation and can use torpor more

effectively to reduce thermoregulatory costs when ambient temperatures are low

(Speakman and Thomas 2003, Turbill 2006). However, male Keen's myotis are still

challenged by the need to meet energetic demands of growth and reproduction and

maintain thermoregulation in the low temperatures and frequent periods of precipitation

characteristic of the climate in Southeast Alaska. Male bats may benefit energetically by

choosing poorly insulated and sun-exposed roosts because they can switch between

torpor and normothermic thermoregulation as daily ambient temperatures fluctuate

(Turbill 2006). Selecting poorly insulated roost sites that facilitate torpor may also

benefit bats by lowering energetic requirements during periods of low insect availability

associated with inclement weather (Turbill 2006, Barclay and Kurta 2007). Male Keen's

myotis on Prince of Wales Island may conserve energy by selecting poorly insulated

roosts under loose bark or in cracks because these types of roosts provide protection from

rain, but still facilitate use of torpor.

Characteristics of the landscape scale appear to be most strongly associated with

selection of day roosts in trees by male Keen's myotis on Prince of Wales Island and

odds of a tree being used for roosting by male Keen's myotis increased closer to roads

and further from streams. As with females, we propose that male Keen's myotis are

using roads to commute from roosts to foraging areas and conserve energy by roosting

closer to commuting corridors. However, we also hypothesized that roosts would be

located closer to riparian areas to lower energetic costs of commuting from roosts to

foraging areas, but roosting behavior by male Keen's myotis in this study do not support

this hypothesis. However, other studies have documented similar preferences for roosts

located further from riparian areas relative to random points and suggest males may

choose to roost farther from streams because temperatures are lower near streams relative to upland habitat (Campbell et al. 1996, Waldien et al. 2001).

Male Keen's myotis in this study were highly flexible in their choice of roosts which can likely be attributed to low energetic constraints and the ability to use torpor to conserve energy. Campbell et al. (1996), suggest that lower energetic requirements may also allow male bats to be more flexible in regards to commuting distances between roosts and foraging areas. We hypothesize that although some associations appear to exist between selection of roosts by male Keen's myotis and characteristics at the tree, plot, and landscape scales, reduced energetic constraints permit males to be more opportunistic in selection of roosts.

Scope and Limitations

This study took place on one of the southernmost islands in the Alexander Archipelago of Southeast Alaska. Cedar species were used as day-roosts by Keen's myotis more often than any other species of tree during this study. Given that western hemlock are the most abundant species on Prince of Wales Island, we suspect cedar trees are preferentially selected as day-roosts by Keen's myotis because structural and decay characteristics of cedars provide optimal cavity formation and therefore greater availability of potential roost sites (as suggested by Vonhof and Barclay 1996). However, Keen's myotis occur as far north as Juneau (Chapter 2) and cedars only occur in the southern half of Southeast Alaska. Keen's myotis on Prince of Wales also roosted in western hemlock trees with structural defects and loose bark. We propose that structural characteristics of the tree ultimately determine the energetic benefits it provides to roosting bats and the energetic requirements of Keen's myotis are similar throughout

Southeast Alaska. In this case, our findings regarding the influence of tree characteristics and characteristics of the landscape on selection of roosts by Keen's myotis on Prince of Wales Island should be applicable to selection of day-roosts by Keen's myotis throughout Southeast Alaska.

Captures of Keen's myotis were restricted to areas within 0.5 km of a road due to logistical constraints. Landscapes containing roads are by nature more fragmented than roadless landscapes and some habitat associations for bats are likely to differ between the two. For example, most of the roads on Prince of Wales Island were built to access forests for logging and consequently landscapes containing roads have higher proportions of clearcuts and young forest. The composition of habitats in landscapes may affect the type of structures used for day roosting by Keen's myotis (Waldien et al. 2000). Therefore, inferences of habitat use by Keen's myotis are restricted to individuals that forage or commute near roads.

We treated each roost tree as an independent sample in our analyses despite the fact that multiple roosts were selected by the same bat. Ideally, we would have treated bats as the independent sampling unit and examined characteristics of roosts selected by a much larger sample of individuals to account for variation in characteristics selected by individuals and among the species. Also, if a roost tree was located within 554 m of another roost tree, landscape units overlapped and consequently created some pseudoreplication in the landscape data. More data are needed for conclusive determination of habitat associations for Keen's myotis in Southeast Alaska. Given the apparent rarity and elusiveness of Keen's myotis, it will be useful to standardize

techniques in order to pool data across efforts and years to achieve more conclusive results.

Available trees and random landscape units were not assumed to be unused by bats. On the contrary, it is highly likely that some of the available trees and random landscape units we sampled were used by bats for roosting. Our sampling design only allows examination of what was used relative to what was available, not what is used relative to what is not used. We determined whether a feature of the habitat was associated with selection of roosts by examining use of that characteristic relative to its availability at each spatial scale. Our conclusions are dependent on the availability of each characteristic at the time of this study. Additional characteristics are likely influencing roost selection, but low variability of those characteristics within each scale inhibits our ability to detect them. It may not be until habitat features become a limiting factor in the environment that their importance can be differentiated between used and available sites (Ford et al. 2006).

Our analyses interpret log linear relationships between odds of use and habitat features, but there are likely minimum and maximum thresholds for values of measurements for many characteristics of the habitat. For example, results of logistic regression analyses and model-averaged coefficient estimates suggest that as bark decreases, the odds of a tree being used as a day-roost by Keen's myotis increase. However, there may be a minimum threshold for the amount of bark on trees used as roosts by female Keen's myotis given only 12% of trees used by females had less than 20% bark.

