

AN ABSTRACT OF THE THESIS OF

Patrick J. Tweedy for the degree of Master of Science in Sustainable Forest Management presented on March 16, 2018.

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Abstract approved: _____

John D. Bailey

Forests in the western United States have changed drastically over the past 150 years given a long history of utilization (harvest and grazing) and associated fire exclusion. These actions have altered the composition and structure of these forests as well as affected ecosystem function. Current policies for federal land management have shifted to improve forest health and resiliency. However, wildlife species sensitive to forest disturbance (e.g., wildfire, timber harvest) often conflict with forest management goals and activities that reduce the amount of available intact habitat and connectivity for mesocarnivores.

Pacific marten (*Martes caurina*) populations have become fragmented and constricted throughout their western range due to a combination of increased wildfire, timber harvest, climate change, and historic fur trapping. Martens rely on rest structures, often live trees, snags, or logs where martens sleep, for protection from inclement weather and predation risk. Rest structures are considered a limiting habitat element; their abundance, type, and distribution has been suggested as a way to evaluate habitat quality. Our study objective was to better understand the selection of resting habitat by martens in order to help foresters and biologists better manage marten species on the landscape.

Our first objective was to understand whether marten rest structure selection was correlated with seasonal activity patterns. Pacific martens in the Sierra Nevada Mountains of California appear primarily nocturnal during winter and diurnal during summer. Diurnal rest sites (live trees, logs, snags, stumps) in both seasons have been described previously, but nocturnal summer rest sites have not. We hypothesized that all resting structures used by martens would be specialized (e.g., larger, older) compared to available structures, but that nocturnal structures would be larger in diameter than daytime sites and restricted to structures with cavity microsites. From 2009 – 2013 and 2015 – 2017, we collected radio telemetry on 37 martens (23♂, 14♀) locating 140 diurnal and 32 nocturnal rest structures. We did not detect a difference in the size of structures between diel periods; however, martens used rest structures that were much larger than the majority of measured random structures (used = 95.5 ± 31.8 cm; random = 52.1 ± 25.2 cm, $\bar{x} \pm SD$, $t = 15.1$, $p < 0.001$). The selection of rest structure and microsite types did not differentiate between diel periods. There was some evidence of increased use of cavity and subterranean microsites at night. Our results emphasize the importance of conserving a diversity of structure types and sizes likely needed for marten habitat.

Our second objective was to examine multiscale habitat relationships at Pacific marten rest structures using fine-resolution vegetation data (30m airborne LiDAR) and ground-based data. Using a moving-window framework to compare selection, we optimized 14 covariates at 12 spatial scales (30m-990m). We monitored martens from 2009-2012 and 2015-2017 ($n=312$ resting structures, 31 martens), and then compared used vs. randomly-sampled locations ($n_{\text{rand}}=624$) in order to develop multivariate habitat selection models. Our top model included trees per acre (990 meter scale) and elevation (900m), suggesting that martens select for increased tree cover at higher elevations at the home range scale. Increased structural complexity

and canopy cover surrounding rest structures (270 and 30 meters, respectively) increased probability of selection. Because martens selected locations with vegetation characteristics optimized at 30-270m, 270m may be an appropriate scale to consider for management, for instance, establishing leave islands or focal areas for restoration. We provide the first evaluation of marten habitat using LiDAR, which can be broadly and accurately extrapolated for management planning and restoration prioritization.

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Diel Rest Structure Selection and Multiscale Analysis of Pacific Marten Resting Habitat in
Lassen National Forest, California

by
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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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CONTRIBUTION OF AUTHORS

Dr. John Bailey, Dr. Katie Moriarty, and Dr. Clinton Epps contributed to all chapters of this thesis. Dr. Katie Moriarty contributed to Appendix A.

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1 | Introduction

Habitat loss and fragmentation are considered to be the greatest threat to global biodiversity (Wilcove et al. 1998). Mammalian carnivore groups are more sensitive to habitat loss than other terrestrial mammals (Karanth and Chellam 2009) due to large space requirements, relatively low birth rates, conflict with human activities, and occurrence at low densities. Carnivores disproportionately affect communities where they reside by increasing biodiversity and ecosystem resilience (Terborgh et al. 2001, Ripple and Beschta 2012), yet species ranges of multiple carnivores have become constricted due to human settlement and interference in forest ecosystems (Woodroffe 2000, Laliberte and Ripple 2004, Ripple et al. 2014). In North America, additional threats to carnivore groups includes climate change (McKelvey et al. 2011, Koen et al. 2014) and increasing severity and size of wildfires (Scheller et al. 2011, Sweitzer et al. 2016).

1.1 History of forests in the Sierra Nevada Mountains

Prior to European settlement, the Sierra Nevada and Cascade Mountains of California contained extensive forests with diverse flora and fauna ecosystems that evolved since the Pleistocene. Complex ecological relationships formed by a variety of environmental components (e.g., habitat, climate, disturbance regimes, and life history traits) influenced the distribution of wildlife species. The presence of early Native American populations elevated the anthropogenic stress on these montane forests but the level of resource extraction was unlikely to disrupt ecosystem function at a large scale. Subsequent discovery of gold and ore deposits increased the demand on these forests for resources to support the western expansion of European Americans (McKelvey and Johnston 1992). Further settlement and population growth across the western United States accelerated the need for more wood products. In the early 1850's, 0.5 million

board feet were removed annually from these forests increasing to nearly five billion board feet by the 1950's. Consequently, at least 20 percent of the forests in the Sierra Nevada and Cascade Mountain ranges had been logged at least once by the mid-twentieth century (Laudenslayer JR. and Darr 1990).

Over the past 150 years, a policy of fire suppression has developed within the national forest system as a means of “protecting” these natural resources (McKelvey and Johnston 1992). Fire exclusion has drastically altered the composition of these forests creating more structurally homogenous, denser forest stands with increased surface litter (Taylor 2000, Beaty and Taylor 2008, Bekker and Taylor 2010). The frequency of high-intensity, high-severity fires has increased in California as a result of this legacy of suppression combined with the impacts of climate change (Laudenslayer JR. and Skinner 1995, Miller et al. 2012, Steel et al. 2015). While suppression continues to be the primary strategy for managing fire on the landscape, wildfire remains an important ecosystem function and major disturbance process. Management strategies focused on increasing the resiliency of the forests and returning the Sierra Nevada Mountains to its natural fire regime is ongoing but has yet to be effectively applied to the landscape (Agee and Skinner 2005, North et al. 2009). The implementation of fuel management strategies combined with the continued harvest of timber often conflicts with the current management strategy for wildlife species sensitive to forest loss.

1.2 Pacific marten

In the western United States, Pacific martens (*Martes caurina*) are typically associated with late-seral, structurally complex coniferous forests (Spencer et al. 1983, Buskirk and Powell 1994, Bull et al. 2005). Older forest stands provide dense canopy cover that martens rely on for

avoidance of predators (Spencer et al. 1983, Moriarty et al. 2016). These stands typically contain specialized features such as coarse woody debris used by martens for foraging (Andruskiw et al. 2008, Vanderwel et al. 2010, McLaren et al. 2013), and large diameter trees used for resting (Bull and Heater 2000) and protection from inclement weather (Taylor and Buskirk 1994). In the Sierra Nevada Mountains, martens are typically found in forests that are subject to persistent snow cover in the winters (Spencer et al. 1983). Their long, thin bodies combined with large feet assists the marten to move efficiently across the snow covered landscape (Krohn et al. 2004). This adaptation to the harsh winter climate allows martens to occupy high elevation areas where other predators (e.g., bobcats (*Lynx rufus*)) are forced to lower elevations for many months of the year.

