NIGHT ROOSTS OF BALD EAGLES (*Haliaeetus leucocephalus*) WINTERING IN NORTHERN ARIZONA

By Prabin K. Joshi

A Thesis

Submitted in Partial Fulfillment

of the Requirements for the Degree of

Master of Science

in Forestry

Northern Arizona University

December 2009

Approved:

____
Carol L. Chambers, Ph.D., Chair

____
Stephen M. Dewhurst, Ph.D.

____
Teryl G. Grubb, M.S.

ABSTRACT

NIGHT ROOSTS OF BALD EAGLES (*Haliaeetus leucocephalus*) WINTERING IN NORTHERN ARIZONA

PRABIN K. JOSHI

Bald eagles (*Haliaeetus leucocephalus*) were delisted from threatened or endangered status in 2007 in the conterminous states because of their encouraging comeback throughout most of North America. However the recent court decision on 1 May 2008 forced USFWS to issue a rule to amend the regulations for the Federal List of Endangered and Threatened Wildlife by designating bald eagles in the Sonoran Desert of central Arizona (also called the 'southwest population') as threatened under the authority of Endangered Species Act of 1973. The southwest population is believed to exist in an ecological setting that is unusual and unique among bald eagle populations. Although it is unknown if the southwest population differs markedly from other bald eagle populations in its genetic characteristics, morphological and behavioral differences suggest that genetic differences may exist. Bald eagles are still protected under the Migratory Bird Treaty and the Bald and Golden Eagle Protection Acts. Bald eagles are habitat generalists and opportunistic feeders (they typically take the easiest and most abundant prey regardless of class or whether live or dead), and roost in a single or group of trees in winter. A roost is an individual or group of trees where ≥1 bald eagle(s) perch overnight. We hypothesized that bald eagles selected night roosts during winter that provided physical safety (e.g., hiding cover), thermal protection, and close proximity to food sources. Our objective was to describe habitat characteristics of night roosts used by migratory bald eagles wintering in ponderosa pine (*Pinus ponderosa*) forests of northern Arizona. Bald eagles are not usually thought to be a migratory species but some populations migrate while other eagles stay on or near their breeding territories year-round. We considered habitat use at two scales: microhabitat (habitat characteristics within a 30-m diameter area centered at the roost tree measured on ground-based plots) and macrohabitat (habitat characteristics within a 90-m diameter plot centered at the roost tree based on spatial data layers from a geographic information system). Arizona Department of Emergency and Military Affairs and Arizona Game and Fish Department captured and fitted 10 bald eagles (≥3.70 kg, mean and standard error [SE]: 4.75 ± 0.22 kg; 7 adults, 1 subadult, and 2 juveniles) with 70-g, solar-charged satellite Platform Transmitter Terminals at Camp Navajo, Flagstaff, Arizona in 2005 and 2007. We measured microhabitat characteristics of 54 night roosts for 7 bald eagles (6 adults, 1 subadult; mean number of locations per eagle and SE: 8 ± 2) in ponderosa pine forests and ≥500 m apart (for spatial independence). We paired each roost site with a randomly-selected plot ≥500 m away. Random plots had to be in a ponderosa pine stand with at least one tree ≥20 cm diameter at breast height (dbh; large enough for eagles to perch overnight). To measure macrohabitat characteristics, we selected 200 night roosts (mean and SE: 25 ± 11 roosts per eagle; range: 7 to 43) for 8 bald eagles (6 adults, 1 subadult, 1 juvenile) that were located within ponderosa pine forests of northern Arizona. Spatial data layers we used were mapped by the Forest Ecosystem Restoration Analysis (ERA) project with a 90-m resolution raster dataset. We generated 200 random points within ponderosa pine stands ≥500-m apart for comparison points and measured the same characteristics as for night roosts. We developed 13 and 11 *a priori* models for microhabitat and macrohabitat use, respectively. We used Akaike's Information Criteria or Akaike's Information Criteria adjusted for small sample sizes to evaluate models describing night roosts. Models with $\Delta AIC_c \leq 2$ were considered the best approximating models. Microhabitat analyses showed that trees used as night roosts were larger dbh (roost: 75.2 ± 2.2 cm, random: 58.2 ± 1.5), on steeper slopes (roost: 12.4 ± 2.2 percent, random: 6.6 ± 1.1) and surrounded by greater basal area (roost: 19.7 ± 8.0 m^2/ha, random: 17.7 ± 7.8), higher densities of large trees (roost: 61.9 ± 4.8 trees/ha, random: 39.6 ± 4.5) and lower densities of small trees (roost: 137.3 ± 17.4 trees/ha, random: 158 ± 24.0) than comparable characteristics of randomly-selected sites. Mean dbh for trees in the plot was larger (61.9 ± 4.8 cm) than for random plots (39.6 ± 4.5 cm). Roost plots were more likely to face east (67%) than west (33%). The global model best predicted use of a roost by bald eagles ($w_i = 0.998$); other models performed poorly in comparison ($\Delta AIC_c \geq 12.34$). Most (94%) of the large trees in roost plots were co-dominant or dominant and had ≥50% live crown ratio (91%). We used a post-hoc analysis to find a more parsimonious model to describe night roost characteristics. The top 3 models ($\Delta AIC_c \leq 3.94$) that best predicted use of a roost by eagles included dbh of the largest tree in each plot, density of large trees, density of small trees, slope, eastness (*Sin* [aspect in degrees] transformed aspect using trigonometric function), tree size variability, and number of trees with live crown ratios ≥75%. At the macrohabitat scale, eagles used roosts that were closer to highways and interstates and farther from lakes than randomly-selected points. Since highways and interstates are believed to provide major sources of food (e.g., road-killed mammals) for bald eagles during winter, eagle roosts appeared to be located in close proximity to food sources. Eagles selected north-facing roosts which may offer protection from southwest winds. Twelve hotspots for bald eagles (used by ≥1 eagle ≥5 times) were identified. Hotspots used by multiple eagles were on generally northeast-facing, on greater slopes and closer to lakes, highways, and interstates. Location and structure of night roosts seemed to provide physical safety, better thermal cover, and sources of food to bald eagles wintering in northern Arizona.

ACKNOWLEDGEMENTS

I am deeply indebted to my supervisor professor Dr. Carol Chambers from the Northern Arizona University, whose help, motivating suggestions and encouragement helped me all the time from writing proposal of this project, doing research on ground to the completion of this thesis.

I would like to express my gratitude to Bill Noble, Forest Biologist of Kaibab National Forest, for his incredible help to initiate this project, without which, I could not have written this thesis.

I would like to thank my committee members, Steve Dewhurst and Teryl Grubb, for their constructive suggestions and analytical thoughts on my research work.

I would like to thank Eric Osborn and Sean Rudzitis for their tireless help to complete the research work on ground.

I would like to thank Arizona Department of Emergency and Military Affairs, USDI Fish and Wildlife Service, Arizona Game and Fish Department, USDA Forest Service, School of Mission Research Funding and Northern Arizona University for their financial support throughout my research and study periods.

I would also like to thank my family specially my brother Nabin Joshi, who have always supported me to move forward and build my career.

Finally, I would like to express my gratitude to all those who gave me the possibility to complete this thesis. Last but not least, I thank my wife Sudha Joshi for her ceaseless and continuous support to achieve my each and every goals and giving me a push whenever I needed a push.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

PREFACE

Chapter 2 of this thesis is formatted for submission to the *Journal of Wildlife Management*. Format differences in Chapter 2 are due to the requirements of the Journal.

CHAPTER 1

LITERATURE REVIEW

Introduction

Bald eagles (*Haliaeetus leucocephalus*) became the national emblem of the United States of America (USA) in the 1780s. Its likeness on the country's official seal and coins became popular and inspiring for Americans of succeeding generations. The scientific name for this species literally means white-headed sea eagle. Other names given to bald eagles were American eagle, Alaska eagle, black eagle, white-headed eagle, bird-o-freedom, and sea eagle. The bald eagle is a bird of the North American continent; its range is from northwestern Alaska eastward through northern Canada and southward across the continent into lower California, Arizona, New Mexico, and the Gulf of Mexico states (Stalmaster 1987).

The bald eagle historically occurred throughout the United States and Alaska. After populations severely declined in the lower contiguous states between the 1870s and 1970s, the bald eagle was listed as an endangered species under Endangered Species Protection Act (ESA) of 1973 in the lower 48 states except in Michigan, Minnesota, Oregon, Washington, and Wisconsin, where it was designated as threatened. In 1995, the bald eagle was downlisted to threatened in all 48 lower States. The bald eagle was delisted from threatened status on 28 June 2007 (United States Fish and Wildlife Service 2007a). Its primary legal protection was transferred from ESA to the Bald and Golden Eagle Protection Act. Further guidance was also finalized under the National Bald Eagle Management Guidelines on 28 June 2007 for eagle management and for preventing negative impacts that violate the Bald and Golden Eagle Protection Act (United States Fish and Wildlife Service 2007b). However the recent court decision on 1 May 2008 forced United States Fish and Wildlife Service (USFWS) to issue a rule to amend the regulations for the Federal List of Endangered and Threatened Wildlife by designating bald eagles in the Sonoran Desert of central Arizona (also called the 'southwest population') as threatened under the authority of ESA of 1973, as amended (Federal Register 2008). The southwest population is believed to exist in an ecological niche that is unusual and unique among bald eagle populations. Though it is unknown if the southwest population differs markedly from other bald eagle populations in its genetic characteristics, morphological and behavioral differences suggest that genetic differences may exist (Hunt et al. 1992). Currently, the United States Forest Service (USFS) has also listed the bald eagle as a sensitive species in southwest region of the United States (United States Forest Service 2008). Although bald eagles have made an encouraging comeback throughout the USA (Chester et al. 1990), they continue to be harassed, injured and killed by guns, traps, power lines, windmills and destruction of habitat (Hunt et al. 1992).

Bald eagles are habitat generalists that use many forest types, structural conditions, and succession stages (Stalmaster 1987) and they are also opportunistic feeders that eat fish, waterfowl, small mammals, turtles, and carrion (Grubb and Lopez 2000). Wintering bald eagles often congregate in large numbers along streams and lakes to feed on spawning fish as well as carcasses along roads, in landfills, and at feedlots (Hunt et al. 1992).

Surveys of wintering eagles in Arizona began in the late 1970s and were conducted by private, state, and federal organizations (Grubb and Kennedy 1982). Counts of bald eagles generally increase during fall (October, November) and winter (December, January) in northern Arizona, where adults outnumber immature birds from late fall through early winter and immatures occur in greater numbers from mid-winter until spring (March, April) departure (Grubb 2003). In recent years, winter populations of bald eagles in Arizona have slowly been growing (Driscoll et al. 2006).

A roost is an individual or group of trees where one or more bald eagles perch overnight (Grubb et al. 1989). In winter, bald eagles use sheltered roosts during severe weather (Steenhof et al. 1980).Winter aggregations and use of communal roosts (use of a night roost by ≥2 bald eagles; Grubb 2003) vary with weather conditions and prey availability. Grubb (2003) found maximum roost counts of 2 to 8 eagles scattered among 11 roosts in prior years increased to counts of 33 to 45 eagles regularly using 2 roosts during 1996 and 1997 in northern Arizona.

Physical appearance

The white head and dark brown body of the mature bald eagle clearly distinguishes it from the dark-headed golden eagle and most other birds of prey, except for the osprey (*Pandionidae haliaetus*), which has a black-marked white head but is smaller bodied. The adult bald eagle generally weighs over 5 kg with a wing span of 200-235 cm and a body length of 84-95 cm. It does not develop its white head and tail until 3 or 4 years of age, so an immature bald eagle can easily be mistaken for a golden eagle (Stalmaster 1987). As is characteristic of many birds of prey, the female bald eagle is larger than the male (Brown

1976). The bald eagle's subadult plumage is one of the most varied of all North American birds. A one-year-old bald eagle looks similar to a golden eagle. Flight feathers are typically black, while the outer wing coverts, breasts, leg, and head feathers tend to be brown. During their second year, belly feathers lighten, sometimes appearing completely white. During the third year, the brown eye and gray beak turn creamy and yellow respectively. The crown of the head also lightens, giving the bald eagle an eye stripe similar to an osprey. At four years of age, bald eagles retain their eye stripe, but the rest of the head turns white, the eye cream, and the beak yellow. The tail will also change to white, except for brown mottling near the base and tip. The wings, breast, and belly become brown (Stalmaster 1987). Some bald eagles in Arizona have retained the eye stripe and brown mottling on the crown of the head and tail into their seventh year (Southwestern Bald Eagle Management Committee 2009). Though bald and golden eagles have different breeding habitat in other parts of United States, they breed in the same habitat and build nests in the same types of trees or cliffs in Arizona (Grubb and Eakle 1987).

Foraging

The diet of the bald eagle is varied, but being a sea eagle, fish is the chief source of food over most of its range. Along the coasts of Alaska and Canada, eagles gather to feed on salmon (*Oncorhynchus* spp.) and herring (*Clupea* spp.) as they move upstream to spawn (Knight and Knight 1983). However, they are opportunistic feeders, so they regularly feed on other types of prey than fish. They typically take the easiest and most abundant prey regardless of class or whether live or dead such as waterfowl, sea birds, grebes

(*Podicipedidae*), loons (*Gavia* spp.), grouse (*Tetraoninae*), muskrats (*Ondatra* spp.), squirrels (*Sciuridae*), rabbits (*Lagomorpha*), and rats (*Rattus* spp; Lang et al. 1999, Grubb and Lopez 2000) as well as carcasses and road-killed deer (*Odocoileus* spp.), cows (*Bos taurus*), and moose (*Alces alces*; Ewins and Andress 1995). As available food decreases, eagles spend more time aerially searching for food, and they use the presence of other eagles as cues in locating food, as a bald eagle standing on the river is more easily visible than salmon carcasses (Knight and Knight 1983). Bald eagles select large fish during the breeding season as opposed to the non-breeding season and they discriminate between large and small prey items based on increased energetic requirements of the breeding season (Jenkins and Jackman 1994). Bald eagles also kleptoparasitize other birds (e.g., osprey; Fischer 1985) and mammals (e.g., sea otter [*Enhydra lutris*]; Watt et al. 1995).

Migration

Bald eagles are not usually thought to be a migratory species but some populations migrate while other eagles stay on or near their breeding territories year-round (Stalmaster 1987). The abundance of food plays a vital role in whether eagles migrate. When lakes and rivers of the north freeze, fishing is difficult and most waterfowl migrate south. Eagles are left with a scant food base and they migrate south in fall (Harmata 2002). They may find food and stay near a large food supply or wander in search of food throughout the winter (Grubb and Kennedy 1982). Juvenile eagles migrate longer distances, travel farther south, and move in a more random pattern than adults (Stalmaster et al. 1979). The timing of migratory flights depends on the age of the eagle. Young eagles move south earlier in fall than older eagles in the Midwest and the Rocky

Mountain Region (McClelland et al. 1981). Eagles migrate during the day, mostly alone, with an average speed of 50 km/hr for daily flights of 150 to 200 km (Laycock 1973).

Migration patterns can be determined by four methods: 1) compiling information from returned bands that were attached to the eagles' legs at an earlier time, 2) resighting eagles that were fitted with color markers, usually on the wings or legs, 3) following birds equipped with radio transmitters, and 4) locating geographic coordinates transmitted from birds equipped with Global Positioning System (GPS) transmitters. Broley (1947) and Linthicum et al. (2007) studied bald eagle migration by banding eagles in Florida and fitting GPS transmitters in California, respectively. Both reported their eagles were found over 2,000 km north in Canada. Similarly, one Arizona eagle began its northward, spring migration with flights of 410 km within two days, and continuously 3,032 km in 37 days, essentially following the Rocky Mountains to north of Great Slave Lake in the Northwest Territories, Canada (Grubb et al. 1994).