We restricted the number of variables we examined with model selection techniques in order to maintain parsimony and accurate inference given our relatively small datasets. We were also unable to include all variables measured within each scale in the same model given multicollinearity between some of the variables. Univariate analyses suggest additional variables that were not included in model selection analyses warrant further examination regarding their influence on selection of day-roosts by Keen's myotis.

Given our sampling design and the need to limit the size of models, we did not include variables from different scales in the same model. Consequently, we can not make inferences to the simultaneous influence of variables at multiple scales.

Conclusions and Management Implications

Understanding the spatial scales at which Keen's myotis select day-roosts can help managers appropriately prioritize conservation strategies for this species in Southeast Alaska. Bats may select trees based on their availability in the environment (Waldien et al. 2000), but even migratory bats that are obligatory opportunists appear to select for certain tree characteristics that provide optimal roosting conditions (Barclay et al. 1988). Evidence from this study suggests that associations with selection of roosts in trees are strongest for female Keen's myotis at the tree scale, but associations at broader scales are also evident. We caution that although our results suggest weaker associations at broad spatial scales for female Keen's myotis, associations at larger spatial scales may be integral parts of a hierarchical decision process (Wiens 1989) that ultimately result in selection of optimal roosts in proximity to other critical habitat elements (e.g., foraging areas; Johnson 1980). We propose that although characteristics of the tree have stronger

associations with selection of roosts by female Keen's myotis, the abundance and availability of suitable roosts is determined by the structure and composition of habitat features in the landscape.

Habitat associations were strongest for males at the landscape scale, but associations were also evident at the tree scale. Male Keen's myotis were found roosting in a variety of roost types, including rocks and tree stumps. Turbill (2006) suggest that male bats may benefit from using poorly insulated, relatively exposed roost sites, but Waldien et al. (2000) suggest that stumps and logs are suboptimal roosting habitat because they are more ephemeral and provide a greater risk of predation by ground predators. If the availability of roost structures is limited in the landscape, it may influence the characteristics of roosts used by bats (Waldien et al. 2000, Hayes 2003, Miles et al. 2006, Hayes and Loeb 2007). In landscapes where there are a greater abundance of high quality potential roosts, bats can conserve energy by selecting roosts closer to water and foraging habitat, but in landscapes where quality roosts are limited, bats may roost farther from foraging sites or roost in suboptimal structures (Miles et al. 2006, Broders et al. 2006).

Spatial segregation of summer roosting habitat is common between males and females of temperate species of bats and may be attributed to different energetic requirements or an attempt to reduce competition for food resources surrounding the roost (Altringham and Senior 2005). We hypothesize that female Keen's myotis select trees that can potentially provide warm, stable microclimates because they need to maintain high and stable body temperatures to facilitate fetal growth and milk production during reproduction. We hypothesize that male Keen's myotis are not limited to roost

sites that are warm and stable and may select cooler sites because they facilitate the use of torpor. Both males and females selected roosts surrounded by an abundance of trees that were similar in size and structure to the trees used for roosting. Although males appear to be somewhat flexible in the types of roosts they use and the composition of landscapes surrounding the roosts, females appear to be more limited in their selection of roosts and female Keen's myotis in this study primarily selected roosts in large diameter trees surrounded by old-growth forest.

A disproportionate amount of logging has occurred on Prince of Wales Island relative to the rest of Southeast Alaska. Prince of Wales Island originally contained almost 10% of all productive old-growth forest in Southeast Alaska, but almost 38% of productive old-growth forest that has been harvested in the region has occurred there (Albert and Schoen 2007). Thirty-two percent of old-growth forest in North Prince of Wales Island has been harvested (Albert and Schoen 2007) and 67% of old-growth in North Prince of Wales and 34% in South Prince of Wales is projected to be cut by 2055 under the current Tongass Land Management Plan (Iverson et al. 1996, USDA Forest Service 1996). Forest management can affect the distribution and abundance of bats by altering the availability and quality of roost sites (Hayes 2003, Hayes and Loeb 2007) and removal of large trees from forest habitats during harvest has been associated with a decrease in abundance of bats (Lunney et al. 1985). However, mitigation may be possible with retention of roost-like trees (Campbell et al. 1996, Hayes and Loeb 2007).

The conservation status of Keen's myotis throughout its range is currently unclear. We have limited knowledge of its biology and habitat associations and no knowledge of population status or trends. This study offers preliminary insights into

habitat associations affecting selection of day roosts by Keen's myotis at multiple spatial scales. Day roosts in trees are a critical resource for many forest-dwelling species of bat. Removal of large diameter trees during timber harvest can reduce the number of potential roosts available to bats and harvesting forests under short rotations can inhibit the development of suitable roosts over time (Hayes and Loeb 2007). Evidence from this study suggests that maintaining forests with high proportions of live or recently dead, large-diameter trees in close proximity to riparian habitats may provide critical roosting habitat for female Keen's myotis on Prince of Wales Island.