Although fur harvest has contributed to the population declines of martens in California, trapping of martens has been outlawed since the 1950s (Grinnell et al. 1937, Biberdorf 1982). Loss of mature forest due to timber harvest in the second half of the 20th century has further contributed to clustered and fragmented marten populations in northern California (Buskirk and Ruggiero 1994, Zielinski et al. 2005, Kirk and Zielinski 2010). Even with canopy cover retained, simplified forest stands due to management activities are often avoided by martens in California (Moriarty et al. 2015, Moriarty et al. 2016). A future decline of 40 – 85% in marten habitat is predicted due to accumulating factors associated with increased temperatures and reduced snowpack via the effects of climate change (Spencer et al. 2015). Due to the marten's specific habitat associations and population changes in response to habitat loss and fragmentation (Chapin et al. 1998, Hargis et al. 1999, Moriarty et al. 2011), the marten is classified as a Management Indicator Species (Pendleton 2007) and as a Species of Special Concern (CA Department of Fish and Wildlife 2017).

1.3 Forest dependent species and vegetation

Forest fragmentation and increased frequency of high-intensity, high-severity fires can negatively impact the habitat of other Management Indicator Species in California such as the California spotted owl (*Strix occidentalis occidentalis*) (Stephens et al. 2014, Stephens et al. 2016) and Pacific fisher (*Pekania pennanti*) (Scheller et al. 2011, Sweitzer et al. 2016); species that require dense canopy cover and large trees (Purcell et al. 2009, North et al. 2017). Managing for sensitive species on public lands where multiple objectives (e.g., timber production, recreation, cattle grazing, etc.) exist is a complex, if not impossible task. One widely used tool in this region includes the California Wildlife Habitat Relationship database, which uses broad-scale habitat associations and life history traits of species to assist with wildlife management. Forest types are classified using the dominant tree size class and the amount of canopy cover (Mayer and Laudenslayer JR. 1988). However, there are significant disadvantages to this database because it does not account for temporal aspects and lacks consideration of special features such as snags, down wood or understory diversity (North and Manley 2012). Further this program will often mistakenly increase predicted habitat quality for late seral species like spotted owls and martens after fuel and fire treatments due to the reduction of canopy cover (Moriarty et al. 2016, Stephens et al. 2016)

Broadly classifying vegetation associations is not synonymous with a species' habitat. We use the definition of habitat described by Krausman and Morrison (2016) as the resources and conditions available in an area that allows occupancy in which species can survive and reproduce. Vegetation is a component of the species-specific resources required for population persistence (Hall et al. 1997, Krausman 1999). While considering vegetation associations when managing multiple species on the landscape there is an inherent scale dependency of habitat

selection (Johnson 1980), or the disproportionate use of available conditions and resources (Mayor et al. 2009). Habitat selection is a hierarchal process both in space and through time (Van Beest et al. 2010).

1.4 Importance of scale

Understanding how martens use their habitat can help identify areas that require habitat protection or restoration as martens require large spatial areas and are associated with forests at multiple scales (Bissonette and Broekhuizen 1995, Bissonette et al. 1997). Vegetation data may be collected at a small scale and extrapolated across the broader landscape, but such practices can obscure the heterogeneity of the landscape. This can overestimate the amount of habitat available especially fine scale selection of functional habitat (conditions for biological fitness) (McCann et al. 2014). Habitat use patterns are directly linked to the scale used for investigation (Ciarniello et al. 2007); nonetheless determining the relevant scale for data collection requires careful consideration of the species' life history traits (Wiens 1989, Morin et al. 2005) as animals may use habitat components at different scales (Apps et al. 2001, Krebs et al. 2007). Temporal and spatial scales are inextricably linked (Wiens 1989). For example, variability in prey populations, predation risk, or even weather is often seasonal and can influence habitat selection (Lima and Bednekoff 1999, Krebs et al. 2007, Zielinski et al. 2015). It is therefore most biologically relevant to measure data at multiple spatial and temporal scales to analyze and infer patterns of species habitat use (Levin 1992).

1.5 Activity patterns

Species' activity patterns are one aspect of temporal scale. Understanding the mechanisms that influence activity patterns (e.g., species' biology, use of vegetation types, seasonality of behavior) can help biologists improve management strategies (Naylor and Kie 2004, Norris et al. 2010). For instance, multiple hypotheses have been put forth regarding the activity patterns of martens, each attributed to either environmental or community-based factors. Zielinski et al. (1983) proposed that martens use an optimal foraging strategy linked to the time period when prey are most active. This hypothesis stipulates martens would be active at the same time of their prey. Support for this prediction was demonstrated from the diet of martens. Scat analysis found nocturnal flying squirrels (*Glaucomys sabrinus*) and snowshoe hares consumed in the winter while diurnal sciurids (e.g., *Callospermophilus lateralis*, *Tamiasciurus douglasii*) comprised most of the diet in the summer (Zielinski et al. 1983). As such, martens could shift their activity patterns from dominantly nocturnal in the winter to diurnal in the summer (Zielinski et al. 1983). Nonetheless, other hypotheses have been put forth that avoidance of diurnal predators would be important for martens, making a nocturnal activity pattern advantageous (Drew and Bissonette 1997). Conversely, due to the marten's meager fat reserves and long, thin body shape, Thompson and Colgan (1994) proposed that marten activity patterns would be more related to temperature, predicting that martens would remain diurnal during the winter and diurnal or nocturnal during the summer.

1.6 Research goals and hypotheses

We use Pacific martens as a case study to evaluate both activity patterns and scale-specific selection. Due to the importance of rest structures for their thermoregulatory benefits and protection from predation, examining how martens perceive the landscape when selecting

resting habitat is critical. We examined rest structure selection in the summer between two spatial scales: the microsite (i.e., the specific resting location) and the rest structure during both day and night, evaluating whether martens change vegetation use with dominant activity patterns. Further, we tested whether rest structure use were similar to other studies in California. If cooler nighttime temperatures influence marten selection of rest structures, we predicted martens would be restricted to larger structures and cavity or subterranean microsites that would have increased thermoregulatory benefits (Green 2017). Conversely, if martens were purely synchronizing their activity with prey, then we predicted rest sites, structures, and microsites would be similar during both diel periods (diurnal, nocturnal) with diverse use of rest structures and microsites.

Next, we wanted to examine resting habitat selection at multiple spatial scales using Light Detecting and Ranging Technology (LiDAR) and ground-based sampling. To our knowledge, this is the first opportunity to pair highly accurate location data from martens with highly accurate vegetation data. First, we hypothesized that rest structures would be located in areas of structurally complex forest with dense canopy cover, which provides suitable habitat for foraging and reducing predation risk. Secondly, we hypothesized that vegetation and topographical covariates would be represented in a hierarchical scale response when compared to randomly sampled locations. Our goal in describing the relationships of diel rest structure use and multiscale resting habitat was to provide scientifically-based information and tools for foresters and biologists to better manage for forest dependent species like marten.