Day Perches

Bald eagles spend over 90% of daylight hours perching in both summer and winter (Stalmaster and Gessaman 1984); however, eagles are more flexible in selecting perch locations than in choosing night roosts (Gerrard et al. 1980). Eagles usually perch close to water because fish, waterfowl, seabirds, and other prey can be acquired (Buehler 1992). If there is a nest, eagles perch near the nest tree where the nest is visible and usually in the closest tall tree, often a snag (Andrew and Mosher 1982, Caton et al. 1992). Perches may serve eagles in several ways such as viewing hunting grounds, sheltering against harsh weather, and guarding their territory, nest, and offspring (Steenhof et al. 1980).

Although eagles choose different species of perch trees (e.g., cottonwood [*Populus* spp.], maples [*Acer* spp.], conifers), snags of any tree species are typically favored. Additionally, bald eagles perch on rocks, cliffs, logs, pilings, driftwood, ice, gravel and mud bars, hay stacks, poles, beaches, fence posts, and even power houses; natural perches are preferred (Dargan 1991, Buehler 1992, Caton et al. 1992). Bald eagles in Arizona selected snags as perch trees over living trees (Grubb and Kennedy 1982). Usually eagles choose the largest trees with suitable branches. For example, at a lake in the Coconino National Forest with 15 juniper (*Juniperus* spp.) snags and 1 large ponderosa pine (*Pinus ponderosa*) snag, the ponderosa snag was used more frequently by more eagles than any of the other small trees. Perching eagles in the southwest tended to be in the upper third of perch trees and often used the highest branches. However, bald eagles also occasionally perch on rocks along a ridge or on the ice of a frozen lake. Thus relative height of the perch varied with the type of perch or its substrate, surrounding vegetation, and topography (Grubb and Kennedy 1982).

Night Roosts Characteristics

A roost is an area where eagles rest and sleep during the night; it can consist of one tree or hundreds of trees in a large area (Stalmaster 1987). Selection of a roost tree depends on which tree species are available and their structural characteristics. Roosts are not as easily identified or located for resource managers as perch sites. Grubb and Kennedy (1982) found night roosts in ponderosa pine stands from several hundred meters to several hundred kilometers from water resources associated with daytime activities. Occasionally, bald eagles were observed remaining in day perches overnight. On several occasions birds from widely separated daytime locations flew in directions at sunset that would indicate a common roost. Most of those communal roosts identified were in protected sites such as small canyons or draws. The majority of roost trees were living and well foliated but with large windows in the canopy (Grubb and Kennedy 1982). Most of the roosts in north-central Arizona identified by Grubb et al. (1989) were clustered in the vicinities of Lake Mary, Mormon Lake, and Apache Maid Mountain. Bald eagles exhibited a preferential habitat selection, with individual repetitive use of some common roosts, but rarely with other individual eagles simultaneously. Preferred roosts were on steep slopes, which were naturally layered above one another, thereby providing a downslope view and easy flight access. Eagles selected stout lateral branches that they could easily grasp with their feet. Protection from wind might be the most important feature of roost microclimate, resulting in winter roosts in depressions, in steep-sided valleys, or on slopes in the lee of prevailing winds (Keister and Anthony 1983, Stohlgren 1993).

Winter ecology

The annual cycle of the bald eagle can be divided into two periods: first, spring and summer when the adults are engaged in breeding activities and juveniles are growing and learning; and second, winter when the life of the eagle changes dramatically with a sudden scarcity of food caused by icing of lakes and migration of waterfowl. Communal night roosting is one of the most important phenomena of wintering eagles. A communal roost is an area where a group of eagles spend the night in close proximity, which can consist of as few as two eagles in one tree to more than 500 in a large stand of trees

(Stalmaster 1987). The extent of winter communal roosting and local movement within the roost varies with weather conditions and prey availability. Eagles tend to congregate in areas of abundant prey and sheltered habitat (Steenhof et al. 1980). Knight and Knight (1983) reported that departures from roosts usually averaged 30 min before sunrise and arrival occurred from several hours before sunset to 30 min afterward, but averaged about 30 min before sunset. A few individuals might travel back and forth between the roost and foraging areas throughout the day.

Besides communal roosting, bald eagles also are group feeders in winter. Overwintering populations locate food in two ways. First, many eagles wander over a large area, enabling more birds to search for prey. Second, once they find food, eagles attract others to it. Eagles congregate near abundant prey not just because there is plenty of food, but also because the presence of other eagles signals that food is available, which enhances the ability of the entire population to exploit their prey (Stalmaster and Gessaman 1984, Bennetts and McClelland 1997). There may be several benefits for roosting in groups such as sharing information on food locations, discouraging attacks by predators, finding mates or pairing (especially in the late winter just prior to the breeding season), and providing a particular type of shelter (Hansen et al. 1980).

Satellite telemetry

Satellite telemetry for tracking wildlife has been used since 1970. It was previously used only on large mammals because of larger transmitter sizes, but reduction in sizes of transmitters has allowed use on several small mammalian and avian species (Grubb et al. 1994, Oort and Daan 1999, Meyburg et al. 2005). Satellite telemetry currently uses the

Argos Data Collection and Location System which is a cooperative international project of the Center National d'Etudes Spatiales of France, the National Oceanic and Atmospheric Administration (NOAA), and the National Aeronautics and Space Administration (NASA).

To initiate this bald eagle project, Arizona Department of Emergency and Military Affairs (DEMA) and Arizona Game and Fish Department (AGFD) used platform transmitter terminals (PTTs) attached as backpacks on bald eagles with teflon ribbon and sewn together with biodegradable cotton thread. The PTTs used for bald eagles weighed 70 g and the lifespan based on timer setup as well as battery power (Grubb et al. 1994, Linthicum et al. 2007). Locations of the PTT-tagged eagles are estimated from the Doppler shift in its carrier frequency and downloaded to a computer. For normal processing Argos requires four transmissions to calculate locations, but special processing for wildlife research estimates locations from as few as two Doppler measurements. Argos grades locations according to precision (e.g., 85% of a series of locations expected within the given distance; Harris et al. 1990).

Study Objectives

This was a joint study with DEMA and AGFD. They fitted 10 bald eagles with PTTs in northern Arizona and collected 2 night locations for each bird every day for 1 to 25 months. This large sample size relative to previous work provided us an opportunity to describe night roosts. With the help of satellite telemetry data provided by DEMA and AGFD, we analyzed night roost characteristics of bald eagles in northern Arizona. Chapter 2 describes and models habitat characteristics of night roosts used by bald eagles wintering in ponderosa pine forests of northern Arizona. Roosts were described at two spatial scales, microhabitat (habitat characteristics within a 30-m diameter area centered at the roost tree and measured on ground-based plots) and macrohabitat (habitat characteristics within a 90-m diameter plot centered at the roost tree based on spatial data layers from a geographic information system).

LITERATURE CITED

Andrew, J. M., and J. A. Mosher. 1982. Bald eagle nest site selection and nesting habitat in Maryland. Journal of Wildlife Management 46:382-390.

Bennetts, R. E., and B. R. McClelland. 1997. Influence of age and prey availability on bald eagle foraging behavior at Glacier National Park, Montana. Wilson Bulletin 109:393-409.

Broley, C. L. 1947. Migration and nesting of Florida bald eagles. Wilson Bulletin 59:3-20.

Brown, L. 1976. Birds of prey: their biology and ecology. A & W Publishers, Inc. New York, USA.

Buehler, D. A. 1992. Nonbreeding bald eagle perch habitat on the northern Chesapeake Bay. Wilson Bulletin 104:540-545.

Caton, E. L., B. R. McClelland, D. A. Patterson, and R. E. Yates. 1992. Characteristics of foraging perches used by breeding bald eagles in Montana. Wilson Bulletin 104:136-142.

Chester, D. N., D. F. Stauffer, T. J. Smith, D. R. Luukkonen, and J. D. Fraser. 1990. Habitat use by nonbreeding bald eagles in North Carolina. Journal of Wildlife Management 54:223-234.

Dargan, C. M. 1991. Roost site characteristics of bald eagles wintering in north-central Arizona. Thesis, Northern Arizona University, Flagstaff, USA.

Driscoll, J. T., K. V. Jacobson, G. Beatty, J. S. Canaca, and J. G. Koloszar. 2006. Conservation assessment and strategy for the bald eagle in Arizona. Arizona

Game and Fish Department, Nongame and Endangered Wildlife Program, Phoenix, USA.

Ewins, P. J., and R. A. Andress. 1995. The diet of bald eagle wintering in the lower Great Lakes Basin, 1987-1995. Canadian Field-Naturalist 109:418-425.

Federal Register. 2008. Endangered threatened wildlife and plants; initiation of status review for the bald eagle in the Sonoran Desert area of Central Arizona and Northwestern Mexico. <http://www.fws.gov/southwest/es/arizona/Documents/SpeciesDocs/BaldEagle/FR_StatusReview.pdf>. Accessed 21 Feb 2009.

Fischer, D. L. 1985. Piracy behavior of wintering bald eagles. The Condor 87:246-251.

Gerrard, J. M., P. N. Gerrard, and D. W. A. Whitfield. 1980. Behavior in a non-breeding bald eagle. Canadian Field-Naturalist 94:391-397.

Grubb, T.G. 2003. Wintering bald eagle trends in northern Arizona, 1975-2000. The Southwestern Naturalist 48:223-230.

Grubb, T. G. and C. E. Kennedy. 1982. Bald eagle winter habitat on southwestern national forests. United States Department of Agriculture, Forest Service, General Technical Report RM 237:1-13.

Grubb, T. G. and R. G. Lopez. 2000. Food habits of bald eagles wintering in northern Arizona. Journal of Raptor Research 34:287-292.

Grubb, T. G. and W. L. Eakle. 1987. Comparative morphology of bald eagle and golden eagle nests in Arizona. Journal of Wildlife Management 51:744-748.

Grubb, T. G., S. J. Nagiller, W. L. Eakle, and G. A. Goodwin. 1989. Winter roosting patterns of bald eagles *(Haliaeetus leucocephalus)* in north-central Arizona. The Southwestern Naturalist 34:453-459.

Grubb, T. G., W. W. Bowerman, and P. H. Howey. 1994. Tracking local and seasonal movement of wintering bald eagles from Arizona and Michigan with satellite telemetry. Pages 347-358 *in* Proceedings of the IV World Conference on Birds of Prey and Owls. B. U. Meyburg and R. D. Chancellor, technical coordinator. Raptor Conservation Today, London, England.

Hansen, A. J., M. V. Stalmaster, and J. R. Newman. 1980. Habitat characteristics, function, and destruction of bald eagle communal roosts in western Washington. Pages 221-229 *in* Proceedings of the Washington bald eagle symposium. R. L. Knight, G. T. Allen, M. V. Stalmaster, and C. W. Servheen, technical coordinators. The Nature Conservancy, Seattle, WA, USA.

Harmata, A. R. 2002. Vernal migration of bald eagles from a southern Colorado wintering area. Journal of Raptor Research 36:256-264.

Harris, R. B., S. G. Fancy, D. C. Douglas, G. W. Garner, S. C. Amstrup, T. R. McCabe, and L. F. Pank. 1990. Tracking wildlife by satellite: current systems and performance. United States Department of the Interior. Fish and Wildlife Service Technical Report 30, Washington, D.C., USA.

Hunt, W. G., D. E. Driscoll, E. W. Bianchi, and R. E. Jackson. 1992. Ecology of bald eagles in Arizona. Report to U.S. Bureau of Reclamation, Contract 6-CS-30-04470. Biosystems Analysis, Inc., Santa Cruz, CA, USA.

Jenkins, J. M., and R. E. Jackman. 1994. Field experiments in prey selection by resident bald eagles in the breeding and non-breeding season. Journal of Field Ornithology 65:441-446.

Keister, G. P. Jr. and R. G. Anthony. 1983. Characteristics of bald eagle communal roosts in the Klamath Basin, Oregon and California. Journal of Wildlife Management 47:1072-1079.

Knight, S. K. and R. L. Knight. 1983. Aspects of food finding by wintering bald eagles. The Auk 100:477-484.

Lang, A. L., R. A. Andress, and P. A. Martin. 1999. Prey remains in bald eagle pellets from a winter roost in the upper St. Lawrence River, 1996 and 1997. Canadian Field-Naturalist 113:621-626.

Laycock, G. 1973. Autumn of the eagle: the American bald eagle's noble past and threatened future. Scribner, New York, USA.

Linthicum, J., R. E. Jackman, and B. C. Latta. 2007. Annual migrations of bald eagles to and from California. Journal of Raptor Research 41:106-112.

McClelland, B. R., L. S. Young, D. S. Shea, P. T. McClelland, H. L. Allen, and E. B. Spettigue. 1981. The bald eagle concentration in Glacier National Park, Montana: Origin, growth, and variation in numbers. Living Bird 21:133-155.

Meyburg, B. U., C. Meyburg, T. Mizera, and G. Maciorowski. 2005. Family break up, departure, and autumn migration in Europe of a family of greater spotted eagles (*Aquila clanga*) as reported by satellite telemetry. Journal of Raptor Research 39:462-466.

Oort, B. E and S. Daan. 1999. Natural entrainment without dawn and dusk: The case of the European ground squirrel (*Spermophilus citellus*). Journal of Biological Rhythms 14:290-299.

Stalmaster, M. V. 1987. The bald eagle. University Books, New York, USA.

Stalmaster, M. V., and J. A. Gessaman. 1984. Ecological energetic and foraging behavior of overwintering bald eagles. Ecological Monographs 54:407-428.

Stalmaster, M. V., J. R. Newman, and A. J. Hansen. 1979. Population dynamics of wintering bald eagles on the Nooksack River, Washington. Northwest Science 53:126-131.

Steenhof, K., S. S. Berlinger, and L. H. Fredrickson. 1980. Habitat use by wintering bald eagles in South Dakota. Journal of Wildlife Management 44:798-805.

Stohlgren, T. J. 1993. Bald eagle winter roost characteristics of Lava Beds National Monument, California. Northwest Science 67:44-54.

Southwestern Bald Eagle Management Committee. 2009. Southwestern Bald Eagle Management Committee homepage. <http://www.swbemc.org>. Accessed 21 Jun 2009.

United States Fish and Wildlife Service. 2007a. Endangered and threatened wildlife and plants; removing the bald eagle in the lower 48 states from the list of endangered and threatened wildlife. <http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=2007_register&docid=fr09jy07-6>. Accessed 16 Oct 2009.

United States Fish and Wildlife Service. 2007b. Draft post-delisting monitoring plan for the bald eagle.

<http://www.fws.gov/midwest/eagle/protect/DraftBAEAPDM.pdf>. Accessed 10 Oct 2008.

United States Forest Service. 2008. The Rocky Mountain Region (Region 2) Forester's sensitive species list. <http://www.fs.fed.us/r2/projects/scp/sensitivespecies/index.shtml>. Accessed 28 Oct 2008.

Watt, J., B. Krausse, and T. M. Tinker. 1995. Bald eagles kleptoparasitizing sea otters at Amchitka Island, Alaska. The Condor 97:588-590.