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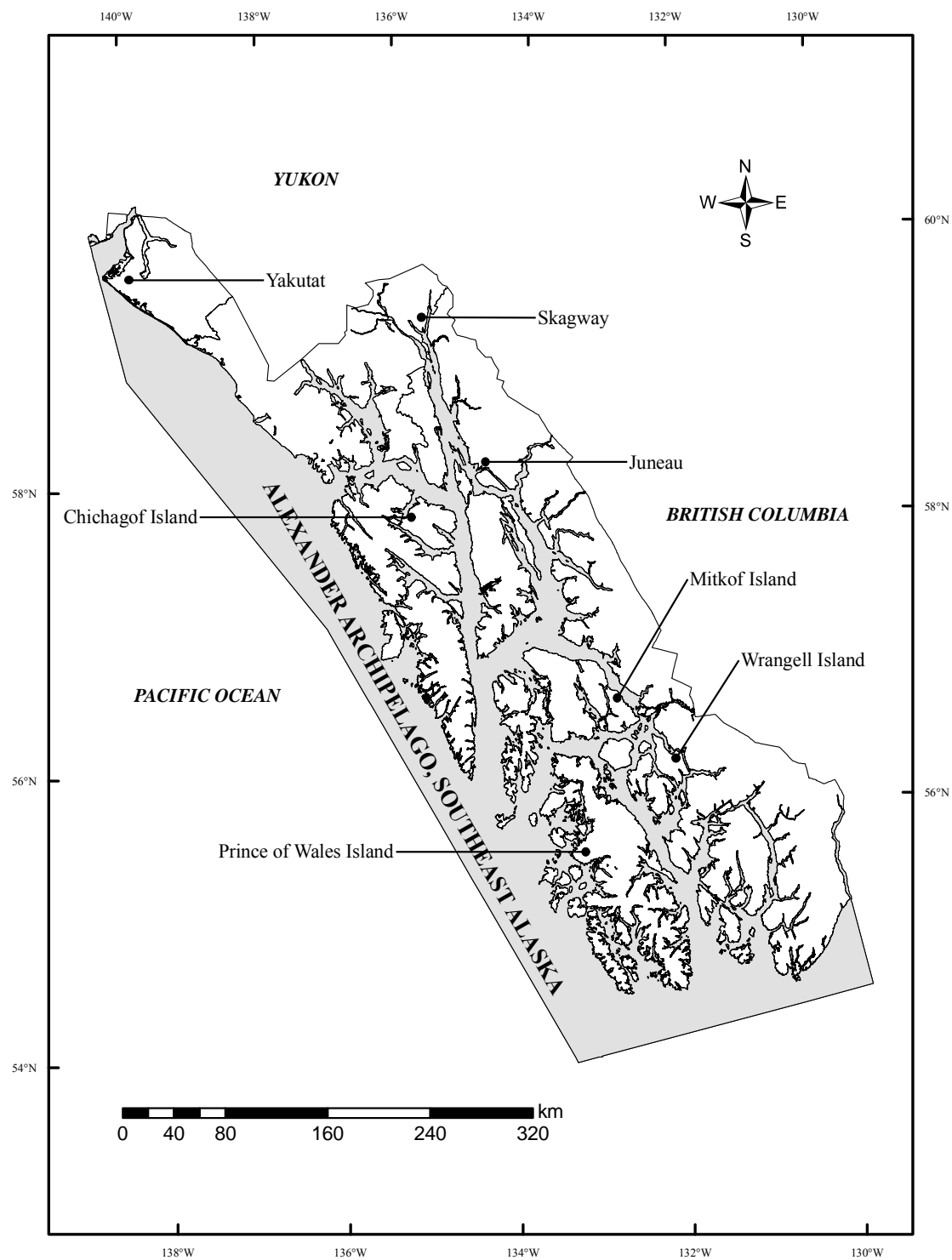
Figure 3.1. Map of Southeast Alaska.
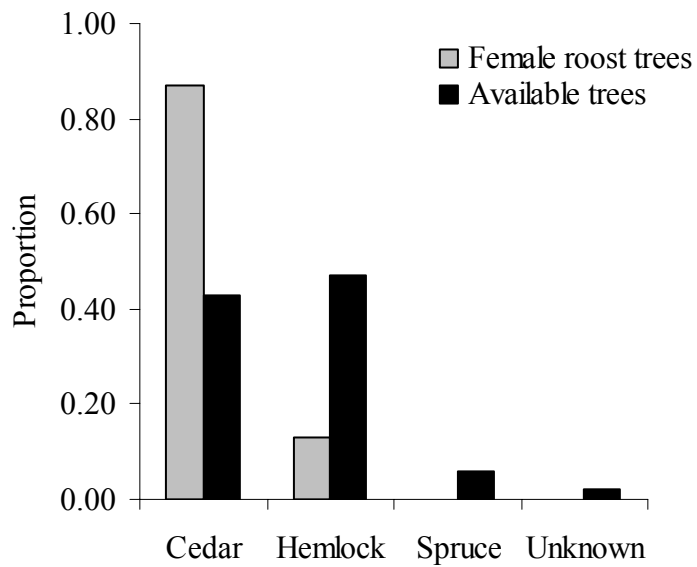
Figure 3.2. The proportion of day-roosts of female Keen's myotis found in each category of conifer species on Prince of Wales Island, Southeast Alaska, 2006.
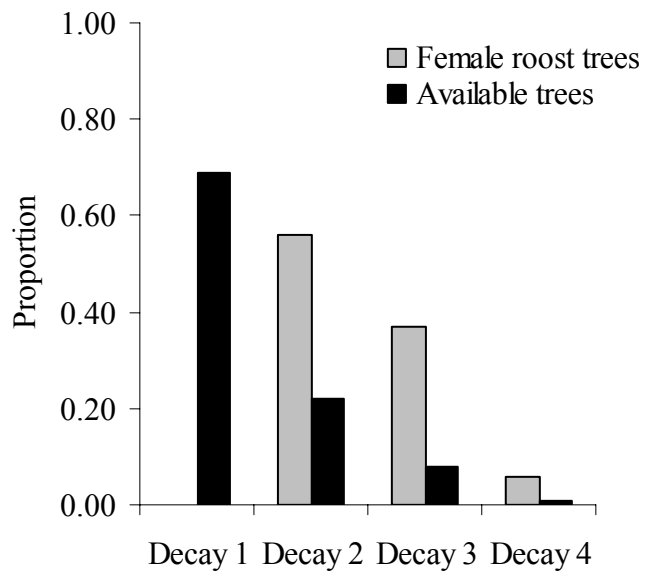
Figure 3.3. The proportion of day-roosts of female Keen's myotis found in each decay class on Prince of Wales Island, Southeast Alaska, 2006.
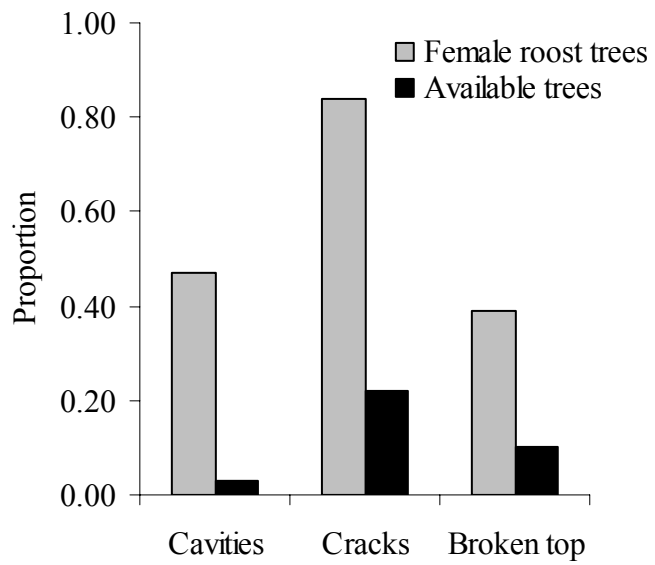
Figure 3.4. The proportion of day-roosts of female Keen's myotis with each category of defect (cavities, cracks, and broken top) on Prince of Wales Island, Southeast Alaska, 2006.