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2 | A comparison of diurnal and nocturnal rest structure use of Pacific martens in Lassen National Forest, California

2.1 Introduction

Pacific martens (*Martes caurina*) are associated with late seral, structurally complex forested environments. These long bodied members of the mustelid family have meager fat reserves. Thus, martens may select rest structures and microsites, or the locations where martens sleep, that provide thermoregulatory benefits (Taylor and Buskirk 1994), compensating for a marten's poor ability to conserve energy (Buskirk and Harlow 1989). Resting habitat is a critical environmental component for martens as they are a daily source of refugia providing protection from extreme weather as well as a physical barrier from predation (Buskirk and Powell 1994, Bull and Heater 2000). Resting structures often include live trees, snags, stumps, mistletoe clumps, logs, rock piles, shrub clumps or underground burrows (Spencer 1987, Bull and Heater 2000, Slauson and Zielinski 2009).

The abundance, type, and distribution of rest sites has been proposed as a way to evaluate habitat quality (Buskirk 1984). The availability of such features has been proposed to either limit or promote marten population viability on the landscape (Ruggiero et al. 1998, Porter et al. 2005). For instance, such structures are essential for female martens during parturition and the raising of kits (Bull and Heater 2000). Dens and cavity microsites may be particularly specialized - dry, insulated, with specific air flow to minimize suffocation risk (Thompson and Purcell 2016), with cavity openings small enough to be inaccessible to other predators (Ruggiero et al. 1998).

Vegetation attributes surrounding rest sites vary by geographic region, but rest structures typically are in areas with horizontal and vertical structural complexity, dense canopy cover,

large diameter trees, and coarse woody debris (Gilbert et al. 1997, Ruggiero et al. 1998, Bull et al. 2005, Andruskiw et al. 2008, Slauson and Zielinski 2009). These vegetative attributes provide escape cover from predators (Moriarty et al. 2016), are thermally beneficial (Weir et al. 2004, Betts et al. 2017) and are often related to increased foraging success (Spencer and Zielinski 1983, Coffin et al. 1997, Andruskiw et al. 2008). The spatial distribution of these resting structures can be associated with increased marten survival by being located near important foraging patches that minimize travel times between structures (Buskirk 1984, Spencer 1987).

Rest structure use has been studied throughout the geographic range of martens in North America including the seasonality of use between the winter and summer months (Buskirk 1984, Spencer 1987, Taylor and Buskirk 1994, Bull and Heater 2000, Wilbert et al. 2000, Joyce 2013, Sanders 2014). Nonetheless, the connection between rest structure use and activity patterns or the time of day when the animal is active, has not been clearly articulated. Activity patterns of carnivores can be an indicator of habitat quality especially if patterns change from prior activities following disturbance (Norris et al. 2010). Activity patterns are based on the outcome of two conflicting demands: (1) the activity required to maximize nutritional and reproductive objectives, and (2) the need to minimize costs and risks from the surrounding environment (Alkon and Saltz 1988). Activity patterns differ across martens' geographic range (Zielinski et al. 1983, Thompson and Colgan 1994, Drew and Bissonette 1997, Foresman and Pearson 1999), providing opportunities to test hypotheses (Table 2.1).

Table 2.1. Marten (*Martes americana*, *M. caurina*) activity patterns during the diel period. Martens selected periods of activity differently during each season and study area with use or selection (“X”), and unknown or unmeasured activity patterns (“?”). Marten activity may be correlated with 3 hypotheses: prey synchronization, predator avoidance, or thermoregulatory efficiency.

Study	Location	Summer			Winter		
		Twilight	Diurnal	Nocturnal	Twilight	Diurnal	Nocturnal
Zielinski et al. (1983)	Sagehen Creek, CA	X	X		X		X
Martin (1987)	Sagehen Creek, CA		X	X	?	?	?
Thompson and Colgan (1994)	Ontario, Canada	X	X	X		X	
Drew and Bissonette (1997)	Newfoundland, Canada	?	?	?			X

An opportunity to test relationships between marten activity patterns and rest structure use is in Lassen National Forest, California due to a recent wealth of information on marten movement and rest structure use. Preliminary analyses suggested martens were predominately diurnal, or active during the day, during the summer and largely nocturnal and active at night during winter (Appendix A). These results largely correspond to the prey synchronization hypothesis (Zielinski et al. (1983) and Bull and Heater (2000)), but this pattern could also correspond with the thermoregulatory hypothesis as lower temperatures at night may provide opportunities for energy conservation with martens being more selective. If martens are conserving energy at night, then their selection of resting structures during summer would be strongly correlated to particular locations of higher importance for individual marten fitness. There is an absence of information on marten rest structure selection at night, when martens appear to spend the majority of their time resting. Due to this lack of information, we may be overlooking ecological characteristics that are critical for martens.

Our objective was to compare marten resting structures and microsites with available locations between diel periods. If cooler nighttime temperatures influence marten selection of rest structures, we predicted martens would be restricted to larger structures and cavity or subterranean microsites that would have increased thermoregulatory benefits. Conversely, if martens were purely synchronizing their activity with prey, then we predicted rest sites,

structures, and microsites would be similar during both diel periods (diurnal, nocturnal) with diverse use of rest structures and microsites. Finally, we examined whether our results were consistent with similar rest structure studies in California (Tahoe National Forest, Martin and Barrett 1991; Six Rivers National Forest, Slauson and Zielinski 2009) to evaluate regional selection. We predicted that martens use similar structures throughout their range in California, however, we also predicted that the proportion of use of rest structure types could be a function of regional availability due to variable vegetation characteristics and disturbance regimes between study areas.

2.2 Methods

2.2.1 Study area

We collected marten activity and rest structure data in two areas of Lassen National Forest, which is approximately 130 km east of Red Bluff, California. The Humboldt study area was located 23.5 km south of Lassen Volcanic National Park. The Swain study area was located adjacent to Lassen Volcanic National Park to the east overlapping the Caribou Wilderness and Lassen National Forest land ownership (Figure 2.1).

Lassen National Forest is comprised of 3 ecoregions: the northern Sierra Nevada Mountains, the southern Cascade Mountains, and the high desert of the Modoc Plateau. Our study area included both the southern extent of the Cascade and northern extent of the Sierra Mountain Ranges (area ~490 km², elevation 3080 – 7160 meters). Forested stands included red fir (*Abies magnifica*), white fir (*Abies concolor*), and lodgepole pine (*Pinus contorta*) with a sparse understory of chaparral whitethorn (*Ceanothus leucodermis*) and manzanita (*Arctostaphylos spp.*). Average minimum and maximum temperatures in July are 6.9°C and 29.5°C respectively, and –6.9°C and 5.3°C in January (Western Regional Climate Center, 1948-

2005). Average annual precipitation is 96 – 253 cm, depending on the location in our study area and typically occurs as snow (Western Regional Climate Center, 1948-2005).