CHAPTER 2

NIGHT ROOSTS OF BALD EAGLES (*Haliaeetus leucocephalus*) WINTERING IN NORTHERN ARIZONA

ABSTRACT

Since the southwest population of bald eagles (*Haliaeetus leucocephalus*) has unique and unusual ecological characteristics and was recently retained as a threatened species, managing the winter roost habitats in Arizona has great value. Bald eagles are still protected by United States law and determining adequate winter roosting structures is important for maintaining their habitat. We hypothesized that bald eagles selected night roosts during winter that provided physical safety (e.g., hiding cover), thermal cover, and close proximity to food sources. Our objective was to describe characteristics of night roosts used by bald eagles wintering in ponderosa pine (*Pinus ponderosa*) forests of northern Arizona. We considered habitat use at two scales: microhabitat (habitat characteristics within a 30-m diameter area centered at the roost tree measured on ground-based plots) and macrohabitat (habitat characteristics within a 90-m diameter plot centered at the roost tree based on spatial data layers from a geographic information system [GIS]). Department of Emergency and Military Affairs (DEMA) and Arizona Game and Fish Department (AGFD) captured and fitted 10 bald eagles (7 adults, 1 subadult, and 2 juveniles) with satellite radio transmitters which recorded 2 locations (taken at 2000 and 2300 Mountain Standard Time) per eagle per night. We obtained 636 night roost locations. We selected for analysis only night roost locations that had Euclidean distances (straight-line distances between the pair of points collected each

night for each eagle) of 0 (n = 279). The remainder had Euclidean distances of 1 to >100 m and were not used in analysis (i.e., we assumed pairs of night locations with Euclidean distances of 0 to be the most accurate). We measured microhabitat characteristics (e.g., slope, aspect, dbh, and height of trees) for 54 night roosts locations for adult bald eagles and compared habitat characteristics of roost sites to 54 randomly-selected sites. To measure macrohabitat characteristics, we selected 200 night roosts for 8 bald eagles (6 adults, 1 subadult, and 1 juvenile) that were located within ponderosa pine forests of northern Arizona. We used 200 random points for comparison and measured habitat characteristics such as slope, aspect, and distance to highways and lakes from roost sites. We developed 13 and 11 *a priori* models for microhabitat and macrohabitat use, respectively. We used Akaike's Information Criteria or Akaike's Information Criteria adjusted for small sample sizes to evaluate models describing night roosts. At the microhabitat scale, roost trees were larger diameter (roost: 75.2 ± 2.2 cm, random: 58.2 ± 1.5), on steeper slopes (roost: 12.4 ± 2.2 percent, random: 6.6 ± 1.1) and surrounded by greater basal area (roost: 19.7 ± 8.0 m^2/ha, random: 17.7 ± 7.8), and higher densities of large trees (roost: 61.9 ± 4.8 trees/ha, random: 39.6 ± 4.5) with lower densities of small trees (roost: 137.3 ± 17.4 trees/ha, random: 158 ± 24.0) than the comparable characteristics of randomly-selected sites. Mean diameter at breast height (dbh) for trees in roost plots (61.9 ± 4.8 cm) was also larger than random plots (39.6 ± 4.5 cm). Roost plots were more likely to face east (67%) than west (33%). Most of the large trees in roost plots were co-dominant or dominant (94%) and had ≥50% live crown ratio (91%). Using a post-hoc analysis, we found a more parsimonious model to describe characteristics of night roost that included diameter of largest tree, density of large trees,

density of small trees, slope, eastness (*Sin* [aspect in degrees] transformed aspect using trigonometric function), variability in tree size, and number of trees with live crown ratio ≥75%. At the macrohabitat scale, eagles used roosts that were closer to highways (roost: 8.4 ± 0.4 km, random: 10.3 ± 0.5) and interstates (roost: 3.9 ± 0.2 km, random: 29.1 ± 1.6) and farther from lakes (roost: 10.3 ± 0.3 km, random: 6.3 ± 0.3) than randomly-selected points. Since highways and interstates are believed to provide major sources of food (e.g., road-killed mammals) for bald eagles during winter, this could indicate that eagle roosts were located in close proximity to food sources. Eagles selected north-facing roosts. North-facing roosts may offer protective roosts to bald eagles by blocking wind at night. Eagles using northeast-facing roosts may receive a thermal benefit at sunrise and early morning. The location and structure of night roosts seemed to provide physical safety, thermal cover, and be close to potential sources of food for bald eagles wintering in northern Arizona.

KEY WORDS Bald eagle, *Haliaeetus leucocephalus*, night roosts, *Pinus ponderosa*, ponderosa pine, winter roosts, winter habitat

INTRODUCTION

Bald eagles (*Haliaeetus leucocephalus*) were delisted from threatened or endangered status in 2007 in the conterminous states (United States Fish and Wildlife Service [USFWS] 2007a) because of their encouraging comeback throughout most of North America (Chester et al. 1990, USFWS 2008). However the recent court decision on 1 May 2008 forced USFWS to issue a rule to amend the regulations for the Federal List of

Endangered and Threatened Wildlife by designating bald eagles in the Sonoran Desert of central Arizona (also called the ‘southwest population’) as threatened under the authority of Endangered Species Act of 1973 (Federal Register 2008). The southwest population is believed to exist in an ecological setting that is unusual and unique among bald eagle populations. Although it is unknown if the southwest population differs markedly from other bald eagle populations in its genetic characteristics, morphological and behavioral differences suggest that genetic differences may exist (Hunt et al. 1992). Bald eagles are also protected under the Migratory Bird Treaty and the Bald and Golden Eagle Protection Acts. Further, the USFWS (2007b) recommended that states should regularly monitor bald eagles for at least 5 yrs after delisting. In the southwestern region of the United States, the bald eagle has also been designated a sensitive species by the United States Forest Service (USFS; USFS 2008).

Arizona supports a substantial wintering population of bald eagles, with an average of 5.5 sightings per day during a 20-yr period of winter from 1975 to 2000 (Grubb and Kennedy 1982, Grubb 2003). Bald eagles that winter in northern Arizona are primarily migratory individuals with breeding grounds in Canada and the northern United States (Young 1983), although there are some resident birds that are present year-round. Migratory eagles arrive in October and leave in April with adults more common in fall and immature birds more abundant in January through April (Grubb 2003).

Bald eagles are habitat generalists and use many forest types, structural conditions, and successional stages (Stalmaster 1987, Garrett et al. 1993, Dellasala et al. 1998). They are opportunistic feeders of fish, waterfowl, small mammals, and occasionally reptiles and amphibians. They also feed on fish and mammal carrion where abundant and readily available (Hunt et al. 1992, Grubb and Lopez 2000). Bald eagles typically congregate in large numbers along streams and lakes to feed (Stohlgren 1993, Isaacs et al. 1996, Thompson et al. 2005).

Bald eagles use roosts that offer protection from severe weather (Steenhof et al. 1980, Keister et al. 1985, Buehler et al. 1991a, Buehler et al. 1991b); roosts are often close to food sources (Steenhof et al. 1980, Grubb et al. 1989, Stohlgren 1993). Roost trees are usually larger diameter at breast height (dbh), taller, and with more open branching compared with surrounding available trees (Keister and Anthony 1983, Buehler et al. 1991b, Stohlgren 1993, Dellasala et al. 1998). In contrast to their territorial behavior during the breeding season, bald eagles may roost communally at night in winter. Winter roosts consist of a single or group of trees where ≥1 bald eagle(s) might perch overnight. Some roosts used year after year by one or multiple eagles may be considered hotspots for bald eagles (Stalmaster 1987). In Arizona, large ponderosa pines (*Pinus ponderosa*) are commonly used for roosting by immature bald eagles (Grubb et al. 1989).

We hypothesized that the structure of night roosts provided more physical safety (e.g., hiding cover), better thermal cover, and were in closer proximity to food sources than randomly-available habitat for wintering bald eagles. Our objective was to describe habitat characteristics of night roosts used by bald eagles wintering in ponderosa pine forests of northern Arizona. We considered habitat use at two scales: microhabitat (habitat characteristics within a 30-m diameter area centered at the roost tree measured on ground-based plots) and macrohabitat (habitat characteristics within a 90-m diameter plot centered at the roost tree based on spatial data layers from a geographic information system [GIS]). We predicted bald eagles would select roosts that were large and sheltered (e.g., with dense crowns) and were within close proximity to food sources as represented by lakes (waterfowl, fish) and highways and interstates (access to carrion; Grubb and Lopez 2000).

STUDY AREA

We measured habitat characteristics of roosts on the Coconino and Kaibab National Forests and Department of Defense Camp Navajo Army National Guard Base (Camp Navajo). Study sites ranged in elevation from 1,981 to 2,694 m. The study area was comprised of nearly pure stands (≥80%) of ponderosa pine (Lowe 1980, Chronic 1983), however at lower elevations Gambel oak (*Quercus gambelii*) and New Mexico locust (*Robina neomexicana*) occurred. Common associates at higher elevations were southwestern white pine (*Pinus strobiformis*), Rocky Mountain Douglas-fir (*Pseudotsuga menziesii*), Rocky Mountain white fir (*Abies concolor*), and quaking aspen (*Populus tremuloides*). Annual precipitation ranged from 45 to 66 cm, with dry springs, summer monsoon rains, and occasional winter snows. Temperature averaged -3.0 ºC in January and 17.2 ºC in July (Lowe 1980, Western Regional Climate Center 2008). There were many lakes formed in shallow depressions surrounded by mountainous, forested terrain (Grubb and Lopez 2000).

METHODS

Night Roost Locations

Arizona Department of Emergency and Military Affairs (DEMA) and Arizona Game and Fish Department (AGFD) jointly captured 10 bald eagles (7 adults [≥5 yrs old], 1 subadult [>2 to <5 yrs], and 2 juveniles [≤2 years of age]; Appendix 1) and fitted them with 70-g, solar-charged satellite Platform Transmitter Terminals (PTTs; Microwave Telemetry, Inc., Columbia, Maryland) at Camp Navajo. Six bald eagles (4 adults, 1 subadult, and 1 juvenile) were captured in Jan or Feb 2005 and 4 (3 adults and 1 juvenile) in Feb or Mar 2007. Transmitters were attached backpack-style using Teflon-coated nylon straps joined together over the sternum with 3 stitches of cotton embroidery thread. Transmitter weight was ≤3% of the eagles' body mass (Kenward 2001). Tagged eagles were tracked for 1 (2007 captures) to 25 months (2005 captures; mean and SE: 22 months ± 1) using the Argos satellite system.

Geographic coordinates were taken daily at 0800, 1100, 1400, 1700, 2000, and 2300 (Mountain Standard Time). Although 9 eagles traveled from Arizona to the northern United States (Montana, Idaho, Wyoming) and Canada (Alberta, Saskatchewan, Manitoba, and Northwest Territories; Fig. 1), we only used locations recorded in Arizona (n = 6,733; ~6 locations per day; Appendix 2). Bald eagles generally arrived at night roosts around sunset and departed from 30 min prior to >100 min after sunrise (Stalmaster 1987, Crenshaw and McClelland 1989, Cornutt 1992), so we considered locations (n = 636) recorded in Arizona during winter at 2000 and 2300 hrs to identify night roosts.

We selected night roosts for each eagle that had identical geographic coordinates for the 2000 and 2300 locations (i.e., had a Euclidean distance of 0 between the 2 locations). Euclidean distances ranged from 0 to >100 m (Fig. 2), thus we had 279 locations in several vegetation types (i.e., ponderosa pine, mixed conifer, pinyon-juniper [*Pinus edulis*-*Juniperus* spp.], and shrublands) with a Euclidean distance of 0 for the study.

Habitat Measurements - Microhabitat

We eliminated roosts for juvenile and resident birds (n = 3; Appendices 1, 2) in our microhabitat analysis since their habitat use might differ from subadult and adult birds (n = 7). We then selected only roosts that were ≥500 m apart (for spatial independence) and in ponderosa pine forests. Because of time and budget constraints, we sampled 54 night roost locations. We had a minimum of 3 night roosts per eagle (range = 3 to 15 eagles; Appendix 3). We compared habitat characteristics of 54 night roosts with paired randomly-selected sites in the field (see below).

We located roosts using hand-held Global Positioning System (GPS) units. We considered any trees that were ≥42 cm dbh (Steenhof et al. 1980, Keister and Anthony 1983) within an error range of the hand-held GPS unit (6.3 m ± 2.4; range: 3-15 m) as roost trees. To confirm use by eagles, we searched for evidence such as eagle-cast pellets, whitewash, and feathers. We used a 30-m diameter circular plot around the roost tree and recorded species and dbh for all trees within the plot. We also measured slope (%), aspect (degrees), and basal area (m^2/ha). We measured height for trees ≥42 cm dbh and categorized them by dominance class (dominant, codominant, intermediate, and suppressed; Avery and Burkhart 1983) and live crown ratio (0% [snags], 25%, 50%, 75% and 100%; Ward 1964).

We paired each roost site with a randomly-selected plot ≥500 m away. Random plots had to be in a ponderosa pine stand with at least one tree ≥20 cm dbh because this dbh was the minimum size for a tree large enough for a bald eagle to use for roosting or perching (Chester et al. 1990). We established a 30-m-diameter plot centered on the random tree and measured the same habitat covariates as in roost plots.

We obtained data on minimum temperatures from the National Climatic Data Center (National Climatic Data Center 2007) for each night that an eagle roosted in one of our microhabitat plots. However, temperatures were not collected from roost locations, rather they were recorded at nearby reporting stations that were from 10 to >50 km from roosts. We used temperature data to see if eagles selected different habitat during cold and extreme cold periods. We considered nights ≤-17 ºC as extreme cold and >-17 ºC as cold for bald eagles (Hayes and Gessman 1980).

Habitat Measurements - Macrohabitat

We selected 200 night roosts (mean and SE: 25 roosts ± 11; range 7 to 43 roosts per eagle; Appendix 3) that were located within ponderosa pine forests for 8 bald eagles (6 adults, 1 subadult, and 1 juvenile). We included the juvenile and subadult eagles to increase sample size but also tested habitat associations for only adult eagles (n = 133 roosts; mean and SE: 22 roosts ± 5; range 7 to 36 roosts per eagle). Spatial data layers were mapped by the Forest Ecosystem Restoration Analysis (ERA) project with a 90-m resolution raster dataset (see Hampton et al. 2003 and Prather et al. 2006 for details). We used the Forest ERA data layers to calculate percent canopy cover, tree density, and basal area. We could not derive data such as tree dbh, tree size variability and live crown ratio from the available spatial data layers so we did not use these in the macrohabitat analysis. Slope, aspect, and elevation were derived from a Digital Elevation Model (DEM). We also measured the nearest distance from each roost location to a highway, interstate, and lake using Hawth's tool, ArcGIS 9.2 version. We generated 200 random points within ponderosa pine stands that were ≥500 m from other randomly-generated points and measured the same characteristics (e.g., percent canopy cover, tree density, basal area, slope, aspect) as for night roosts.

To determine whether eagles selected night roosts close to potential food sources (e.g., fish or waterfowl at lakes or large ungulate carrion near interstates and roads), we measured distances between roost locations for all eagles, all age classes (n = 10) in all vegetation types (ponderosa pine forest, pinyon-juniper woodland, and Montane scrub) using all error classes (Appendix 2) at 1700 and 2000 hrs of the same day (n = 636) and between 2300 and 0800 hrs of the next morning (n = 388; on some mornings transmitters failed to record the 0800 location). Because diet shifts seasonally (Grubb and Lopez 2000) in northern Arizona, we compared roosts used in fall (October, November, December) with those used in winter (January, February, March) for adults versus juvenile eagles. We compared night roost locations by slope, aspect, and distance to potential food sources (highways, interstates, lakes).