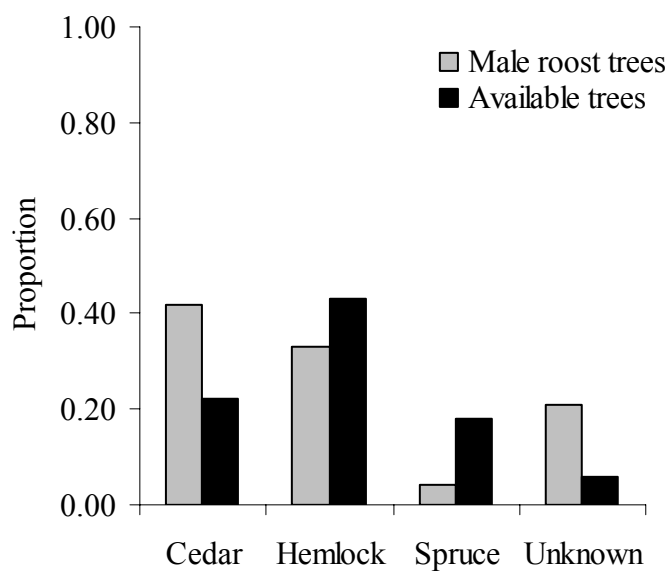
Figure 3.5. The proportion of day-roosts of male Keen's myotis in each category of conifer species on Prince of Wales Island, Southeast Alaska, 2006.
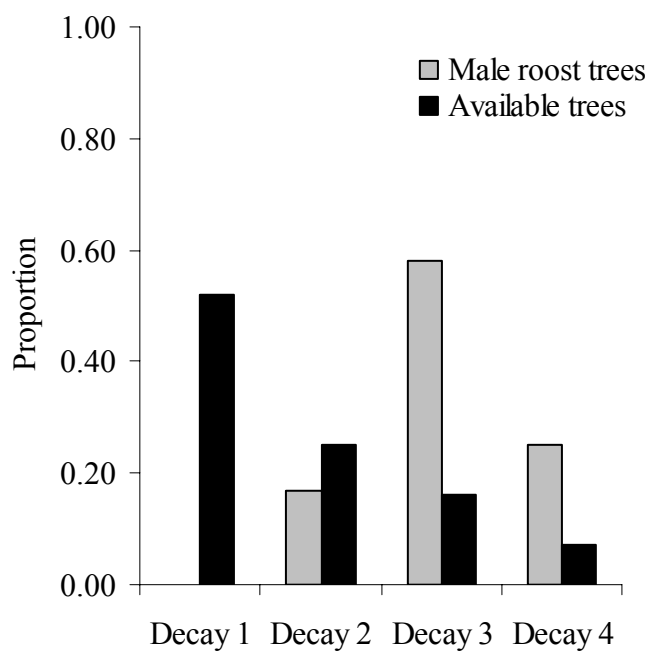
Figure 3.6. The proportion of day-roosts of male Keen's myotis in each category of decay class on Prince of Wales Island, Southeast Alaska, 2006.
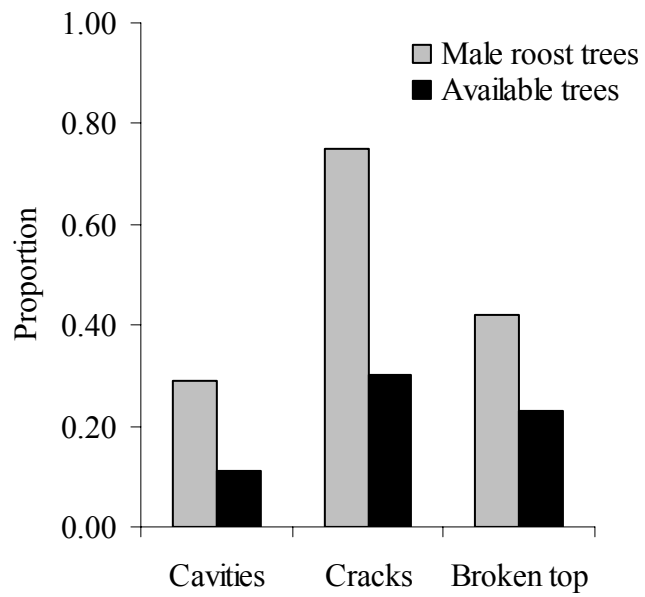
Figure 3.7. The proportion of day-roosts of male Keen's myotis with each category of defect (cavities, cracks, broken top) on Prince of Wales Island, Southeast Alaska, 2006.