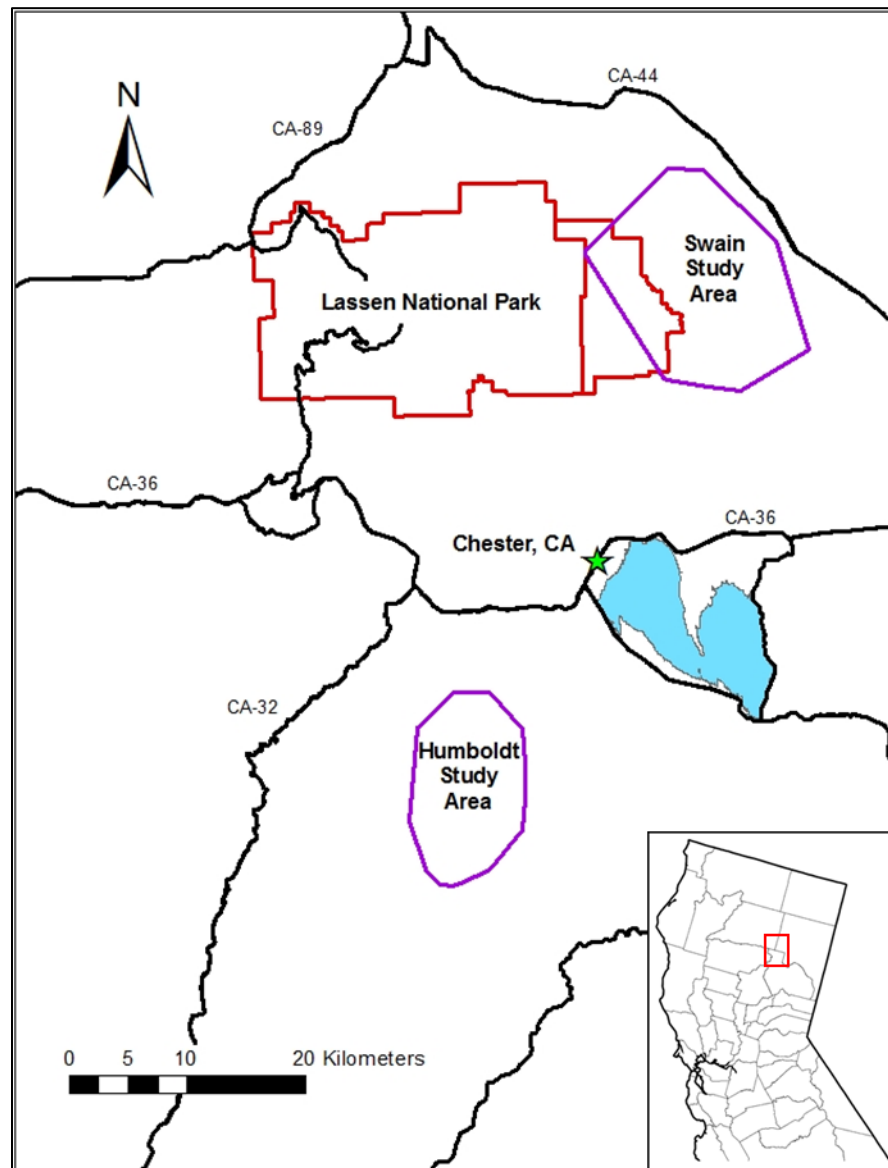


Figure 2.1. We collected Pacific marten (*Martes caurina*) activity and rest structure location in two locations south and east of Lassen National Park, California. The Humboldt study area was $\sim 128\text{km}^2$ and the Swain study area was $\sim 225\text{km}^2$. In comparison, Lassen Volcanic National Park is 431km^2 .

To examine regional variation, we looked at previous studies within California that examined diurnal summer rest structure use and also reported proportion of use among structure

types. Martin and Barrett (1991) tracked martens from 1981-1983 in Sagehen Creek basin on the Tahoe National Forest in red fir, mixed conifer and yellow pine (*Pinus jeffreyi*) stands. The study area was located on the eastern slope of the Sierra Nevada Mountains approximately 12km northwest of Truckee, California. Slauson and Zielinski (2009) tracked martens from 2001-2002 on Six Rivers National Forest in Douglas-fir (*Psuedotsuga menziesii*) and tanoak (*Lithocarpus densiflora*) stands with redwood (*Sequoia sempervirens*) along the western edge. The study area was located in the northwest coastal region approximately 30km east of Klamath, California.

2.2.2 *Marten capture and handling*

We radio tracked Pacific marten using both VHF and GPS transmitters from 2009–2013 and 2015–2017. To live-capture martens, we used Tomahawk® live traps (models 106, 108, Hazelhurst, Wisconsin, USA) that were modified with an enclosed waterproof plywood box. We baited traps with raw chicken legs, bacon, or beaver and applied a commercial scent lure (Gusto, Minnesota Trapline Products Inc., Pennock, Minnesota, USA). During winter, traps were covered in a plastic case (Coroplast), bark, and fir boughs to shield against snowfall and extreme temperature changes. We placed fleece blankets inside the wooden box to aid insulation from cold temperatures. During summer, we placed traps in shaded areas and added water (i.e., hamster bottle). We checked stations daily to minimize the amount of time martens spent in traps. Captured martens were chemically anesthetized with a combination of ketamine (25 mg/kg) and midazolam (0.2 mg/kg) (Mortenson and Moriarty 2015) and were fitted with a VHF collar (MI-2, Holohil Systems LTD., Carp, Ontario, Canada; M1800, Advanced Telemetry Systems Inc., Isanti, Minnesota, USA) or GPS collar (Telemetry Solutions, Concord, CA).

Animal capture and handling protocols were established following guidelines from the American Society of Mammalogists (Sikes and the Animal Care and Use Committee of the American Society of Mammalogists 2016). Our methods for capturing and processing martens were approved by Oregon State University's Institute for Animal Care and Use Committee (2009–2013, Permits: 3944, 4367) and the USDA Forest Service's Institute for Animal Care and Use Committee (2015–2017, Permit: USFS-003).

2.2.3 *Locating resting structures and microsites*

Our primary objective was to characterize marten resting sites, structures and microsites. During field data collection, we acoustically determined whether radio collared martens were resting using a telemetry receiver (R-1000, Communication Specialists, Orange, California, USA). If the marten was inactive for >1 minute, we attempted to locate the resting marten on foot and only continued to find the marten if it remained inactive. We attempted to locate rest sites every 3 days on average to avoid harassment and increase independence between samples. If martens were found reusing the same structure, the site was only included once for these analyses. We pooled all locations for both sexes after preliminary graphs did not depict differences in size classes used between sexes. Subsetting the data would decrease the sample size and therefore reduce the power of our inference for rest structure selection.

We evaluated marten resting habitat at two spatial scales: the resting structure and the microsite. We defined the structure as any specific feature where a marten was resting, categorized as burrow, coarse woody debris, live tree, log, rock pile, shrub clump, snag, or stump (Appendix B.1). We also recorded diameter at breast height (DBH) and tree species (if applicable). We defined the microsite as any specific location within or on the structure that a

marten was using, and attempted to determine the resting microsite using either visual identification or a signal strength consistently > 6 bars. We categorized microsites as arboreal, basal hollow, branch platform, broken top, cavity, ground or subterranean (Appendix C.1 for definitions). Occasionally, dense canopy cover or large ground features prevented the identification of a specific microsite feature being used. If the structure was located, but we were unable to determine the microsite with certainty, we classified the microsite as either arboreal or ground depending on the structure type and location of the signal. Distinguishing between unknown arboreal or ground microsites allowed us to retain resolution for whether frequency of use at specific structures varied between diel periods.

We distinguished between diurnal and nocturnal time periods based on nautical twilight. Nautical twilight in the mornings and evenings occurs when the center of the sun is geometrically 12 degrees below the horizon (United States Naval Observatory, Astronomical Applications Department, Washington, D.C.). At this time of day stars are generally visible and polarized light is absent (Chernetsov et al. 2011). Further, we divided the year into two time periods: summer (June – November) and winter (December – May). Because we only collected nocturnal locations during summer 2016, we only compared those with diurnal locations collected during the summer months. Rest site data collection and methods did not differ between diurnal and nocturnal field efforts.