We also defined 500-m-radius plots that were used for ≥5 nights by ≥1 bald eagle(s) as hotspots. We searched for hotspots using all night roost locations (n = 636) for all bald eagles (n = 10) of all age classes (Fig. 3). We calculated habitat variables (e.g., slope, aspect, distances to lakes, highways and interstates) for hotspots based on DEM and spatial data layers from a GIS.

Model Development and Analysis

To explain differences in habitat between roosts used by bald eagles and random sites, we used binary logistic regression (Hosmer and Lemeshow 2000) for a case-control (microhabitat) or a use-availability (macrohabitat) sampling design (Keating and Cherry 2004). We developed 13 and 11 *a priori* models for microhabitat and macrohabitat use, respectively. Models were developed based on a review of the literature (e.g., Grubb et al. 1989, Buehler et al. 1991b, Dargan 1991, Stohlgren 1993) and expert opinion. Models for use of microhabitat included variables that provided physical protection (e.g., hiding cover such as dbh of the largest tree, mean dbh for trees >10 cm in the plot) and thermal cover (e.g., protection from cold and wind such as density of large [≥42 cm dbh] or small [<42 cm dbh] trees, basal area, slope, and aspect). Models for use of macrohabitat included variables that were related to food resources (distance to highways, interstates, and lakes) or variables such as canopy cover, basal area, tree density, slope, and aspect that provided physical safety or thermal cover to eagles. Six models were developed for comparing distance moved in evening versus morning and included the variables season (fall versus winter), age class of birds (adult versus juvenile and subadult; Stalmaster 1987, Mojica and Millsap 2008), and distances (m) moved.

To describe roost orientation, we categorized aspect as northeast (1 to 90º), southeast (91 to 180º), southwest (181 to 270º), or northwest (271 to 360º). However, for statistical analyses, we transformed aspect using a trigonometric function (Roberts 1986): northness = *Cos* (aspect in degrees) and eastness = *Sin* (aspect in degrees). Eastness had values close to +1 if the aspect was eastward and -1 if westward. Values were 0 if the aspect was north- or south-facing. Similarly, northness took values close to +1 if the aspect was northward and -1 if southward and 0 if the aspect was east- or west-facing.

We used Akaike's Information Criteria (AIC; for analysis of locations [macrohabitat] of night roosts and first or last location during the day) or Akaike's Information Criteria adjusted for small sample size (AIC_c, for other analyses [microhabitat]) to identify the most parsimonious models and to predict parameter importance (Akaike 1973, Burnham and Anderson 2002). Models with $\Delta AIC_c \leq 2$ were considered the best approximating models. We used Akaike weight (w_i) to determine the probability of each model as being the best model in the set of candidate models, to rank variable importance, and to adjust coefficients and odds ratio of competing models (Burnham and Anderson 2002).

For post-hoc analysis of microhabitat, we added 2 variables: density of trees with live crown ratios ≥75% and a measure of variability of tree size calculated as the standard deviation of mean dbh of all trees in each plot. We used variability of tree size instead of mean dbh because we suspected that bald eagles searched for multistory canopies rather than a mean dbh of trees (Keister and Anthony 1983). We created 6 *a posteriori* models to describe night roosts using these variables and dbh of the largest tree, slope, aspect, and density of large trees.

RESULTS

Night Roosts – Microhabitat

Trees used as night roosts were larger diameter, on steeper slopes, and surrounded by greater basal area. There were higher densities of large trees and lower densities of small trees than in random plots (Table 1). Mean dbh for trees in the roost plots was larger than for random plots. Roost plots were more likely to face east (67%) than west (33%; Fig. 4). The global model best predicted use of a roost by bald eagles (Table 2; $w_i = 0.9978$); other models performed poorly in comparison ($\Delta AIC_c \geq 12.34$).

Most of the large trees in roost plots were co-dominant or dominant (94%; Fig. 5) and had ≥50% live crown ratio (91%; Fig. 6). We found few snags in roost plots (Fig. 6). Evidence of presence of bald eagles such as whitewash or feathers was found at 10 of the 54 roost sites.

We used a post-hoc analysis to find a more parsimonious model to describe night roost characteristics. The top 3 models ($\Delta AIC_c \leq 3.94$; Table 3) that best predicted use of a roost by eagles included dbh of the largest tree, slope, variability in tree size, number of trees with live crown ratios ≥75%, eastness, density of large trees, and density of small trees. Based on the sum of Akaike weights, diameter of largest tree, variability in tree size, slope, and live crown ratio were the most important variables describing night roost plots (Table 4).

Mean minimum temperature at nearby reporting stations of night roosts was -10 ºC (range = -0.6 º to -24 ºC). Most night roosts ($n = 43$) were used on cold nights; 11 were used on extreme cold nights. We did not find variation between roosts used on cold and extreme cold nights for tree sizes (average dbh of all trees in each plot for cold nights

= 39.8 ± 2.4 cm; for extreme cold nights = 42.4 ± 5.2 cm; dbh for the largest tree in each plot for cold nights = 76.3 ± 2.6 cm; for extreme cold nights = 70.8 ± 3.3 cm), slope (cold nights = 12.9 ± 2.7 %, extreme cold nights = 10.3 ± 2.6 %), basal area (cold nights = 21.7 ± 2.3 m^2/ha, extreme cold nights = 19.8 ± 4.6 m^2/ha), and tree density (small tree [<42 cm dbh] density for cold and extreme cold nights was 140.6 ± 18.3 and 140.7 ± 48.4 trees/ha, respectively; large tree [≥42 cm dbh] density for cold and extreme cold nights was 61.7 ± 5.35 and 60.2 ± 11.3 trees/ha, respectively). Eagles used east-facing roosts on cold nights and north-facing roosts on extreme cold nights (Fig. 7).

Night Roosts – Macrohabitat

The 3 models (ΔAIC_c <2) that best described night roosts for bald eagles at the macrohabitat scale included distance to lakes, highways, interstates, and measures of aspect (Table 5). Other models performed poorly in comparison ($\Delta AIC_c \geq 6.289$). Eagles used roosts that were closer to highways and interstates and farther from lakes than random points (Table 6). Roosts were more likely to face north than south (Fig. 8A). Model-averaged estimates suggested that distances to highways and lakes and a north-facing aspect were important predictors of roosting (Table 7). Eastness was of moderate importance and distance to interstate was of lower importance. Top models for adult eagles were identical to those that included the subadult and juvenile birds (Table 8). Compared to random points, roosts for adults were closer to highways (mean and SE: 4.52 km ± 0.34 compared to 29.13 km ± 1.93 for random points), interstates (9.28 km ± 0.66 compared to 11.07 km ± 0.68 for random points), and farther from lakes (9.33 km ±

0.47 compared to 6.28 km ± 0.39 for random points); roosts for adult eagles faced northeast (Fig. 8B).

The global model best described the relationship between locations of night roosts and first or last location during the day. Other models were poor fitting or had $\Delta AIC_c \geq 500$ (Table 9). Eagles roosted closer to their last location of the day (<1.50 km) than their first location of the next morning (>11.00 km) in fall and winter (Table 10). Distances for adult eagles were greater than for juveniles and the subadult in winter for both time periods and fall for movement between 2300 and 0800 hrs (Table 10). Most (85%) distances measured between 1700 and 2000 hrs were ≤2.00 km, whereas, only 33% of distances measured between 2300 and 0800 hrs were ≤2.00 km.

Night roosts were on greater slopes (Fall: 11.4%, Spring: 9.3%), were at higher elevation (Fall: 2,128 m, Spring: 1,981 m), closer to highways (Fall: 4.66 km, Spring: 7.13 km) and interstates (Fall: 26.46 km, Spring: 34.73 km) in fall (n = 226) than in spring (n = 410).

We identified 12 hotspots (500-m-radius plots that were used for ≥5 nights by ≥1 bald eagle[s] as night roosts) based on 636 night roost locations in northern Arizona. Seven hotspots (H1, H2, H3, H5, H9, H11, and H12) were used by a single eagle (Table 11). Three hotspots (H2, H5, and H11) were used by a single eagle for multiple years (2-3 yrs). Five hotspots (H4, H6, H7, H8, and H10) were used by multiple eagles (n = 2-4 eagles); three hotspots (H6, H7, and H8) were used for multiple years by multiple eagles (Table 11). Six of 12 hotspots faced northeast, 2 faced northwest, 2 faced southwest and 2 faced southeast (Table 11). Hotspots used by multiple eagles had greater slope, higher elevation, and closer proximity to lakes, highways and interstates than the hotspots used by a single eagle (Table 12).

DISCUSSION

The structure of night roosts seemed to provide physical safety and thermal cover to bald eagles. Eagles roosted in clumps of large ponderosa pine trees with intact and co-dominant trees with deep live crowns. These characteristics probably provided more thermal cover to bald eagles, especially on cold nights, and large trees could have served as proximate cues in selecting night roosts. Clumps of large trees also may have provided security since other large trees in these clumps could serve as roosts. If disturbed or threatened, eagles could therefore move short distances to find another roost. We found that eagles roosted in live trees in relatively dense stands, protected situations, and often several kilometers away from daytime loafing and foraging areas.

Small trees were of minor importance in our *a priori* model, but they contributed to create a multistory forest cover when combined with large trees at roost sites, so were indirectly incorporated into our *a posteriori* model. Keister and Anthony (1983) also found that roost sites for bald eagles were in old growth with large trees and multistory forests stands in the Klamath Basin, Oregon.

We did not find direct evidence of use by eagles (e.g., eagle-cast pellets, whitewash, and feathers) at most roost sites; however, we visited most locations 1 to 2 years (2005, 2006) after their use as night roosts. Keister and Anthony (1983) reported that castings of eagles lasted about a year thus we were unlikely to have found sign of eagles.

Our macrohabitat analysis identified night roosts as closer to highways and interstates but farther from lakes than random points. We suggest that this is because during winter, eagle diet in northern Arizona is comprised mostly of carrion of large ungulates and small mammals rather than fish (Grubb and Kennedy 1982). Grubb (1984) also found carrion of big game was the primary food source for bald eagles followed by small mammals, waterfowl, and fish at Navajo Lake, New Mexico. Ewins and Andress (1995) reported that bald eagles wintering inland in southern Ontario relied heavily on garbage at municipal dumps and white-tailed deer (*Odocoileus virginianus*) carcasses. Todd et al. (1982) mentioned wintering bald eagles in inland Maine consumed starved or road-killed deer, domestic cows (*Bos taurus*), and moose (*Alces alces*). Keister and Anthony (1983) also reported that roosting habitat was not necessarily close to water though prey sources were in the general vicinity but more importantly eagles chose a roost that had a protected microclimate, big trees, and locations that provided clear views and an open flight lane. We believe that bald eagles searched for road-killed animal carcasses near highways and selected roost sites near their last location of the day. Bald eagles flew shorter distances between 1700 and 2000 hrs of the same day which may indicate that they roosted near food sources. Although we expected their first location of the morning would be near the previous night roost, eagles traveled much longer distances. Distances eagles moved between last or first day locations to roosts in the fall were shorter than in winter. We found differences in aspects used by eagles at different scales of measurement. Eagles used east-facing, steeper slopes for the night roosts at the microhabitat scale. Roosts facing this direction may provide thermal advantages because east-facing, steeper slopes provide earliest exposure to sunlight and perhaps protect against severe westward winds at night (Keister et al. 1985, Buehler et al. 1991a). During very cold nights, eagles used roosts that faced northeast.

Hayes and Gessman (1980) found that cold stress began in American kestrel (*Falco sparverius*) at -5 °C; however, red-tailed hawks (*Buteo jamaicensis*) and golden eagles (*Aquila chrysaetos*) were not appreciably stressed even at -17 °C. Resistance to cold varies from species to species. We used -17°C as a cold stress point for bald eagles (Stalmaster 1983). The average minimum temperature of nearby reporting stations from roosts was -10 °C (range = -0.6 °C to -24 °C) so we did not have many roosts for extreme cold nights in our study. We found selection of microhabitat by bald eagles in response to cold versus extreme cold nights was similar. Either our sample size was inadequate to detect differences, or cold stress might be less important in the survival of larger-bodied birds like bald eagles (Keister et al. 1985, Craig et al. 1988). Stalmaster (1983) reported that bald eagles near the Nooksack River in Washington conserved 7.8% to 9.8% energy by roosting in coniferous forests as compared with deciduous riparian areas.

At the macrohabitat scale, eagles selected north-facing roosts. North-facing roosts may offer more protection to bald eagles by blocking prevailing southwest winds (Western Regional Climate Center 2009) at night. In addition, eagles using northeast-facing roosts may receive a thermal benefit at sunrise and during the early morning. Microhabitat analyses reflected that eagles selected night roosts with greater slopes in ponderosa pine forests. Hotspots used by multiple eagles also were on greater slopes which may provide better thermal cover. Hotspots used by multiple eagles were located near lakes, highways, and interstates and thus more likely to be communal roosts that provided proximity to food sources (Keister and Anthony 1983, Keister et al. 1985, Grubb and Lopez 2000).

MANAGEMENT IMPLICATIONS

Night roosts for bald eagles in northern Arizona can be maintained by protecting clumps (3-4 trees) of large (>75 cm dbh) ponderosa pine trees which have greater live crown ratio (>50%), are dominant or codominant and are situated on moderate to steeper slopes (≥8%). We should maintain multilayered patches in ponderosa pine stands to create or maintain existing roosts for bald eagles. Resource managers should avoid activities (e.g., timber harvesting, road development, prescribed fire) from October to April that disturb night-roosting bald eagles. Since insect outbreaks and fires influence the size, distribution, and spatial patterns of ponderosa pine age classes, management techniques to reduce fuels (e.g., an active prescribed burning program or mechanical thinning) may be useful to reduce heavy fuel loads and the possibility of catastrophic fires in roost areas.

LITERATURE CITED

Akaike, H. 1973. Information theory as an extension of the maximum likelihood principle. Pages 267-281 *in* B. N. Petrov and F. Csaksi, editors. Second International Symposium on Information Theory. Akademiai Kiado, Budapest, Hungary.

Avery, T. E. and H. E. Burkhart. 1983. Forest measurements. McGraw Hill, New York, USA.

Brown, D. E. 1982. Biotic communities of the American Southwest United States and Mexico. Desert Plants 4:1-34.

Buehler, D. A., T. J. Mersmann, J. D. Fraser, and J. K. D. Seegar. 1991a. Winter microclimate of bald eagle roosts on the northern Chesapeake Bay. The Auk 108:612-618.

Buehler, D. A., T. J. Mersmann, J. D. Fraser, and J.D. Seeger. 1991b. Nonbreeding bald eagle communal and solitary roosting behavior and roost habitat on the northern Chesapeake Bay. Journal of Wildlife Management 55:273-281.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and inference: a practical information-theoretic approach. Springer, New York, USA.

Chester, D. N., D. F. Stauffer, T. J. Smith, D. R. Luukkonen, and J. D. Fraser. 1990. Habitat use by nonbreeding bald eagles in North Carolina. Journal of Wildlife Management 54:223-234.

Chronic, H. 1983. Roadside geology of Arizona. Mountain Press, Missoula, Montana.