Table 3.1. Decay-stage classifications for trees (modified from Cline et al. 1980).

Decay Stage	Description
1	Live with no significant defects (i.e., cavities, cracks, or broken top)
2	Live with defects (i.e., cavities, cracks, or broken top)
3	Dead with some bark and branches
4	Dead with no bark or branches

Table 3.2. Characteristics of trees, plots, and landscapes measured to determine influence on selection of day-roosts by Keen's myotis, Southeast Alaska, 2006.

Scale	Variable	Description
Tree	Bark*	Bark remaining on tree stem (%)
	Dbh*	Diameter at breast height (cm)
	Defects*	Presence of cavities, cracks, or broken top
	Slope-height*	Height of tree given the slope (m)
	Decay	Decay class 1-4
	Cavities	Presence/ absence of cavities
	Cracks	Presence/ absence of cracks
	Broken top	Presence/ absence of a broken top
	Height	Height of tree (m)
	Slope	Slope on downhill side of roost/available tree (%)
	Nearest tree	Mean distance to nearest tree of equal or greater height (m)
	Species	Species of tree
Tree Plot	Female-PR*	Relative abundance of potential roosts for females; proportion of basal area from trees with dbh ≥20 cm and in decay stages 2 and 3.
	Male-PR*	Relative abundance of potential roosts for males; proportion of basal area from trees with dbh ≥20 cm and in decay stages 3 and 4.
	Density*	Number of trees >20cm dbh per plot
	QMD*	Quadratic mean diameter (cm)
Landscape	Edge	Distance (m) to nearest hard edge (not roads and streams)
	Road*	Distance (m) to nearest road
	Stream*	Distance (m) to nearest flowing waterway
	Clearcut*	Proportion of unit that is recently clearcut (<25 years old)
	Old growth*	Proportion of unit that is old-growth forest
	Open-veg	Proportion of unit that is naturally open, but vegetated
	Peat-mixed	Proportion of unit that is peatland-mixed conifer forest
	Young forest	Proportion of unit that is young forest (<75 years old)
	Total edge	Total distance (m) of hard edge
	Total road	Total distance (m) of road
	Total stream	Total distance (m) of stream

* variable used in models for logistic regression and $QAIC_c$ analyses

Table 3.3. Proportion of available trees and roost trees used by Keen's myotis with defects. Odds ratios calculated from estimates of relative risk from Chi-squared likelihood analyses. Odds ratios indicate the amount by which the odds a tree is a roost-site for Keen's myotis increase with the presence of the defect.

	Sex	Proportion available	Proportion used	Fisher's Exact P (roost vs. available)	Odds ratio	UCL	LCL	Fisher's Exact P (♀roost vs. ♂roost)
Cavities	Female	0.03	0.47	<0.0001	24.16	7.56	99.21	>0.10
	Male	0.11	0.29	0.10	2.95	0.72	12.17	
Cracks	Female	0.22	0.84	<0.0001	18.51	7.78	46.01	>0.10
	Male	0.30	0.75	0.0001	8.3	2.42	30.54	
Broken top	Female	0.10	0.39	<0.0001	5.37	2.29	12.9	>0.10
	Male	0.23	0.42	0.09	2.79	0.83	9.22	

Table 3.4. Differences in means of tree variables between roosts of female Keen's myotis and available trees, roosts of male Keen's myotis and available trees, and roosts of females and males. Means with 95% confidence intervals and P-values for differences in means

Variable		n	Mean	95% CI	P (♀roost vs. available)	n	Mean	95% CI	P (♂roost vs. available)	P (♀roost vs. ♂roost)
				Females				**Males**		
Bark	Available	114	91	85, 96	<0.0001	49	78	70, 87	<.0001	0.0003
	Roost	62	63	56, 70		24	37	26, 49		
DBH	Available	114	50.7	44.2, 57.2	<0.0001	49	49.9	40, 59.8	0.21	<.0001
	Roost	62	106.5	97.7, 115.2		24	65.6	51.6, 79.6		
Slope-height	Available	114	28.9	26.7, 31	0.01	49	25.0	21.7, 28.3	0.38	0.02
	Roost	62	33.0	30.3, 35.7		24	27.4	23.1, 31.8		
Height	Available	114	24.0	22, 26	0.04	49	20.4	17.4, 23.5	0.54	0.03
	Roost	62	27.2	24.7, 29.8		24	22.2	18.1, 26.3		
Slope	Available	114	49	44, 54	0.009	49	46	38, 53	0.25	0.36
	Roost	62	58	52, 64		24	52	42, 62		
Nearest tree	Available	114	9.0	8.1, 9.9	0.82	49	9.3	7.9, 10.8	0.46	0.65
	Roost	62	10.1	8.8, 11.3		24	11.7	9.7, 13.8		

Table 3.5. Logistic regression models with $\Delta QAIC_c < 7$ and null models from the set of candidate models predicted to influence selection of day-roosts by female Keen's myotis at each spatial scale. Variables, number of parameters (K), Akaike's Information Criterion adjusted for small sample size ($QAIC_c$), difference in $QAIC_c$ value between the model and the model with the lowest $QAIC_c$ value ($\Delta QAIC_c$), Akaike weights (w_i), and Nagelkerke's coefficient of determination (R^2_G).