2.2.4 *Vegetation sampling at rest and random sites*

We compared structure size, structure type (proportion of use), and microsite type (proportion of use) between used and random locations. Randomly-sampled locations were created with a random location generator (Beyer 2012). To minimize disturbance, we returned to

rest sites after a marten vacated the area to establish vegetation plots. Vegetation plots were established for a prior study to examine plot level selection using variable radius plots (see Moriarty et al. *in press*). We used DBH measurements gathered from these plots for structure size comparisons. The plots were 30x30 meters (0.007 acres) in size with plots at rest sites centered on the structure and random sites centered on the closest tree from the random point. At each plot, we collected DBH (1.37 meters) of each woody structure (i.e., live tree, snag, log, and stump) within the plot boundaries. Woody features were required to be ≥ 15 centimeters DBH for our survey. Stumps were classified as any standing structure less than two meters in height and logs had to be greater than two meters in length.

2.2.5 *Statistical analysis*

We compared mean difference in structures sizes between diel periods and random sites using Welch's t-tests to account for our unequal variances and sample sizes. We compared structure and microsite types with Fisher's exact test to evaluate differences in frequency of use between nocturnal and diurnal time periods for proportion data (as used in Martin and Barrett 1991), as Fisher's exact test would likely perform better than Pearson's chi-squared test with our sample sizes (Kim 2017). We graphically depicted mean and 95% confidence intervals of structure sizes using ggplot2 (Wickham 2009). All analysis was performed in Program R (R Development Core Team 2016).

2.3 **Results**

2.3.1 *Marten rest structures*

We located 140 diurnal and 32 nocturnal summer rest sites (23♂, 14♀). We collected structure diameter data (DBH) at 154 rest sites (127 diurnal, 27 nocturnal) and 191 random sites where all trees within the variable radius plot were measured (n=1109 structures). Analysis of used rest structures (live trees, logs, snags, and stumps) did not detect a difference in the size of structures between nocturnal and diurnal time periods (Figure 2.2, Table 2.2). Because there was no difference in size between diel periods, we combined nocturnal and diurnal structures into one used category to compare with random structures. Marten rest structures were much larger than a majority of measured random structures (used = $95.5 \pm 31.8\text{cm}$; random = $52.1 \pm 25.2\text{cm}$, $\bar{x} \pm \text{SD}$, $t = 15.1$, $p < 0.001$, Figure 2.3, Table 2.3).

Martens selected structure types similarly between diel periods (Fisher's Exact test, $p = 0.42$). Nonetheless, in our study martens rested in snags more than any other structure type during both diurnal and nocturnal periods (46% and 50%, respectively, Figure 2.4, Table 2.4). Use of stumps (diurnal = 22%, nocturnal = 16%) and live trees (diurnal = 17%, nocturnal = 13%) accounted for a majority of the remaining proportion of use with limited shrub clump (diurnal = 4%, nocturnal = 6%), logs (diurnal = 5%, nocturnal = 6%), burrows (diurnal = 1%, nocturnal = 3%) and coarse woody debris locations (diurnal = 0%, nocturnal = 3%).

Martin and Barrett (1991) radio-collared nine martens (5♂, 4♀) and located 109 rest structures on Tahoe National Forest. Martens primarily rested in stumps (32%) compared to snags (16%), logs (17%), and live trees (16%) (Martin and Barrett 1991, Figure 2.5). Slauson and Zielinski (2009) radio-collared 13 martens (7♂, 5♀, 1 unknown) and located 52 rest structures on Six Rivers National Forest. Martens primarily rested in snags (37%), logs (23%), and live trees (17%) but also utilized available slash piles (10%) on private timberlands (Slauson

and Zielinski 2009). Comparison across the three study areas demonstrates an association of structure use depending on region (Fisher's Exact Test, $p < 0.001$).

2.3.2 *Microsites*

We identified used microsites at a majority of rest structures (diurnal = 76%, nocturnal = 81%). Martens used cavities (47%) more than any other microsite during nocturnal periods followed by subterranean chambers (28%) and broken tops (6%). In contrast, subterranean microsites (27%) were used more often than cavities (23%) during the diurnal period followed by broken tops (15%), basal hollows (9%), and platforms (2%) (Figure 2.6, Table 2.4). We were unable to determine arboreal microsites for 12% of diurnal rest sites and 13% of nocturnal rest sites. Ground microsites accounted for 11% of diurnal rest sites and 6% of nocturnal rest sites. Martens did not select for a particular microsite type during either diel period (Fisher's Exact Test, $p = 0.10$).

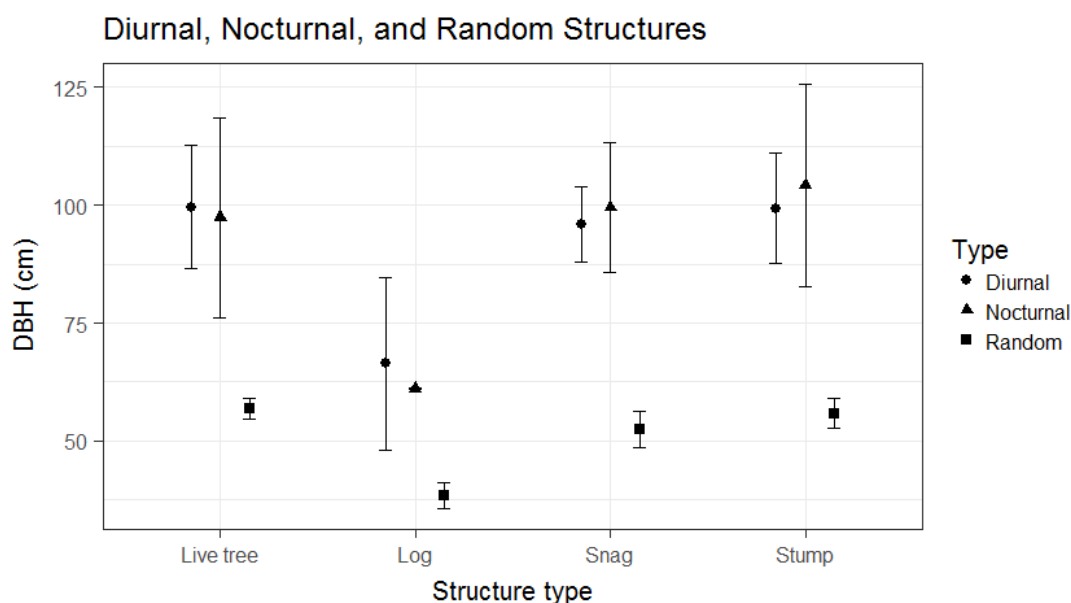


Figure 2.2. Comparison of mean diameter at breast height of diurnal ($n = 127$) and nocturnal ($n = 27$) rest structures and random structures ($n = 1109$). Random structure measurements are from all measured structures within variable radius plots ($n=191$). The mean and 95% confidence intervals displayed.

Table 2.2. Summary statistics of size measurements for rest structures used between diurnal and nocturnal periods. Test statistics and p-values are the results of Welch's t-tests comparing the mean diameter at breast height of diurnal and nocturnal rest structures.