Cornutt, J. L. 1992. Dynamics of a year-round communal roost of bald eagles. The Wilson Bulletin 104:536-540.

Craig, R. J., E. S. Mitchell, and J. E. Mitchell. 1988. Time and energy budgets of bald eagles wintering along the Connecticut River. Journal of Field Ornithology 59:22-32.

Crenshaw, J. G., and B. R. McClelland. 1989. Bald eagle use of a communal roost. The Wilson Bulletin 101:626-633.

Dargan, C. M. 1991. Roost site characteristics of bald eagles wintering in north-central Arizona. Thesis, Northern Arizona University, Flagstaff, USA.

Dellasala, D. A., R. G. Anthony, T. A. Spies, and K. A. Engel. 1998. Management of bald eagle communal roosts in fire-adapted mixed-conifer forests. Journal of Wildlife Management 62:322-333.

Ewins, P. J., and R. A. Andress. 1995. The diet of bald eagle wintering in the lower Great Lakes Basin, 1987-1995. Canadian Field-Naturalist 109:418-425.

Federal Register. 2008. Endangered threatened wildlife and plants; initiation of status review for the bald eagle in the Sonoran Desert arean of Central Arizona and Northwestern Mexico. <http://www.fws.gov/southwest/es/arizona/Documents/SpeciesDocs/BaldEagle/FR_StatusReview.pdf>. Accessed 21 Feb 2009.

Garrett, M. G., J. W. Watson, and R. G. Anthony. 1993. Bald eagle home range and habitat use in the Columbia River Estuary. Journal of Wildlife Management 57:19-27.

Grubb, T. G. 1984. Winter activity of bald eagles at Navajo lake, New Mexico. The Southwestern Naturalist 29:335-341.

Grubb, T. G. 2003. Wintering bald eagle trends in northern Arizona, 1975-2000. The Southwestern Naturalist 48:223-230.

Grubb, T. G. and C. E. Kennedy. 1982. Bald eagle winter habitat on southwestern national forests. United States Department of Agriculture, Forest Service, Technical Report RM 237:1-13.

Grubb, T. G. and R. G. Lopez. 2000. Food habits of bald eagles wintering in northern Arizona. Journal of Raptor Research 34:287-292.

Grubb, T. G., S. J. Nagiller, W. L. Eakle, and G. A. Goodwin. 1989. Winter roosting patterns of bald eagles *(Haliaeetus leucocephalus)* in north-central Arizona. The Southwestern Naturalist 34:453-459.

Hampton, H. M., Y. Xu, J. W. Prather, E. A. Aumack, B. G. Dickson, M. M. Howe, and T. D. Sisk. 2003. Spatial tools for guiding forest restoration and fuel reduction efforts. *in* Proceedings of the 23rd annual Environmental Systems Research Institute (ESRI) international user conference, 7-11 July 2003, San Diego, California, USA.

Hayes, S. R., and J. A. Gessman. 1980. The combined effects of air temperature, wind and radiation on the resting metabolism of avian raptors. Journal of Thermal Biology 5:119-125.

Hosmer, D. W. and S. Lemeshow. 2000. Applied logistic regression. Second edition, John Wiley & Sons, Inc. New York. USA

Hunt, W. G., D. E. Driscoll, E. W. Bianchi, and R. E. Jackson. 1992. Ecology of bald eagles in Arizona. Report to U.S. Bureau of Reclamation, Contract 6-CS-30-04470. Biosystems Analysis, Inc., Santa Cruz, CA. USA.

Isaacs, F. B., R. G. Anthony, M. VanderHeyden, C. D. Miller, and W. Weatherford. 1996. Habits of bald eagles wintering along the Upper John Day River, Oregon. Northwest Science 70:1-9.

Keating, K. A., and S. Cherry. 2004. Use and interpretation of logistic regression in habitat-selection studies. Journal of Wildlife Management 68:774-789.

Keister, G. P. Jr. and R. G. Anthony. 1983. Characteristics of bald eagle communal roosts in the Klamath Basin, Oregon and California. Journal of Wildlife Management 47:1072-1079.

Keister, G. P., R. G. Anthony, and H. R. Holbo. 1985. A model of energy consumption in bald eagles: an evaluation of night communal roosting. Wilson Bulletin 97:148-160.

Kenward, R. E. 2001. A manual for wildlife radio tagging. London: Academic Press.

Lowe, C. H. 1980. Arizona's natural environment landscapes and habitats. University of Arizona Press, Tucson, USA.

Mojica, E. K, and B. A. Millsap. 2008. Migration of Florida subadult bald eagles. The Wilson Journal of Ornithology 120:304-310.

National Climatic Data Center. 2007. US Department of Commerce. <http://www.ncdc.noaa.gov/oa/mpp/digitalfiles.html>. Accessed 15 April 2008.

Prather, J. W., N. L. Dodd, B. G. Dickson, H. M. Hampton, Y. Xu, E. N. Aumack, and T. D. Sisk. 2006. Landscape models to predict the influence of forest structure on tassel-eared squirrel populations. Journal of Wildlife Management 70:723-731.

Roberts, D. W. 1986. Ordination on the basis of fuzzy set theory. Vegetatio 66:123-131.

Stalmaster, M. V. 1983. An energetic simulation model for managing wintering bald eagles. Journal of Wildlife Management 47:349-359.

Stalmaster, M. V. 1987. The bald eagle. University Books. New York, USA.

Steenhof, K., S. S. Berlinger, and L. H. Fredrickson. 1980. Habitat use by wintering bald eagles in South Dakota. Journal of Wildlife Management 44:798-805.

Stohlgren, T. J. 1993. Bald eagle winter roost characteristics in Lava Beds National Monument, California. Northwest Science 67:44-54.

Thompson, C. M., P. E. Nye, G. A. Schmidt, and D. K. Garcelon. 2005. Foraging ecology of bald eagles in a freshwater tidal system. Journal of Wildlife Management 69:609-617.

Todd, C. S., L. S. Young, R. B. Owen, Jr., and F. J. Gramlich. 1982. Food habits of bald eagles in Maine. Journal of Wildlife Management 46:636-645.

United States Fish and Wildlife Service. 2007a. Endangered and threatened wildlife and plants; removing the bald eagle in the lower 48 states from the list of endangered and threatened wildlife. <http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=2007_register&docid=fr09jy07-6>. Accessed 16 Oct 2009.

United States Fish and Wildlife Service. 2007b. Draft post-delisting monitoring plan for the bald eagle (*Haliaeetus leucocephalus*). <http://www.fws.gov/midwest/eagle/protect/DraftBAEAPDM.pdf>. Accessed 10 Oct 2008.

United States Fish and Wildlife Service. 2008. Bald eagle breeding pairs 1990-2006. <http://www.fws.gov/midwest/eagle/population/nos_state_tbl.html>. Accessed 10 Oct 2008.

United States Forest Service. 2008. The Rocky Mountain Region (Region 2) Forester's sensitive species list. <http://www.fs.fed.us/r2/projects/scp/sensitivespecies/index.shtml>. Accessed 28 Oct 2008.

Ward, W. W. 1964. Live crown ratio and stand density in young, even aged red oak stands. Forest Science 10:56-65.

Western Regional Climate Center. 2008. Historical Climate Information. Temperature and precipitation for Flagstaff, Arizona. <http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?az3009>. Accessed 11 Oct 2008.

Western Regional Climate Center. 2009. Prevailing wind direction for Flagstaff, Arizona. <http://www.wrcc.dri.edu/htmlfiles/westwinddir.html#ARIZONA>. Accessed 23 Dec 2009.

Young, L. S. 1983. Movements of bald eagles associated with autumn concentrations in Glacier National Park. Thesis, University of Montana, Missoula, USA.

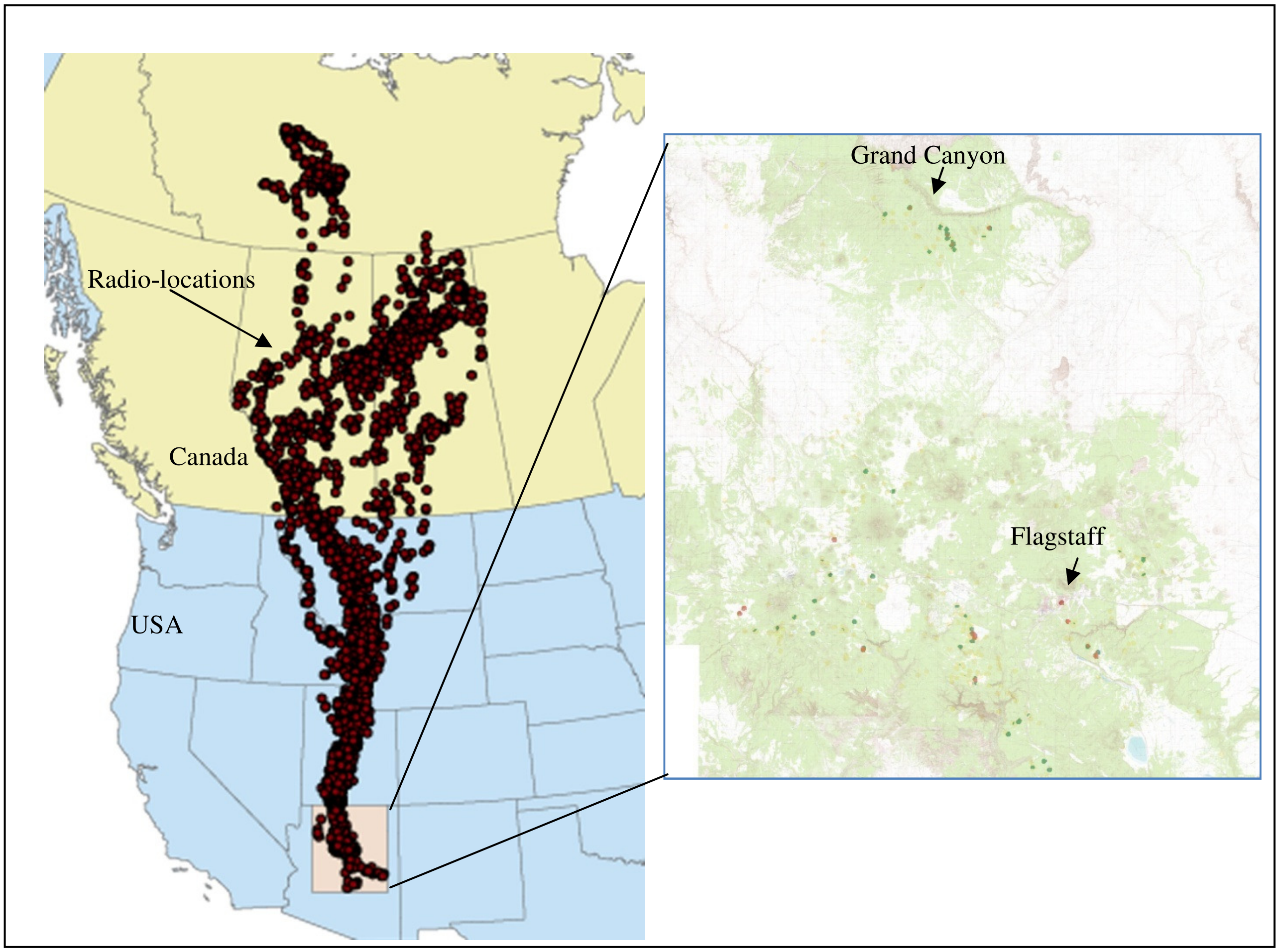


Figure 1. Locations (filled circles) of 10 bald eagles (7 adults, 1 subadult, and 2 juveniles) in North America from Arizona, USA to Northwest Territory, Canada during 2005, 2006 and 2007. Eagles were radio tagged by Department of Emergency and Military Affairs and Arizona Game and Fish Department in 2005 and 2007 during winter at Camp Navajo, Arizona. Winter locations for Arizona are depicted in the box.

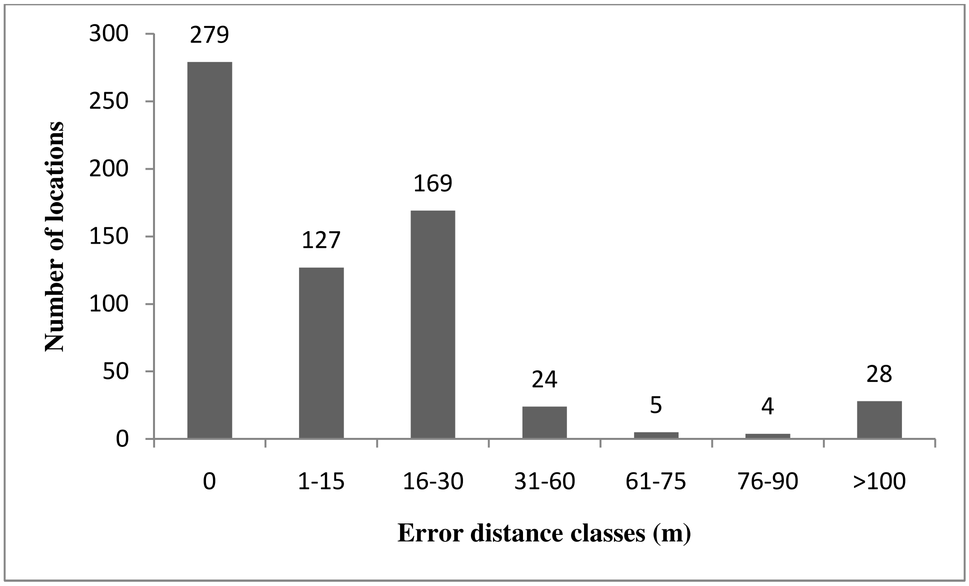


Figure 2. Number of satellite locations in Arizona (*n* = 636, all vegetation types) recorded at 2000 and 2300 hrs (Mountain Standard Time) for 10 bald eagles monitored using satellite telemetry during winter (Oct-Apr) 2005-2007. Error distances are the Euclidean (i.e., straight-line) distances between each pair of points recorded at 2000 and 2300 hrs. Error distances of 0 (*n* = 279) were assumed to be most accurate, and therefore the only ones used in roost analyses.