Scale	Model	K	$QAIC_c$	$\Delta QAIC_c$	w_i within scale	R^2_G
Tree	Dbh, Slope-height, Bark, Defects	5	117.27	0	0.56	0.67
	Dbh, Bark, Defects	4	117.77	0.50	0.44	0.66
	Null	1	224.06	106.79	0	0
Tree Plot	Female-PR, QMD	3	193.03	0	0.70	0.25
	Female-PR, Density, QMD	4	195.12	2.09	0.25	0.25
	Female-PR	2	199.55	6.52	0.03	0.20
	Female-PR, Density	3	199.92	6.89	0.02	0.21
	Null	1	224.06	31.03	0	0
Landscape	Old growth, Clearcut, Stream, Road	5	135.90	0	0.72	0.59
	Old growth, Stream, Road	4	137.89	1.99	0.27	0.57
	Null	1	224.06	88.16	0	0

Table 3.6. The influence of habitat characteristics at multiple spatial scales on selection of day-roosts by female Keen's myotis as indicated by model averaged coefficient estimates, 95% confidence intervals (LCL, UCL), odds ratios, and cumulative Akaike weights $(\sum w_i)$.

Spatial Scale	Variable	Relationship†	Estimate	SE	LCL	UCL	Odds ratio	$\sum w_i$
Tree	Bark	10% (-)	-0.307	0.089	-0.482	-0.132	1.36	0.997
	Dbh	10cm (+)	0.278	0.071	0.139	0.418	1.32	1.000
	Defects*	(+)	.	.	.	.	37.16	0.999
	Slope-height	5m (+)	0.213	0.075	0.066	0.359	1.24	0.562
Tree Plot	Female-PR	10% (+)	0.653	0.141	0.376	0.929	1.92	1.000
	Density$^?$	5 trees (?)	0.009	0.020	-0.030	0.048	1.01	0.254
	QMD	5cm (+)	0.238	0.082	0.077	0.399	1.27	0.983
Landscape	Clearcut	10% (-)	-0.381	0.146	-0.668	-0.093	1.46	0.731
	Road	20m (-)	-0.104	0.026	-0.154	-0.053	1.11	1.000
	Stream	20m (-)	-0.147	0.050	-0.246	-0.049	1.16	0.989
	Old growth	10% (+)	0.538	0.118	0.307	0.769	1.71	1.000

† the value and sign indicate unit increase in the variable and direction of relationship
*odds ratio was calculated from relative risk estimates of likelihood ratio chi-squared analysis
? No detectable effect given inclusion of zero in 95% confidence limits for the coefficient estimate

Table 3.7. Logistic regression models with ΔQAIC$_c$<7 and null models from the set
of candidate models predicted to influence selection of day-roosts by male Keen's myotis
at each spatial scale. Variables, number of parameters (K), Akaike's Information
Criterion adjusted for small sample size (QAIC$_c$), difference in QAIC$_c$ value between the
model and the model with the lowest QAIC$_c$ (ΔQAIC$_c$), Akaike weights (w_i), and
Nagelkerke's coefficient of determination (R^2$_G$).

Scale	Model	K	QAIC$_c$	Δ QAIC$_c$	w_i	R^2$_G$
Tree	Defects, Bark, Slope-height	4	70.41	0	0.57	0.47
	Defects, Bark, Slope-height, Dbh	5	72.65	2.25	0.19	0.47
	Bark, Slope-height	3	72.72	2.32	0.18	0.41
	Defects, Bark	3	77.29	6.88	0.02	0.36
	Null	1	94.51	23.16	0	0
Tree plot	Male-PR	2	82.85	0	0.56	0.24
	Male-PR, QMD	3	85.02	2.18	0.19	0.24
	Male-PR, QMD	3	85.03	2.18	0.19	0.24
	Male-PR, QMD, Density	4	87.26	4.42	0.06	0.24
	Null	1	94.52	11.67	0	0
Landscape	Stream, Road	3	68.45	0	0.32	0.47
	Stream, Road, Old growth	4	69.30	0.85	0.21	0.49
	Road	2	70.11	1.66	0.14	0.42
	Stream, Road, Clearcut	4	70.61	2.17	0.11	0.47
	Stream, Road, Old growth, Clearcut	5	71.49	3.05	0.07	0.49
	Road, Clearcut	3	71.74	3.29	0.06	0.43
	Road, Old growth	3	71.89	3.44	0.06	0.43
	Road, Old growth, Clearcut	4	73.45	5.00	0.03	0.44
	Null	1	94.52	26.07	0	0

Table 3.8. The influence of habitat characteristics at multiple spatial scales on selection of day-roosts by male Keen's myotis as indicated by model averaged coefficient estimates, 95% confidence intervals (LCL, UCL), odds ratios, and cumulative Akaike weights ($\sum w_i$).