Structure	Diel Period	n	Mean	Min	Max	SD	95% CI	p-value
			DBH (cm)				Interval	
Live Tree	Diurnal	24	99.6	44.2	174.5	32.7	86.5 - 112.7	0.89
	Nocturnal	4	97.4	76.2	118.7	21.7	76.2 - 118.7	
Log	Diurnal	7	66.4	25.4	101.6	24.6	48.2 - 84.6	0.59
	Nocturnal	2	61.1	61.0	61.2	0.2	60.8 - 61.3	
Snag	Diurnal	65	96.0	18.8	228.6	32.9	88.0 - 104.0	0.60
	Nocturnal	16	99.5	45.5	141.2	28.3	85.7 - 113.4	
Stump	Diurnal	31	99.3	43.2	152.4	33.1	87.7 - 111.0	0.27
	Nocturnal	5	104.3	76.2	125.0	24.4	82.9 - 125.7	

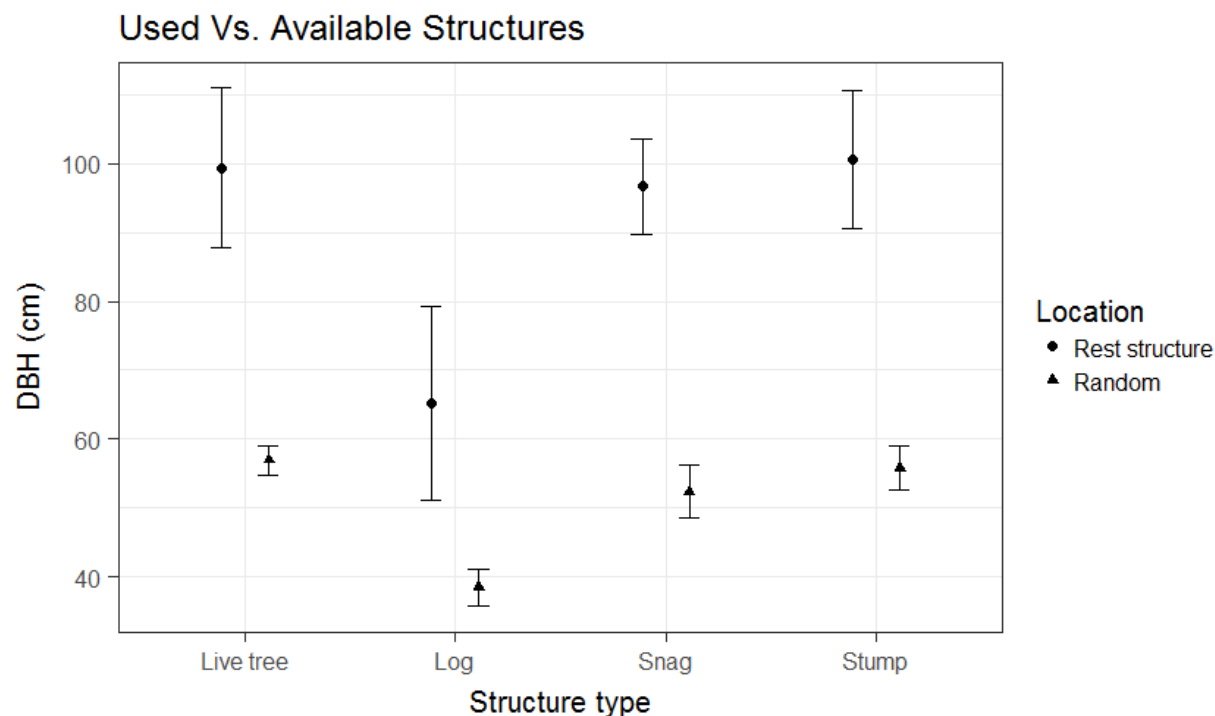


Figure 2.3. Comparison of mean diameter at breast height of all woody rest structures (n = 152) and random (n = 1109) structures. Random structure measurements are from all measured structures within a variable radius plot. The mean and 95% confidence intervals displayed.

Table 2.3. Summary statistics of rest and random structures. Test statistics and p-values are the results of Welch's t-tests comparing the mean of rest and random structures.

Table 1. Welch's t tests comparing the mean of Rest and Random structures.								
Structure	Type	n	Mean	Min	Max	SD	95% CI	p-value
			DBH (cm)				Interval	
Live tree	Rest	28	99.3	44.2	174.5	31.27	87.75 - 110.91	< 0.001
	Random	433	56.9	7.1	163.6	23.07	54.76 - 59.10	
Log	Rest	9	65.2	25.4	101.6	21.42	51.19 - 79.19	0.005
	Random	235	38.5	15.2	143.3	21.42	35.74 - 41.22	
Snag	Rest	81	96.7	18.8	228.6	31.88	89.74 - 103.62	< 0.001
	Random	149	52.4	10.4	174.8	24.36	48.52 - 56.34	
Stump	Rest	36	100.5	43.2	152.4	30.65	90.47 - 110.49	< 0.001
	Random	292	55.8	18.3	176.0	27.40	52.64 - 58.92	

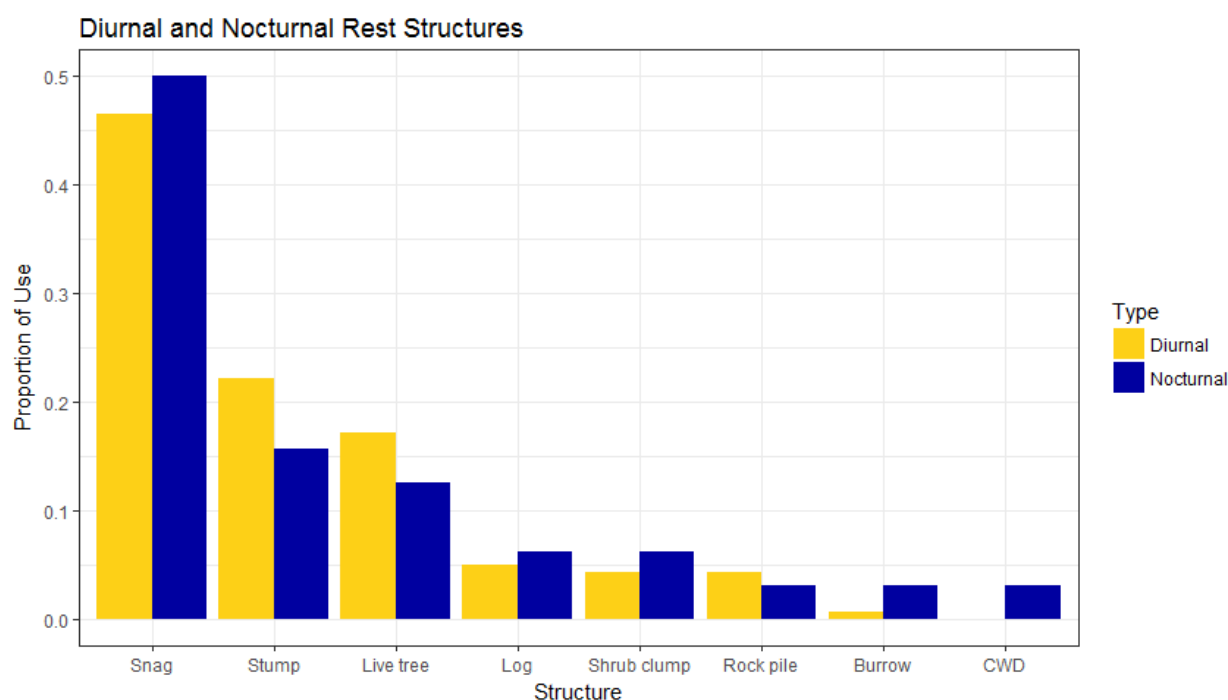


Figure 2.4. We did not detect an association between the selection of rest structure type and diel period (Fisher's Exact Test, $p=0.42$). Rather, martens rested in snags more than other rest structure types regardless of the diel period during the summer. Coarse woody debris (CWD) is a grouping of natural woody (e.g., stumps, logs, live trees) materials.