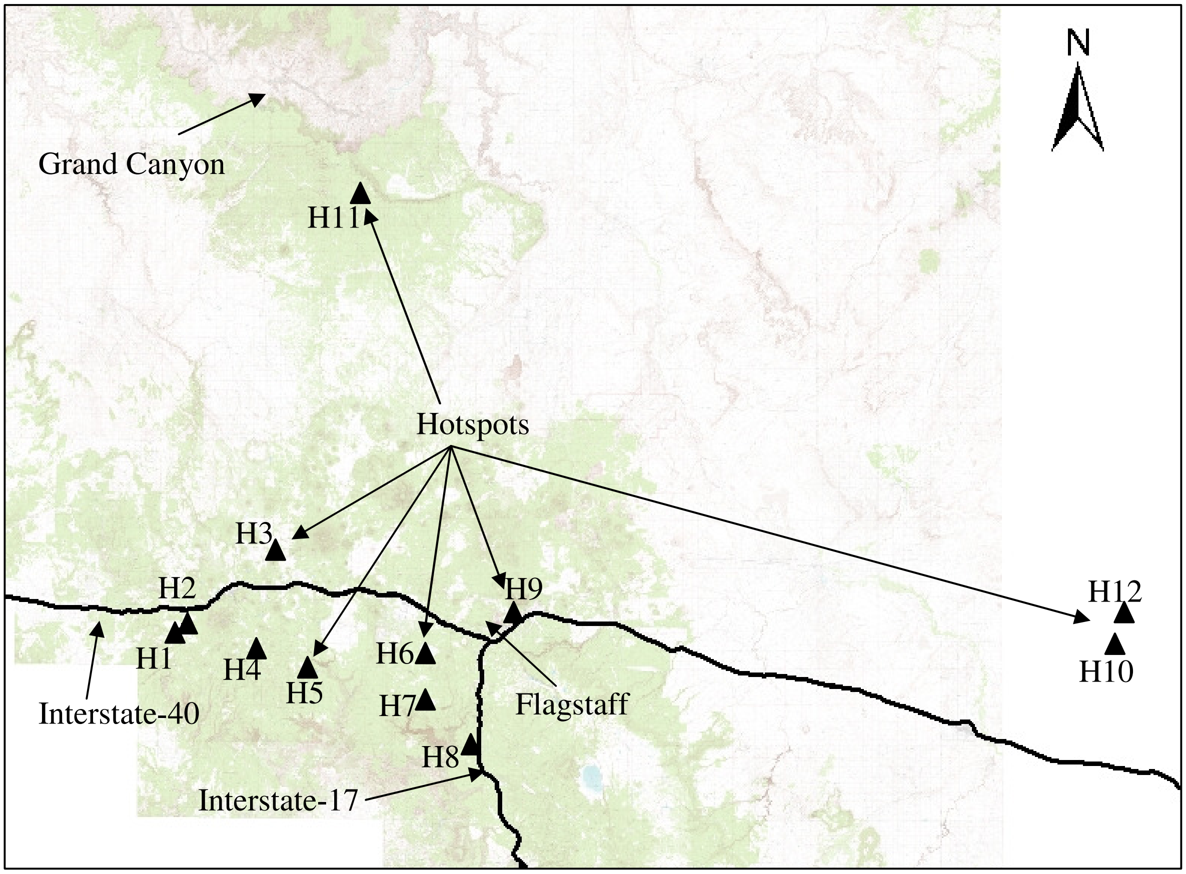


Figure 3. Hotspots (n = 12; 500-m-radius plots used for ≥5 nights by ≥1 eagle(s) as night roosts) for 10 bald eagles (7 adults, 1 subadult, and 2 juveniles) in northern Arizona during winter in 2005, 2006, and 2007.

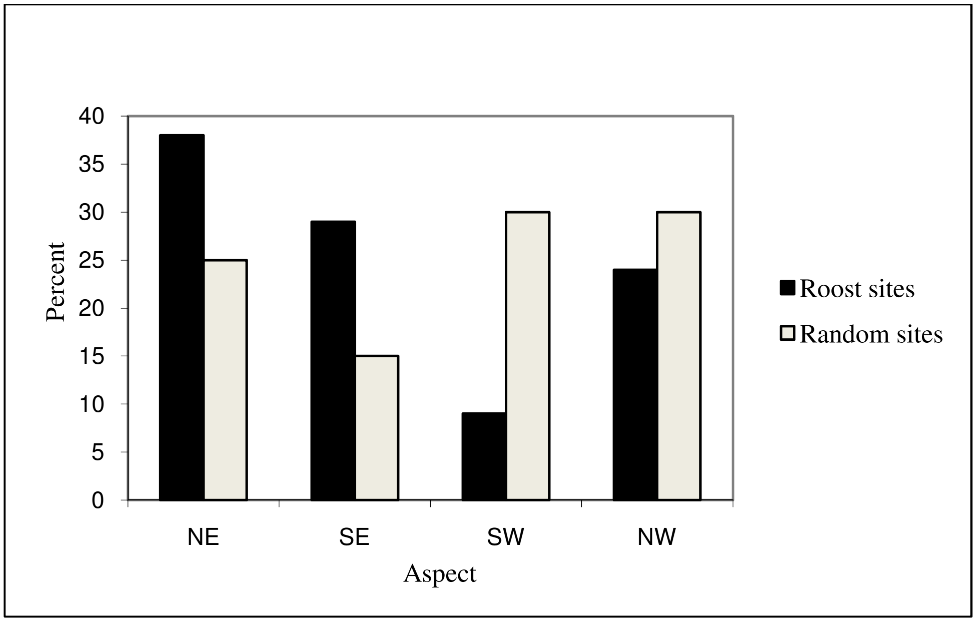


Figure 4. Aspects of roost and random microhabitat plots (habitat characteristics within a 30-m diameter area centered at the roost tree and measured on ground-based plots) for 7 (6 adult and 1 subadult) bald eagles wintering in northern Arizona from 2005 to 2007. Aspect was categorized as northeast (NE, 1° - 90°), southeast (SE, 91° - 180°), southwest (SW, 181° - 270°) and northwest (NW, 271° - 360°).

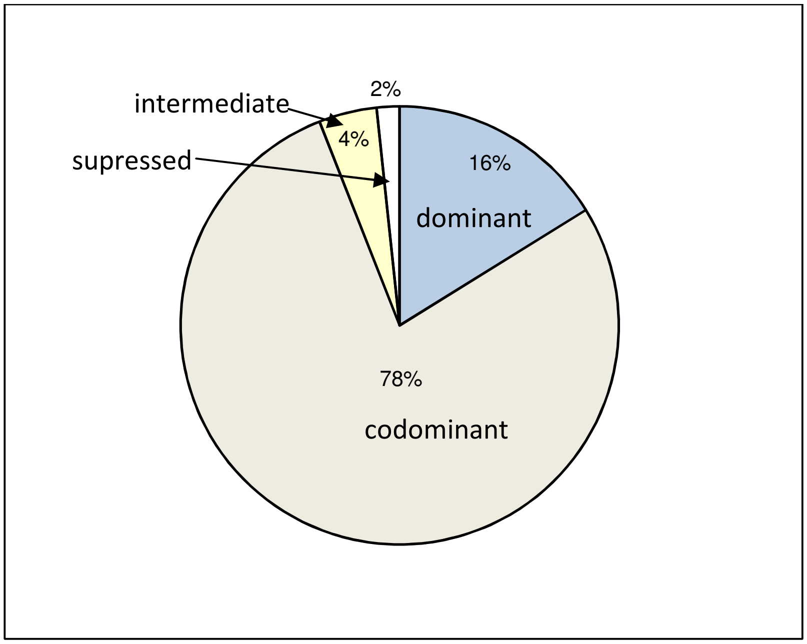


Figure 5. The percent of trees used as night roosts categorized under 4 dominance classes (dominant, co-dominant, intermediate and suppressed; Avery and Burkhart 1983) for 7 (6 adult and 1 subadult) bald eagles wintering in northern Arizona during 2005-2007.

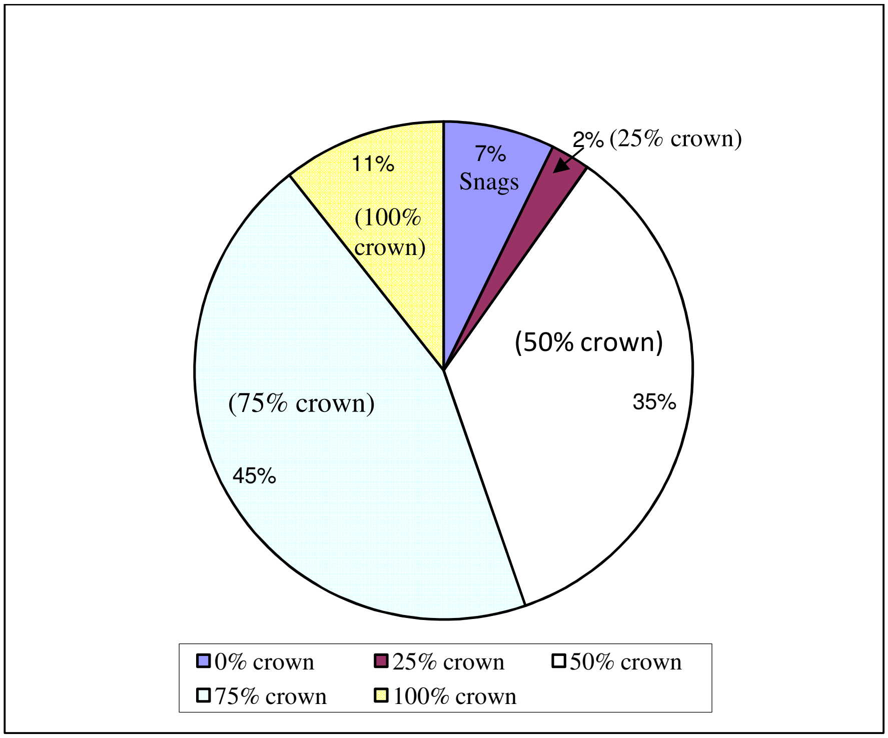


Figure 6. Percent of trees used as night roosts categorized by live crown ratio (0% [snags], 25%, 50%, 75% and 100%; Ward 1964) for 7 (6 adults and 1 subadult) bald eagles wintering in northern Arizona during 2005-2007.

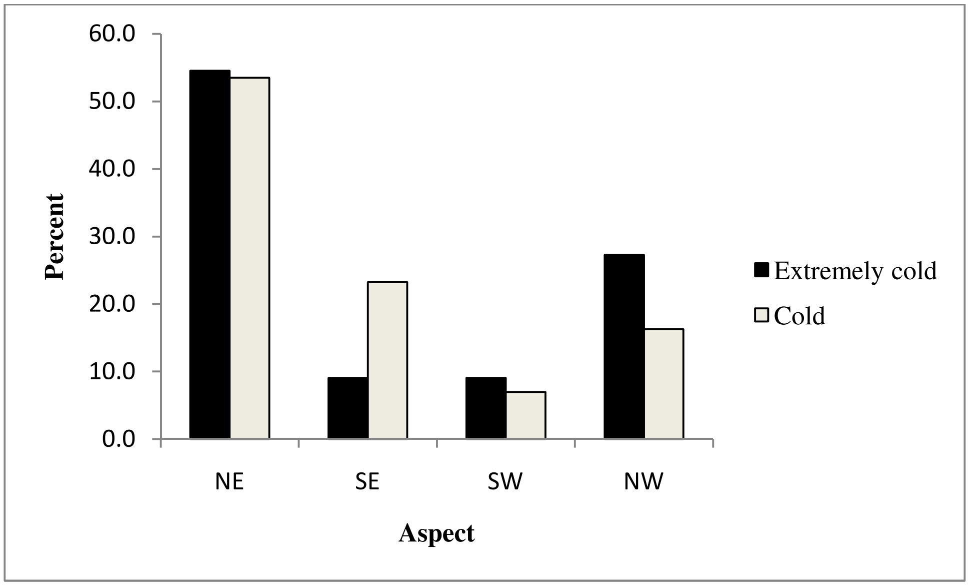
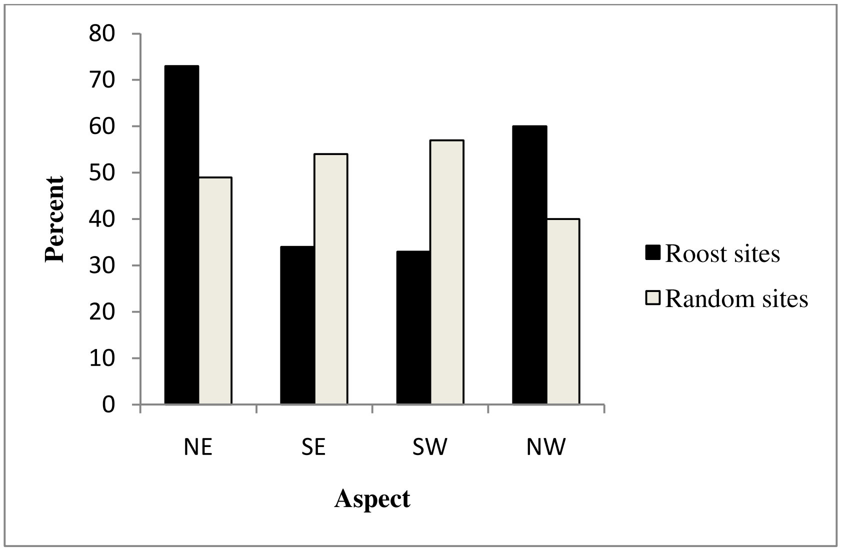
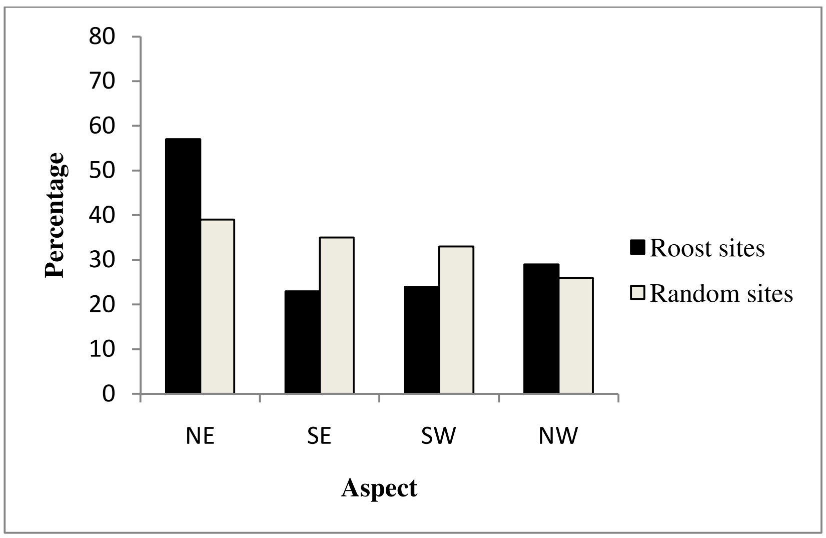


Figure 7. Aspects of night roost sites (n = 54) for 7 (6 adult and 1 subadult) bald eagles wintering in northern Arizona from 2005 to 2007 on extreme cold (≤-17 ºC; n = 11) and cold (>-17 ºC; n = 43) nights. Aspect was categorized as northeast (NE, 1° - 90°), southeast (SE, 91° - 180°), southwest (SW, 181° - 270°) and northwest (NW, 271° - 360°).



A.



B.

Figure 8. A. Aspects of night roost (n = 200) and random (n = 200) sites for macrohabitat (habitat characteristics within a 90-m diameter plot centered at the roost tree based on spatial data layers from a geographic information system) calculated from Digital Elevation Model for 8 bald eagles (6 adults, 1 subadult, and 1 juvenile) wintering in northern Arizona from 2005 to 2007. Aspect was categorized as northeast (NE, 1° - 90°), southeast (SE, 91° - 180°), southwest (SW, 181° - 270°) and northwest (NW, 271° - 360°). B. Aspects of night roosts (n = 133) and random (n = 133) sites for macrohabitat analysis for 6 adult bald eagles wintering in ponderosa pine forests in northern Arizona from 2005

to 2007.

Table 1. Means ($\bar{x}$), standard errors (SE) and ranges of microhabitat characteristics (habitat characteristics within a 30-m diameter area centered at the roost tree and measured on ground-based plots) of night roosts (*n* = 54) selected by 7 (6 adult and 1 subadult) bald eagles wintering in northern Arizona from 2005 to 2007 compared with randomly-selected plots (*n* = 54).