Spatial Scale	Variable	Relationship†	Estimate	SE	LCL	UCL	Odds ratio	Cumulative weight
Tree	Bark	10% (-)	-0.347	0.103	-0.549	-0.144	1.41	0.999
	Dbh$^?$	10cm (?)	-0.008	0.026	-0.058	0.042	1.01	0.207
	Defects*	(+)	.	.	.	.	6.00	0.804
	Slope-height	5m (+)	0.421	0.148	0.131	0.712	1.52	0.934
Tree Plot	Male-PR	10% (+)	0.924	0.296	0.343	1.500	2.52	1.00
	Density$^?$	5 trees (?)	0.011	0.027	-0.043	0.065	1.01	0.248
	QMD$^?$	5cm (?)	0.001	0.023	-0.045	0.044	1.00	0.245
Landscape	Clearcut$^?$	10% (?)	-0.065	0.040	-0.144	0.014	1.07	0.242
	Road	20m (-)	-0.121	0.047	-0.214	-0.029	1.13	1.000
	Stream	20m (+)	0.089	0.035	0.022	0.157	1.09	0.713
	Old growth	10% (+)	0.179	0.065	0.051	0.307	1.20	0.365

† the value and sign indicate unit increase in the variable and direction of relationship
*odds ratio was calculated from relative risk estimates from likelihood-ratio chi-squared analysis
? No detectable effect given inclusion of zero in 95% confidence limits for the estimate

Table 3.9. Differences in means for variables measured at the tree plot scale. Means with 95% confidence intervals and P-values for differences in means between roosts of female Keen's myotis and available trees, roosts of male Keen's myotis and available trees, and roosts of females and males. Medians reported for variables that were ln-transformed for analysis (†).

Variable		*N*	Mean	95% CI	P (♀roost vs. random)	*n*	Mean	95% CI	P (♂roost vs. random)	P (♀roost vs. ♂roost)
				Females				**Males**		
Female-PR	Random	114	0.27	0.24, 0.30	<0.001	49	0.27	0.23, 0.30	0.43	0.006
	Roost	59	0.39	0.35, 0.42		24	0.29	0.24, 0.35		
Male-PR	Random	114	0.16	0.14, 0.19	0.06	49	0.20	0.17, 0.23	0.0002	0.0002
	Roost	59	0.20	0.17, 0.23		24	0.30	0.26, 0.35		
Density†	Random	114	32.5	27.5, 38.4	0.57	49	26.7	20.6, 34.7	0.40	0.77
	Roost	59	30.0	24.0, 37.6		24	31.9	22.5, 45.3		
QMD	Random	114	50.5	47.5, 53.4	0.001	49	46.0	41.4, 50.6	0.97	0.004
	Roost	59	55.4	52.0, 58.7		24	46.1	40.8, 51.3		

Table 3.10. Differences in means for variables measured at the intermediate landscape scale. Means with 95% confidence intervals and P-values for differences in means between roosts of female Keen's myotis and available trees, roosts of male Keen's myotis and available trees, and roosts of females and males. Medians reported for ln-transformed variables (†).

Variable		*N*	Mean	95% CI	P (♀roost vs. random)	*n*	Mean	95% CI	P (♂roost vs. random)	P (♀roost vs. ♂roost)
			Females				**Males**			
Edge	Random	114	249	200, 299	0.89	49	268	193, 344	0.30	0.24
	Roost	59	245	176, 314		24	302	194, 410		
Road†	Random	114	713	593, 833	0.01	49	854	672, 1037	0.006	0.88
	Roost	59	231	65,398		24	180	81, 441		
Stream	Random	114	179	153, 204	0.001	49	182	143, 221	0.24	0.0003
	Roost	59	102	66, 137		24	219	164, 275		
Clearcut†	Random	114	0.11	0.09, 0.14	0.01	49	0.11	0.07, 0.14	0.21	0.004
	Roost	59	0.05	0.02, 0.09		24	0.18	0.12, 0.23		
Old growth	Random	114	0.48	0.44, 0.53	<0.0001	49	0.46	0.39, 0.53	0.46	<.0001
	Roost	59	0.73	0.67, 0.80		24	0.38	0.28, 0.48		
Open-veg†	Random	114	0.03	0.01, 0.04	0.11	49	0.06	0.03, 0.08	0.07	0.13
	Roost	59	0.05	0.03, 0.07		24	0.02	0.01, 0.05		
Peat-mixed†	Random	114	0.20	0.17, 0.24	<0.0001	49	0.22	0.16, 0.28	0.39	0.07
	Roost	59	0.08	0.03, 0.13		24	0.16	0.08, 0.24		
Young forest	Random	114	0.12	0.09, 0.16	0.11	49	0.11	0.06, 0.17	0.04	0.002
	Roost	59	0.07	0.02, 0.12		24	0.21	0.14, 0.29		

Table 3.10. (Continued)

Variable		N	Mean	95% CI	P (♀roost vs. random)	n	Mean	95% CI	P (♂roost vs. random)	P (♀roost vs. ♂roost)
			Females				**Males**			
Total edge	Random	114	2505	2115, 2896	0.005	49	2194	1599, 2789	0.53	0.03
	Roost	59	1560	1017, 2102		24	2758	1907, 3608		
Total stream	Random	114	2133	1903, 2362	0.0003	49	2150	1800, 2500	0.87	0.007
	Roost	59	2882	2563, 3201		24	2066	1566, 2566		

Table 3.12. Comparisons of competitive models across spatial scales for female Keen's myotis.