Table 2.4. Sample size (proportion of total) of rest structure and microsite use between diurnal and nocturnal periods.

Structure	Diurnal	Nocturnal	Total	Microsite	Diurnal	Nocturnal	Total
Burrow	1(1%)	1(3%)	2	Basal hollow	13(9%)	0(0%)	13
CWD	0(0%)	1(3%)	1	Broken top	21(15%)	2(6%)	23
Live tree	24(17%)	4(13%)	28	Cavity	32(23%)	15(47%)	47
Log	7(5%)	2(6%)	9	Platform	3(2%)	0(0%)	3
Rock pile	6(4%)	1(3%)	7	Subterranean	38(27%)	9(28%)	47
Shrub clump	6(4%)	2(6%)	8	Unknown(Arboreal)	17(12%)	4(13%)	21
Snag	65(46%)	16(50%)	81	Unknown(Ground)	16(11%)	2(6%)	18
Stump	31(22%)	5(16%)	36	Total	140	32	172
Total	140	32	172				

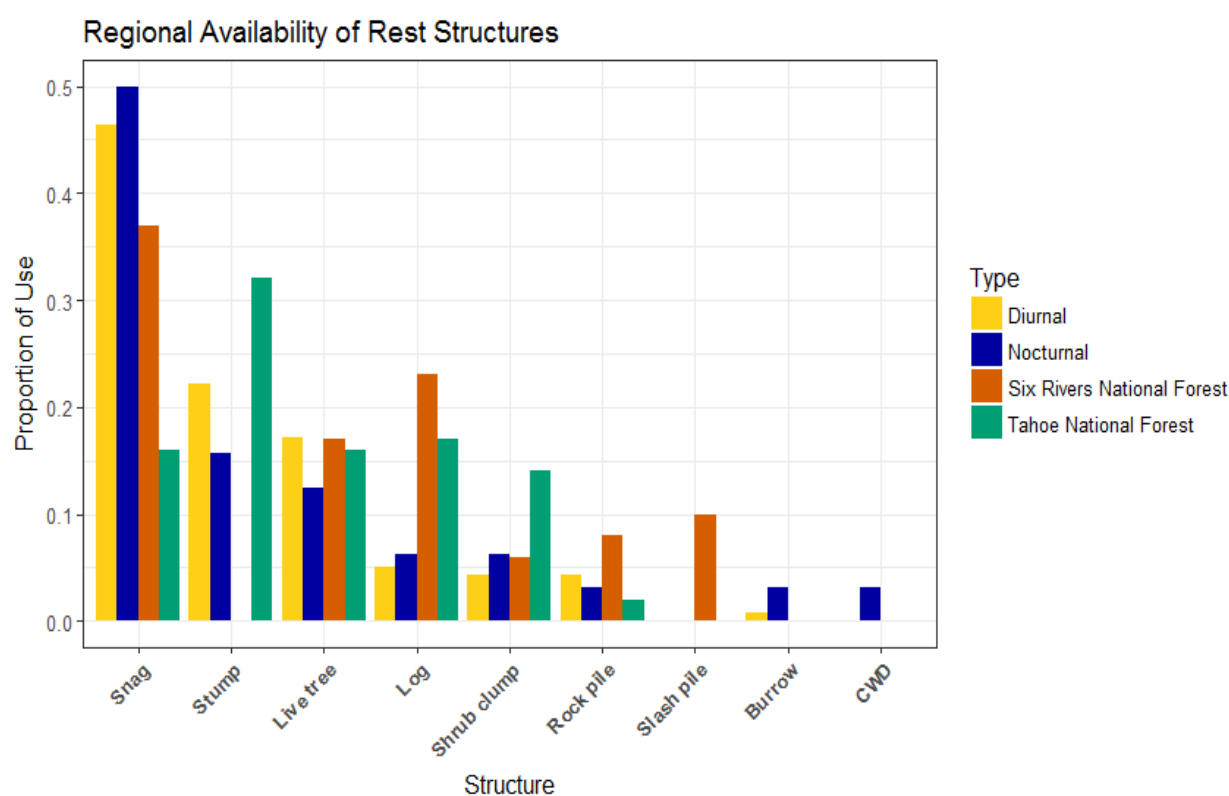


Figure 2.5. Regional availability of rest structures in California. Results were from this study and previous diurnal summer research in Six Rivers National Forest (Slauson and Zielinski 2009) and Tahoe National Forest (Martin and Barrett 1991). Coarse woody debris (CWD) is a grouping of natural woody (e.g., stumps, logs, live trees) materials.