Variables	Roost			Random		
	$\bar{x}$	SE	Range	$\bar{x}$	SE	Range
LargestTreeDbh[1]	75.2	2.2	43.7 - 109.0	58.2	1.5	28.0 - 83.1
Slope[2]	12.4	2.2	0.0 - 75.0	6.6	1.1	0.0 - 35.0
Large (≥42 cm dbh)						
tree density[3]	61.9	4.8	14.3 - 157.1	39.6	4.5	14.3 - 157.1
Small (<42 cm dbh)						
tree density[4]	137.3	17.4	0.0 - 542.9	158.4	24.0	0.0 - 728.6
Mean dbh[5]	40.3	2.2	19.9 - 106.0	37.2	2.0	19.3 - 83.1
BasalArea[6]	19.7	8.0	4.6 - 78.2	17.7	7.8	4.6 - 82.8
Tree size variability[7]	17.5	1.0	0.0 - 35.1	10.5	0.8	0.0 - 25.2
Number of trees with						
LCR ≥75%[8]	2.4	0.3	0.0 - 9.0	0.8	0.2	0.0 - 5.0

[1]LargestTreeDbh is the dbh (cm) of the largest tree in each plot.

[2]Slope is the percent slope for each plot.

[3]Large tree density is the number of trees ≥42 cm dbh per ha.

[4]Small tree density is the number of trees <42cm dbh per ha.

[5]Mean dbh is the average dbh (cm) of all trees in each plot.

[6]BasalArea is the cross section area of the stems of trees (m^2/ha).

[7]Tree size variability is the standard deviation of the dbh (cm) of all trees in the plot.

[8]LCR is the ratio of live crown length to total tree for trees ≥42 cm dbh.

Table 2. Variables, number of parameters in the model (K), Akaike's Information Criterion adjusted for small sample size (AIC_c), difference in AIC_c value between the model and the model with the lowest AIC_c value (ΔAIC_c), and Akaike weight (w_i) for 13 *a priori* candidate, global, and null models used to predict microhabitat characteristics (habitat characteristics within a 30-m diameter area centered at the roost tree and measured on ground-based plots) of night roosts selected by 7 (6 adult and 1 subadult) bald eagles in northern Arizona ponderosa pine forests 2005-2007 (n = 54) compared to random plots (n = 54).

Model	Variables	K	AIC_c	ΔAIC_c	w_i
1	Global Model (LargestTreeDbh[1] + Slope[2] + Eastness[3] + Mean dbh[4] + Large tree density[5] + Small tree density[6] + BasalArea[7])	8	22.89	0.00	0.9978
2	LargestTreeDbh + Slope + Eastness	4	35.23	12.34	0.0021
3	LargestTreeDbh + Mean dbh	3	41.81	18.92	0.0001
4	LargestTreeDbh	2	44.20	21.32	0.0000
5	Large tree density + Slope + Eastness	4	58.44	35.55	0.0000
6	Large tree density + Small tree density + BasalArea + Slope + Eastness	6	59.52	36.63	0.0000
7	Large tree density	2	64.64	41.75	0.0000
8	Slope	2	68.63	45.74	0.0000
9	Slope + Eastness	3	68.82	45.93	0.0000
10	Small tree density + Slope + Eastness	4	70.14	47.26	0.0000
11	Null Model	1	74.90	52.01	0.0000

Table 2. Continued.

Model	Variables	K	AIC_c	ΔAIC_c	w_i
12	BasalArea	2	75.61	52.72	0.0000
13	Mean dbh	2	75.81	52.92	0.0000
14	Eastness	2	75.84	52.95	0.0000
15	Small tree density	2	76.30	53.42	0.0000

[1]LargestTreeDbh is the dbh (cm) of the largest tree in each plot.

[2]Slope is the percent slope for each plot.

[3]Eastness is the transformed aspect using trigonometric function (*Sin* [aspect in degrees]).

[4]Mean dbh is the average dbh (cm) of all trees in each plot.

[5]Large tree density is the number of trees ≥42 cm dbh per ha.

[6]Small tree density is the number of trees <42cm dbh per ha.

[7]BasalArea is the cross section area of the stems of trees (m^2/ha).

Table 3. Variables, number of parameters in the model (K), Akaike's Information Criterion adjusted for small sample size (AIC_c), difference in AIC_c value between the model and the model with the lowest AIC_c value (ΔAIC_c), and Akaike weight (w_i) for 6 *a posteriori*, global, and null models used to predict microhabitat characteristics (habitat characteristics within a 30-m diameter area centered at the roost tree and measured on ground-based plots) for night roosts selected by 7 (6 adult and 1 subadult) bald eagles in northern Arizona ponderosa pine forests during winter 2005-2007 (n = 54) compared to random plots (n = 54).

Model	Variables	K	AIC_c	ΔAIC_c	w_i
1	LargestTreeDbh[1] + Slope[2] + Tree size variability[3] + LCR[4]	5	19.84	0.00	0.6027
2	LargestTreeDbh + Slope + Eastness[5] + Tree size variability + LCR	6	21.80	1.96	0.2255
3	Global (LargestTreeDbh + Slope + Eastness + Large tree density[6] + Small tree density[7] + Tree size variability + LCR)	8	23.78	3.94	0.0840
4	LargestTreeDbh + Slope + Eastness + Large tree density + Tree size variability + LCR	7	23.98	4.14	0.0757
5	LargestTreeDbh + Slope + Eastness + Tree size variability	5	27.75	7.91	0.0115
6	LargestTreeDbh + Tree size variability + LCR	4	34.87	15.03	0.0003

Table 3. Continued.

Model	Variables	K	AIC_c	ΔAIC_c	w_i
7	LargestTreeDbh + LCR	3	37.87	18.03	0.0000
8	Null Model	1	74.89	55.05	0.0000

[1]LargestTreeDbh is the dbh (cm) of the largest tree in each plot.

[2]Slope is the percent slope for each plot.

[3]Tree size variability is the standard deviation of the dbh (cm) of all trees in the plot.

[4]LCR is the ratio of live crown length to total tree for trees ≥42 cm dbh.

[5]Eastness is the transformed aspect using trigonometric function (*Sin* [aspect in degrees]).

[6]Large tree density is the number of trees ≥42 cm dbh per ha.

[7]Small tree density is the number of trees <42cm dbh per ha.

Table 4. Model-averaged parameter estimates, unconditional standard errors (UCSE), odds ratios, and sum of AIC weights ($\sum w_i$) of variables used in 6 *a posteriori*, global and null models to predict microhabitat characteristics (habitat characteristics within a 30-m diameter area centered at the roost tree and measured on ground-based plots) of night roosts selected by 7 bald eagles (6 adult, 1 subadult) in northern Arizona ponderosa pine forests 2005-2007 (n = 54) compared to random plots (n = 54).

Parameter (β)	Estimate of β	UCSE	Odds Ratio	$\sum w_i$
LargestTreeDbh[1, 2]	0.0944	0.0272	1.0990	1.0000
Tree size variability[1, 3]	0.1237	0.0512	1.1317	0.9999
Slope[1, 4]	0.0705	0.0270	1.0731	0.9996
LCR[1, 5]	0.8125	0.2231	2.2535	0.9885
Eastness[6]	-0.3228	0.4769	0.7241	0.3968
Large tree density[7]	0.0835	0.1101	1.0871	0.1598
Small tree density[8]	-0.0086	0.0265	0.9915	0.0840

[1]95% confidence interval does not include zero.

[2]LargestTreeDbh is the dbh (cm) of the largest tree in each plot.

[3]Tree size variability is the standard deviation of the dbh (cm) of all trees in the plot.

[4]Slope is the percent slope for each plot.

[5]LCR is the ratio of live crown length to total tree for trees ≥42 cm dbh.

[6]Eastness is the transformed aspect using trigonometric function (*Sin* [aspect in degrees]).

[7]Large tree density is the number of trees ≥42 cm dbh per ha.

[8]Small tree density is the number of trees <42cm dbh per ha.

Table 5. Variables, number of parameters in the model (K), Akaike's Information Criterion adjusted for small sample size (AIC_c), difference in AIC_c value between the model and the model with the lowest AIC_c value (ΔAIC_c), and Akaike weight (w_i) for 11 *a priori* candidate, global, and null models used to predict macrohabitat characteristics (habitat characteristics within a 90-m diameter plot centered at the roost tree based on spatial data layers from geographic information system) of night roosts selected by 8 bald eagles (6 adults, 1 subadult, and 1 juvenile) in northern Arizona ponderosa pine forests 2005-2007 (n = 200) compared to random plots (n = 200).

Model	Variables	K	AIC_c	ΔAIC_c	w_i
1	Hway[1] + Lake[2]+ Northness[3]	4	247.79	0.00	0.3870
2	Hway + Lake + Northness + Eastness[4]	5	248.27	0.47	0.3057
3	Hway + Interstate[5] + Lake + Northness + Eastness	6	248.37	0.57	0.2905
4	Global (PCC[6] + BasalArea[7] + Treeden[8] + Slope[9] + Aspect[10] + Hway + Interstate + Lake + Northness + Eastness)	11	254.08	6.28	0.0166
5	Hway	2	289.92	42.13	0.0000
6	Hway + Interstate	3	291.21	43.41	0.0000
7	Interstate	2	550.95	303.15	0.0000
8	Null	1	556.52	308.72	0.0000
9	PCC + BasalArea	3	556.99	309.19	0.0000
10	PCC	2	558.30	310.50	0.0000

Table 5. Continued.

Model	Variables	K	AIC_c	ΔAIC_c	w_i
11	Treeden	2	558.52	310.72	0.0000
12	Slope	2	558.52	310.72	0.0000
13	PCC + BasalArea + Treeden + Slope + Aspect	6	561.50	313.70	0.0000

[1]Hway is the distance (km) from roost to the nearest highway.

[2]Lake is the distance (km) from roost to the nearest lake.

[3]Northness (*Cos* [aspect in degrees]) is the transformed aspect using trigonometric function.

[4]Eastness (*Sin* [aspect in degrees]) is the transformed aspect using trigonometric function.

[5]Interstate is the distance (km) from roost to the nearest interstate.

[6]PCC is the percentage of area on the ground (map view) covered by crowns of trees.

[7]BasalArea is the cross section area of the stems of trees (m^2/ha).

[8]Treeden is a measure of the number of trees per ha.

[9]Slope is the percent slope of the site.

[10]Aspect is the compass direction of the slope.

Table 6. Means ($\bar{x}$), standard errors (SE) and ranges of macrohabitat characteristics (habitat characteristics within 90-m diameter plot centered at roost tree based on spatial data layers from geographic information system) of night roosts selected by 8 bald eagles (6 adults, 1 subadult, and 1 juvenile; $n = 200$) wintering in northern Arizona from 2005 to 2007 compared with randomly-selected plots ($n = 200$).

Variables	Roost			Random		
	$\bar{x}$	SE	Range	$\bar{x}$	SE	Range
PCC[1]	47.8	1.4	0.0 - 81.2	48.6	1.1	0.0 - 87.7
BasalArea[2]	20.1	0.5	0.0 - 41.3	19.3	0.5	0.0 - 46.5
Treeden[3]	351.4	10.6	0.0 - 843.4	349.1	10.8	0.0 - 908.3
Slope[4]	8.7	0.7	0.0 - 68.4	8.8	0.7	0.2 - 82.2
Hway[5]	3.9	0.2	0.1 - 18.1	29.1	1.6	0.1 - 7.9
Interstate[6]	8.4	0.4	0.1 - 52.4	10.3	0.5	0.1 - 34.8
Lake[7]	10.3	0.3	0.1 - 32.8	6.3	0.3	0.1 - 21.2
Northness[8]	0.1	0.0	n/a[9]	0.0	0.0	n/a
Eastness[10]	0.1	0.0	n/a	0.0	0.0	n/a

[1]PCC is the percentage of area on the ground (map view) covered by crowns of the trees.

[2]BasalArea is the cross section area of the stems of trees (m^2/ha).

[3]Treeden is a measure of the number of trees per ha.

[4]Slope is the percent slope of the site.

[5]Hway is the distance (km) from roost to the nearest highway.

[6]Interstate is the distance (km) from roost to the nearest interstate.

[7]Lake is the distance (km) from roost to the nearest lake.

[8]Northness (*Cos* [aspect in degrees]) is the transformed aspect using trigonometric function.

[9]Not applicable for the numeric value.

[10]Eastness (*Sin* [aspect in degrees]) is the transformed aspect using trigonometric function.

Table 7. Model-averaged parameter estimates, unconditional standard errors (UCSE), odds ratios, and sum of AIC weights ($\sum w_i$) of variables used in models to predict macrohabitat characteristics (habitat characteristics within a 90-m diameter plot centered at the roost tree based on spatial data layers from geographic information system) of night roosts selected by 8 bald eagles (6 adults, 1 subadult, and 1 juvenile; n = 200) in northern Arizona ponderosa pine forests 2005-2007 compared to random plots (n = 200).

Parameter (β)	Estimate of β	UCSE	Odds Ratio	$\sum w_i$
Hway[1, 2]	-0.0003	0.0000	0.9997	0.9999
Lake[1, 3]	0.0002	0.0000	1.0002	0.9999
Northness[4]	0.3642	0.2307	1.4394	0.9999
Eastness[5]	0.2656	0.2357	1.3042	0.5643
Interstate[6]	0.0000	0.0000	1.0000	0.2856
PCC[7]	0.0047	0.0123	1.0047	0.0215
BasalArea[8]	-0.0046	0.0417	0.9954	0.0215
Treeden[9]	-0.0004	0.0019	0.9996	0.0215
Slope[10]	0.0225	0.0204	1.0228	0.0215
Aspect[11]	-0.0025	0.0017	0.9975	0.0215

[1]95% confidence interval does not include zero.

[2]Hway is the distance (km) from roost to the nearest highway.

[3]Lake is the distance (km) from roost to the nearest lake.

[4]Northness (*Cos* [aspect in degrees]) is the transformed aspect using trigonometric function.

[5]Eastness (*Sin* [aspect in degrees]) is the transformed aspect using trigonometric function.

[6]Interstate is the distance (km) from roost to the nearest interstate.

[7]PCC is the percentage of area on the ground (map view) covered by crowns of trees.

[8]BasalArea is the cross section area of the stems of trees (m^2/ha).

[9]Treeden is a measure of the number of trees per ha.

[10]Slope is the percent slope of the site.

[11]Aspect is the compass direction of the slope.

Table 8. Variables, number of parameters in the model (K), Akaike's Information Criterion adjusted for small sample size (AIC_c), difference in AIC_c value between the model and the model with the lowest AIC_c value (ΔAIC_c), and Akaike weight (w_i) for 11 *a priori* candidate, global, and null models used to predict macrohabitat characteristics (habitat characteristics within a 90-m diameter plot centered at the roost tree based on spatial data layers from geographic information system) of night roosts selected by 6 adult bald eagles in northern Arizona ponderosa pine forests 2005-2007 (n = 133) compared to random plots (n = 133).

Model	Variables	K	AIC_c	ΔAIC_c	w_i
1	Hway[1] + Lake[2] + Northness[3]	4	188.54	0.00	0.45
2	Hway + Lake + Northness + Eastness[4]	5	189.60	1.06	0.27
3	Hway + Interstate[5] + Lake + Northness + Eastness	6	190.46	1.92	0.17
4	Global (PCC[6] + BasalArea[7] + Treeden[8] + Slope[9] + Aspect[10] + Hway + Interstate + Lake + Northness + Eastness)	11	191.36	2.81	0.11
5	Hway	2	205.38	16.84	0.00
6	Hway + Interstate	3	206.81	18.27	0.00
7	Interstate	2	369.23	180.69	0.00
8	Null	1	370.77	182.22	0.00
9	Treeden	2	372.12	183.65	0.00
10	Slope	2	372.57	184.02	0.00
11	PCC	2	372.76	184.21	0.00

Table 8. Continued.