Spatial Scale	Variables	K	$QAIC_c$	$\Delta QAIC_c$ within scale	$\Delta QAIC_c$ between scales	w_i within scale	w_i between scales
Tree	Dbh, Defects, Bark, Slope-height	5	117.27	0	0	0.56	0.56
	Dbh, Defects, Bark	4	117.77	0.50	0.50	0.44	0.44
Landscape	Old growth, Stream, Road, Clearcut	5	135.90	0	18.63	0.72	0
	Old growth, Stream, Road	4	137.89	1.99	20.62	0.27	0
Tree plot	Female-PR, QMD	4	193.03	0	75.76	0.70	0

Table 3.13. Comparisons of competitive models across spatial scales for male Keen's myotis.

Spatial Scale	Variables	K	$QAIC_c$	$\Delta QAIC_c$ within scale	$\Delta QAIC_c$ between scales	w_i within scale	w_i between scales
Landscape	Stream, Road	3	68.45	0	0	0.32	0.43
	Stream, Road, Old growth	4	69.30	0.85	0.85	0.21	0.28
	Road	2	70.11	1.66	1.66	0.14	0.19
Tree	Dbh, Bark, Defects, Slope-height	4	70.41	0	1.96	0.57	0.10
Tree Plot	Male-PR	2	82.85	0	14.40	0.56	0

CHAPTER 4: GENERAL CONCLUSIONS

The purpose of this work was to provide a better understanding of distribution and habitat associations of bats in Southeast Alaska and to help wildlife and land managers develop monitoring protocols and management plans aimed at maintaining viable populations of bats in this region. Racey and Entwistle (2003) suggest four main topics need to be addressed before appropriate management plans and conservation efforts can be developed for bats:

1. current distribution and abundance;

2. ecological requirements essential to continued persistence;

3. identification of potential threats to population viability; and

4. approaches to avoid or mitigate for potential threats.

Our work substantially builds on information of earlier efforts of Parker et al. (1997) documenting distribution of bats in Southeast Alaska. Based on these efforts, it appears that little brown myotis are widely distributed throughout the region, Keen's and California myotis occur as far north as Juneau, long-legged myotis are found as far north as Admiralty Island, and silver-haired bats from Juneau to Prince of Wales Island. Each species appears to occur in low densities, but little brown myotis appears to be the most abundant species of bat in Southeast Alaska given capture success relative to other species. Although Keen's myotis appears to occur in very low densities, they may not be as rare as once thought and California myotis was captured with similar levels of success as Keen's myotis. Given exceptionally low rates of capture for long-legged myotis and no captures of silver-haired bats, they appear to be very rare in Southeast Alaska.

Southeast Alaska is a unique biome and techniques used to detect species of bats and general bat activity in more southern areas of the country were not always effective in Southeast

Alaska. Our capture survey was the first large-scale, intensive effort conducted in this region and much of what we learned regarding effective capture techniques for bats was learned through trial-and-error. There is still much to learn and more surveys should be conducted in northern areas of the region incorporating capture techniques we learned in the second year of our study on Prince of Wales Island. Our capture success for little brown myotis was highest when nets were set up over calm water sources with relatively low clutter and capture success was highest for Keen's, California, and long-legged myotis when flight corridors were completely blocked on all sides- this is most effectively accomplished in small stream and trail corridors.

Maintenance of conditions that provide the ecological requirements essential to persistence of bat populations is required for development of effective management plans and conservation efforts. Day-roost habitat is critical for bats and habitat associations for male and female Keen's myotis were starkly different. Female Keen's myotis primarily selected roosts in relatively tall, large-diameter trees and snags with structural abnormalities in stands with higher mean diameters and a high relative abundance of roost-like trees. Selection of roosts by female Keen's myotis were negatively associated with proportion of clearcut and positively associated with proportion of old-growth and abundance of riparian habitat. Roost trees of female Keen's myotis were closer to roads and streams relative to random points. In contrast, male Keen's myotis demonstrated a high degree of plasticity with the types of roosts they chose and when they roosted in trees it was in snags in early to intermediate stages of decay, but diameter of the tree was not strongly associated with selection. Male Keen's myotis selected roosts in trees where there was a high relative abundance of roost-like trees in the immediate vicinity. In the landscape, male Keen's myotis selected roosts that were closer to roads and further from riparian habitat.

Although we do not have conclusive evidence regarding the status of bat populations in Southeast Alaska, there are many biological and ecological factors that suggest population densities are low, which is supported by extremely low rates of capture. Keen's myotis, long-legged myotis, and silver-haired bats are primarily associated with forests for roosting and foraging. Determining the status and trends of bat populations in Southeast Alaska will require a commitment from wildlife and land management agencies to multiyear monitoring efforts using standardized protocols. In the meantime, clearcutting of forests is projected to continue at a rapid rate in many parts of the region and is especially high on Prince of Wales Island. If the goal of managers is to maintain viable populations of forest dwelling bats in Southeast Alaska we suggest prioritization of strategies aimed at mitigating the potentially detrimental effects of habitat loss. Mounting evidence suggests managing forests to maintain structural components characteristic of old-growth may ameliorate negative effects of deforestation on populations of forest-dwelling bats. Where timber harvest occurs, thinning of second growth forests may be an effective tool to manage for bat habitat because it creates low stem density and accelerates development of large-diameter trees (Hayes et al. 1997, Humes et al. 1999, Law and Chidel 2002, Hayes 2003, Erickson and West 2003). Retention of large-diameter trees and snags in various stages of decay, buffer zones on riparian areas, and appropriately long harvest rotations to allow development of vertical heterogeneity and recruitment of new roosts, are also highly recommended by researchers for mitigating negative impacts of forest management on bat populations (Campbell et al. 1996, Erickson and West 2003, Hayes 2003, Lloyd et al. 2006).

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