Model	Variables	K	AIC_c	ΔAIC_c	w_i
12	PCC + BasalArea	3	373.03	184.48	0.00
13	PCC + BasalArea + Treeden + Slope + Aspect	6	376.74	188.19	0.00

[1]Hway is the distance (km) from roost to the nearest highway.

[2]Lake is the distance (km) from roost to the nearest lake.

[3]Northness (*Cos* [aspect in degrees]) is the transformed aspect using trigonometric function.

[4]Eastness (*Sin* [aspect in degrees]) is the transformed aspect using trigonometric function.

[5]Interstate is the distance (km) from roost to the nearest interstate.

[6]PCC is the percentage of area on the ground (map view) covered by crowns of trees.

[7]BasalArea is the cross section area of the stems of trees (m^2/ha).

[8]Treeden is a measure of the number of trees per ha.

[9]Slope is the percent slope of the site.

[10]Aspect is the compass direction of the slope.

Table 9. Variables, number of parameters in the model (K), Akaike's Information Criterion (AIC), difference in AIC value between the model and the model with the lowest AIC value (ΔAIC), and Akaike weight (w_i) for *a priori* candidate, global, and null models used to describe the relationship between locations of night roosts and first or last location during the day for 10 bald eagles (7 adults, 1 subadult, and 2 juveniles) of all vegetation types in northern Arizona during winter 2005-2007 (n = 1052).

Model	Variables	K	AIC	ΔAIC	w_i
1	Global (distance[1], age class[2], season[3])	4	885.70	0.00	1.00
2	Season	2	1,385.70	500.00	0.00
3	Null	1	1,387.11	501.41	0.00

[1]Distance from first or last locations to the night roost locations during the day.

[2]Age class of 10 bald eagles, i.e., adult, subadult and juvenile, which were captured and radio-tagged by Arizona Department of Emergency and Military Affairs and Arizona Game and Fish Department in 2005-2007.

[3]Seasons, i.e., fall (Oct-Dec) and winter (Jan-Apr), when the locations of 10-radio-tagged eagles were recorded.

Table 10. Distance moved by 10 radio tagged bald eagles (n = 1052; 7 adults, 1 subadult, and 2 juveniles) between the last location of the day (1700 hr) and first location of the night (2000 hr; n = 636) compared to last location of the night (2300 hr) and first location of the next day (0800 hr; n = 388). Eagles were monitored during winters of 2005, 2006 and 2007 in northern Arizona.

	Distance (km) moved between 1700 and 2000				Distance (km) moved between 2300 and 0800			
	n	$\bar{x}$	SE	Range	n	$\bar{x}$	SE	Range
Fall								
Adult	112	0.55	0.12	0.0 - 11.54	64	48.94	7.70	0.09 - 251.90
Subadult and Juvenile	100	0.59	0.09	0.0 - 6.21	39	11.22	1.95	0.0 - 51.60
Winter								
Adult	317	1.41	0.15	0.0 - 21.74	218	48.80	4.98	0.0 - 298.35
Subadult and Juvenile	135	0.73	0.13	0.0 - 12.31	67	15.50	3.92	0.0 - 189.78

Table 11. Habitat characteristics of hotspots (500-m-radius plots used for ≥5 nights by ≥1 eagle[s] as night roosts; *n* = 12) for 10 bald eagles (7 adults, 1 subadult, and 2 juveniles) wintering in northern Arizona during 2005, 2006, and 2007.

Hot spot	Eagle ID[1]	Yrs Used[2]	Latitude[3]	Longitude[4]	Slope[5]	Asp[6]	Elevation[7]	Dist to lakes[8]	Dist to highways[9]	Dist to interstates[10]
H1	53788	2006	35.18467	112.29350	5.8 ± 0.3	NE	2,014.2 ± 0.2	14.4 ± 0.0	4.0 ± 0.0	4.0 ± 0.0
H2	53788	2006, 2007	35.19417	112.28433	1.8 ± 0.2	NE	2,008.5 ± 0.7	14.3 ± 0.0	3.0 ± 0.0	3.0 ± 0.0
H3	53785	2005	35.31933	112.09567	5.3 ± 0.2	NE	2,069.7 ± 0.3	4.6 ± 0.0	4.6 ± 0.0	6.4 ± 0.0
H4	53783, 53788	2005	35.14933	112.13983	5.5 ± 0.9	NW	2,170.1 ± 0.8	12.2 ± 0.0	3.2 ± 0.0	12.1 ± 0.0
H5	53788	2005, 2006, 2007	35.12517	112.03183	7.1 ± 0.5	NW	2,029.4 ± 0.6	18.6 ± 0.0	0.3 ± 0.0	14.6 ± 0.0
H6	53784, 53787, 53788, 73450	2005, 2006, 2007	35.14633	111.79783	9.2 ± 1.2	NE	2,220.4 ± 1.7	7.6 ± 0.0	0.1 ± 0.0	6.7 ± 0.0
H7	53787, 53788	2005, 2006	35.07117	111.79583	2.39 ± 1.2	NE	2,177.3 ± 0.5	5.7 ± 0.0	7.9 ± 0.1	9.9 ± 0.0
H8	53788, 73450	2006, 2007	34.99667	111.70267	11.9 ± 2.4	SW	2,053.8 ± 2.4	2.9 ± 0.0	9.2 ± 0.0	1.3 ± 0.0
H9	53788	2006	35.20933	111.61533	2.0 ± 0.3	NE	2,014.2 ± 0.2	4.7 ± 0.0	11.7 ± 0.0	26.7 ± 0.0
H10	73447, 73448	2007	35.17617	111.60233	28.7 ± 0.9	SE	2,008.5 ± 2.2	4.1 ± 0.0	9.5± 0.0	22.9 ± 0.0

Hot spot	Eagle ID[1]	Yrs Used[2]	Latitude[3]	Longitude[4]	Slope[5]	Asp[6]	Elevation[7]	Dist to lakes[8]	Dist to highways[9]	Dist to interstates[10]
H11	53784	2005, 2006	35.91617	111.94317	3.2 ± 0.6	SW	2,120.5 ± 2.4	6.4 ± 0.0	7.0 ± 0.0	72.5 ± 0.0
H12	53784	2007	36.99517	112.29183	2.6 ± 0.2	SE	2,085.4 ± 0.4	12.5 ± 0.0	24.1 ± 0.0	191.9 ± 0.0

[1]Eagle ID is the transmitter numbers used by Arizona Game and Fish Department and Department of Emergency and Military Affairs when the eagles were tagged.

[2]Years when bald eagles used plots as night roosts.

[3]Latitude of the hotspots taken at the center of the 500-m radius plot.

[4]Longitude of the hotspots taken at the center of the 500-m radius plot.

[5]The average percent slope of multiple roost locations within a hotspot.

[6]The aspect of the 500-m radius plot (hotspot) calculated from the Digital Elevation Model.

[7]The average elevation (m) of multiple roost locations within a hotspot.

[8]The average distance (km) of multiple roost locations to the corresponding nearest lake from a hotspot.

[9]The average distance (km) of multiple roost locations to the corresponding nearest highway from a hotspot.

[10]The average distance (km) of multiple roost locations to the corresponding nearest interstate from a hotspot.

Table 12. Comparison of habitat characteristics (slope, elevation, distances to lakes, highways, and interstates) of hotspots (n = 12; 500-m-radius plots used for ≥5 nights by ≥1 eagle[s] as night roosts) between hotspots used by 1 bald eagle and the hotspots used by ≥2 bald eagles wintering in northern Arizona for 10 bald eagles (7 adults, 1 subadult, and 2 juveniles) during winter 2005-2007.

Habitat characteristics	Hotspots used by 1 eagle	Hotspots used by >1 eagles
Slope (%)[1]	4.0 ± 0.3	11.54 ± 1.3
Elevation (m)[2]	2,048.8 ± 0.7	2,126.0 ± 1.5
Distance to lakes (km)[3]	10.8 ± 0.0	6.6 ± 0.0
Distance to highways (km)[4]	7.8 ± 0.0	6.0 ± 0.0
Distance to Interstates (km)[5]	45.6 ± 0.0	10.6 ± 0.0

[1]The average slope (%) of multiple roost locations within a hotspot.

[2]The average elevation (m) of multiple roost locations within a hotspot.

[3]The average distance (km) from multiple roost locations in a hotspot to the corresponding nearest lake.

[4]The average distance (km) from multiple roost locations in a hotspot to the corresponding nearest highway.

[5]The average distance (km) from multiple roost locations in a hotspot to the corresponding nearest interstate.

Appendix 1. Age class, capture date, migratory status, weight, capture location, and number of night roost locations in Arizona for bald eagles with Global Positioning System (GPS) transmitters by vegetation type and eagle. Ten bald eagles were captured and radio tagged by Arizona Department of Emergency and Military Affairs and Arizona Game and Fish Department in northern Arizona. Night roost locations were recorded in 2005, 2006, and 2007 in northern Arizona.

Trans. No.[1]	Age Class[2]	Capture Date[3]	Mig. Status[4]	Wt. (kg)[5]	UTMe[6]	UTMn[7]	NAZ[8]	PIPO[9]	P-J[10]	M-C[11]	G/SL[12]	BL[13]	DA[14]
53783	Juvenile	2/8/2005	Migratory	4.8	419625	3893418	31	25	0	0	6	0	0
53784	Adult	1/25/2005	Migratory	5.1	423576	3896279	190	97	48	0	39	4	2
53785	Adult	2/14/2005	Migratory	5.2	419625	3893418	66	55	9	0	1	0	1
53786	Adult	2/10/2005	Migratory	5.0	419625	3893418	14	8	5	0	1	0	0
53787	Adult	1/21/2005	Migratory	5.2	423576	3896279	55	37	5	0	6	1	6
53788	Subadult	2/25/2005	Migratory	6.0	419625	3893418	187	157	17	4	4	3	2
73447	Juvenile	3/5/2007	Migratory	3.9	419625	3893418	19	0	0	0	9	7	3
73448	Adult	3/5/2007	Resident	4.2	419625	3893418	16	0	0	0	8	8	13

Appendix 1. Continued.

Trans. No.[1]	Age Class[2]	Capture Date[3]	Mig. Status[4]	Wt. (kg)[5]	UTMe[6]	UTMn[7]	NAZ[8]	PIPO[9]	P-J[10]	M-C[11]	G/SL[12]	BL[13]	DA[14]
73449	Adult	2/1/2007	Migratory	3.7	419625	3893418	34	14	0	3	4	0	9
73450	Adult	2/1/2007	Migratory	4.5	419625	3893418	24	11	0	0	4	0	0

[1]Eagles were given unique ID based on GPS transmitter number.

[2]Eagles were categorized as adult (≥5 yrs of age), subadult (>2 to <5 yrs of age), and juvenile (≤2 yrs of age) based on their age at time of capture. Trans. No. 53788 was categorized as an adult for microhabitat analysis but as a subadult for macrohabitat analysis.

[3]The date (month/day/year) eagles were captured and fitted with GPS transmitters.

[4]Migration status (migratory or resident) of eagles based on their movement throughout the year.

[5]Weight of eagle measured in kilograms during capture.

[6]UTMe (Universal Transverse Mercator east), a coordinate to specify the location of the bald eagle capture site (NAD 1983, UTM Zone 12N).

[7]UTMn (Universal Transverse Mercator north), a coordinate to specify the location of the bald eagle capture site (NAD 1983, UTM Zone 12N).

[8]Number of night roost locations (n = 636) in Arizona.

[9]Number of night roost locations (n = 404) in ponderosa pine forests.

[10]Number of night roost locations (n = 84) in pinyon-juniper forests.

[11]Number of night roost locations (n = 7) in mixed conifer forests.

[12]Number of night roost locations (n = 82) in grassland or shrub land.

[13]Number of night roost locations (n = 23) in barren land.

[14]Number of night roost locations (n = 36) in development areas.

Appendix 2. Number of locations recorded for 10 bald eagles (7 adults, 1 subadult, and 2 juveniles) during 2005-2007. Bald eagles were captured and radio tagged by Arizona Department of Emergency and Military Affairs and Arizona Game and Fish Department during winter 2005 and 2007 in northern Arizona.

Observation Type	No. of eagles	No. of observation	Reference
All locations[1]	10	23,822	USA and Canada
Arizona (AZ) only[2]	10	6,733	~6 locations per day
Total AZ night locations[3]	10	636	Error 0 to >100 m
AZ night locations with Euclidean distance of zero[4]	10	279	Error = 0 m
AZ night locations with migratory adults and subadult[5]	7	173	Error = 0 m
Sample observations on the ground[6]	7	54	Error = 0 m

[1]All locations = Locations throughout the United States and Canada.

[2]Arizona (AZ) only = the number of locations in only Arizona taken daily at 0800, 1100, 1400, 1700, 2000, and 2300 (Mountain Standard Time [MST]).

[3]Total AZ night locations = number of locations in Arizona taken at 2000 and 2300 hrs MST from all vegetation types.

[4]AZ night locations with Euclidean distance of zero = number of night locations per eagle with Euclidean distance of zero between 2000 and 2300 locations (all vegetation types).

[5]AZ night locations with migratory adults and subadult = number of night locations per eagle with Euclidean distance of zero between 2000 and 2300 locations (all vegetation types) only for adult and subadult migratory eagles (excluding juveniles and resident eagles).

[6]Sample observations on the ground = number of night locations randomly sampled for microhabitat analysis from AZ night locations with migratory adults and subadult (n = 173, error = 0). Each sample was in ponderosa pine forest.

Appendix 3. Number of and years used as for night roosts by 10 bald eagles (7 adults, 1 subadult, and 2 juveniles) in Arizona with their age classes and migration status (migratory or resident). Bald eagles were captured and radio tagged by Arizona Department of Emergency and Military Affairs and Arizona Game and Fish Department during 2005-2007 in northern Arizona. Microhabitat was habitat characteristics within a 30-m diameter area centered at the roost tree and measured on ground-based plots. Macrohabitat was habitat characteristics within a 90-m diameter plot centered at the roost tree based on spatial data layers from a geographic information system.

Eagle ID	No. of roosts in microhabitat	Yrs recorded in microhabitat	No. of roosts in macrohabitat	Yrs recorded in macrohabitat	Age class	Migration status
53783	0	0	24	2005	Juvenile	Migratory
53784	15	2005-2007	34	2005-2007	Adult	Migratory
53785	9	2005-2006	31	2005-2007	Adult	Migratory
53786	3	2005-2006	7	2005-2006	Adult	Migratory
53787	13	2005-2006	36	2005	Adult	Migratory
53788	3	2005-2007	43	2005-2007	Subadult	Migratory
73447[1]	0	0	0	0	Juvenile	Migratory

Appendix 3. Continued.

Eagle ID	No. of roosts in microhabitat	Yrs recorded in microhabitat	No. of roosts in macrohabitat	Yrs recorded in macrohabitat	Age class	Migration status
73448[1]	0	0	0	0	Adult	Resident
73449	4	2007	14	2007	Adult	Migratory
73450	7	2007	11	2007	Adult	Migratory
Total	54		200			

[1]These locations were not included in microhabitat or macrohabitat analysis but the locations of these two eagles were used to analyze relationship between locations of night roosts and first or last location of the day.