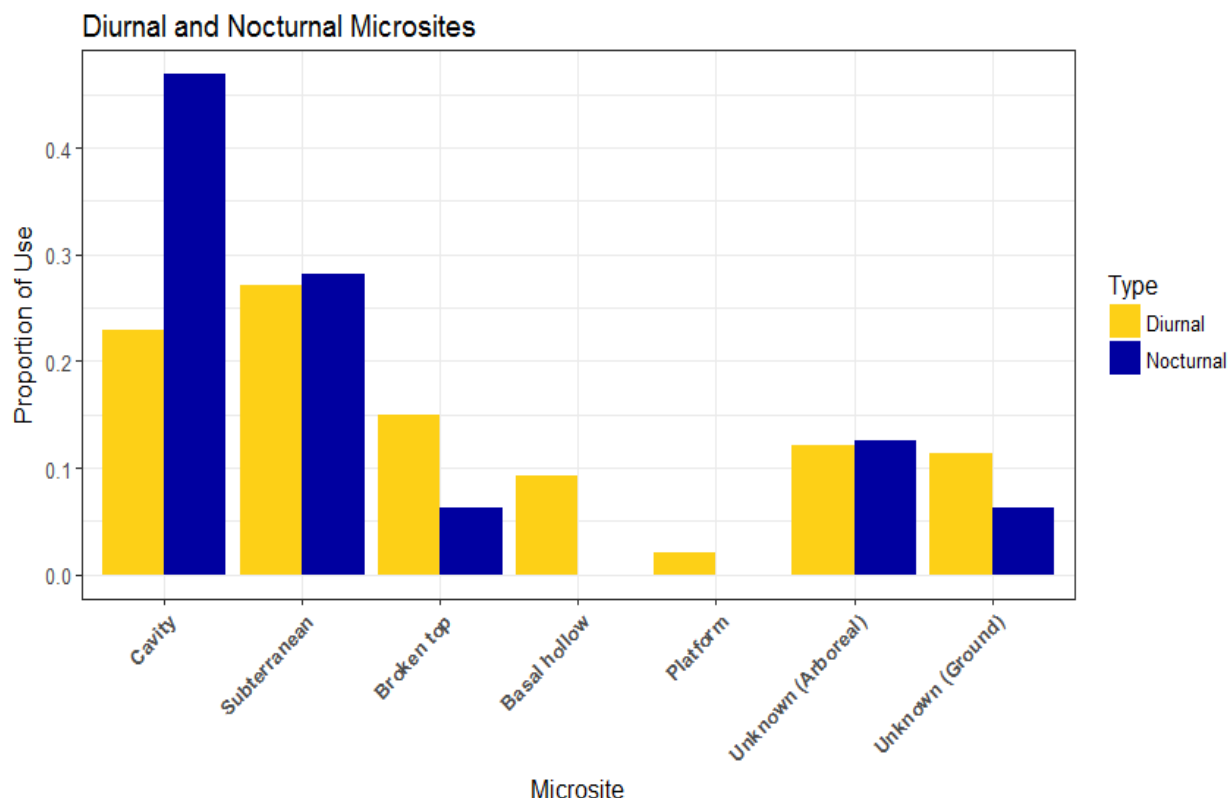


Figure 2.6. We did not detect an association between the selection of microsite type and diel period (Fisher's Exact Test, $p=0.1$). Martens used cavities (47%) and subterranean chambers (28%) more than other microsite types during the nocturnal period. During the diurnal period, martens used subterranean chambers (27%) and cavities (23%) predominately.

2.4 Discussion

2.4.1 Use of large structures for resting sites

Pacific martens clearly used larger resting structures (live trees, logs, stumps, and snags) relative to all available structures, a result similar to prior research in the western United States (Martin and Barrett 1991, Raphael and Jones 1997, Slauson and Zielinski 2009, Moriarty et al. *in review*). Large woody structures were notably absent at random sites, as demonstrated by an average diameter of 52cm (used = 96 cm) and small confidence intervals at random locations. As such, these larger trees, snags, logs, and stumps that martens used as rest structures appear to be

limiting and/or may have unique preferred properties that martens identify as suitable or necessary for resting (for instance, see Tweedy et al., Chapter 3).

Selecting larger woody structures is not unique to martens, as these provide habitat for cavity nesters such as woodpeckers (Zahner et al. 2012), owls (Hershey et al. 1998), bears (Immell et al. 2013), and other mustelids (Bull et al. 1997, Purcell et al. 2009). For instance, woodpeckers foraged most on the largest logs even though that size class of logs represented a small portion (14%) of the total distribution surveyed (Torgersen and Bull 1995). These preferred woody structures can take centuries to develop (Kroll et al. 2012, Weir et al. 2012, Bunnell 2013, Hennon and Mulvey 2014). Although we did not measure structure age, martens used 262 – 666 year old trees and snags as rest structures in northwest California (Slauson and Zielinski 2009).

2.4.2 Predominant use of snags for rest structures

Nocturnal structures appear to be more specialized as we observed martens predominantly using snags and logs with cavities and stumps with subterranean chambers. Similar to prior studies, snags (Slauson and Zielinski 2009) and stumps (Martin and Barrett 1991) were the primary source of rest structure selection during the nocturnal time period, with logs used less frequently. This could mean that snags and stumps provide thermoregulatory benefits and protection from predation better than other structure types. Martens selected snags at a higher proportion of use more than any other structure type during both periods. The prevalent use of snags by martens could be due to regional availability (Figure 2.5). A diversity of rest structure selection is observed in the Six Rivers and Tahoe National Forests compared to the majority snag selection within our study area (Slauson and Zielinski 2009, Martin and Barrett

1991. We suggest that nest structure availability varies within the geographic range and therefore local field efforts are needed to ensure adequate retention of critical features.

Snags may not necessarily be the most important feature for martens, but the process that created these features and microsites may be essential to habitat creation and maintenance. Snags and cavities are created over long temporal periods (e.g., >100 years, Hannon and Mulvey 2014) and must start in larger live trees for heart rot fungal processes. Other methods have been proposed to accelerate snag and cavity creation. Artificial inoculation of fungal decay into healthy trees has been explored to increase the amount and distribution of snags but has yielded mixed results (Conner et al. 1983, Lewis 1998, Filip et al. 2004, Bednarz et al. 2013). Other methods to increase the distribution of snags on the landscape includes girdling, silvicide treatment and tree topping; however, these methods do not produce consistent results (Brandeis et al. 2002). Fungal infection can take many years before they can be efficiently utilized by wildlife populations (Zielinski et al. 2004, Raley et al. 2012, Weir et al. 2012), and these studies may need decades of monitoring to determine the effectiveness. The temporal longevity of structures once dead is also a gap in knowledge; snags may quickly decay, break apart, fall over and/or burn. We monitored 44 structures (live trees, snags) used by martens (2009 – 2013) and observed 52% were used by a new marten generation, but 21% had fallen over likely due to wind or snow (B. Woodruff, USDA Forest Service, unpublished data). Because there are mixed results from trials to increase snags or decay, preserving existing snags and large trees would be the most cost effective and beneficial strategy for maintaining these features (Bull et al. 1997). However, all dead wood is on a decay curve so planning processes must also include future snag recruitment.

2.4.3 *Microsite use between diel periods*

The predominant use of large snags, live trees, stumps, and logs during both diel periods may be a function of the microsite types available in these decaying structures. We observed that cavities and subterranean features were used the most during the nocturnal and diurnal periods. Larger trees and snags with suitable cavities often have thicker bark protecting martens from inclement weather and provide physical barrier from predation (Buskirk 1984, Martin and Barrett 1991, Bull et al. 1997, Slauson and Zielinski 2009). Enclosed cavities or chambers provide mutual benefits during times of heat and cold offering more stable microclimates than other features such as platforms or broken tops (Green 2017), especially during the summer time when diurnal temperatures reached 31°C and nocturnal temperatures were as low as -1°C during our 2016 fieldwork (Western Regional Climate Center, 2016). Understanding the link between microsite selection and temperature could be more relevant as prolong droughts become more frequent in California.

We did not observe martens disproportionately using specific microsites, but martens may prefer cavities or subterranean microsites at night. Almost half (47%) of the microsites identified during the nocturnal period were cavities followed by subterranean sites (28%). Whether the little to no absence of nocturnal broken top (6%) or platform (0%) use is a function of thermoregulation or predator avoidance is unknown. During times of low temperatures during the diurnal period, broken tops and platforms may benefit martens with solar radiation. Using broken tops or platforms at night would not include such benefits and could increase the risk of predation by specialist nocturnal hunters, specifically owls. Great horned owls (*Bubo virginianus*) and California spotted owls (*Strix occidentalis occidentalis*) have been detected within our study area (P. Tweedy, personal observation) and can be potential predators of weasel

species (Bull and Heater 2001, Wiens et al. 2014, Linnell et al. 2017). The higher proportion of use for enclosed microsites likely reflects the need for thermoregulation and protection from predation at night therefore highlighting the importance of structures with cavities or subterranean features. Our lack of association between the diel periods may also be due to the low sample size of rest structures located at night.

Our efforts represent the first examination of nocturnal rest structure use, but additional research is needed to acquire a sample size large enough to evaluate selection throughout the diel period. The lack of association of microsites between diel periods could be due to the unknown arboreal and ground microsite locations. Arboreal and ground microsites accounted for 13% and 6% of the total locations, respectively. We recognize that the unknown microsite locations might bias our results; however, we feel that recognizing whether the marten was located in the tree canopy or on the ground can provide relevant information for future management especially when ground microsites were primarily associated with shrub clumps. For instance, we observed eight marten resting events ($n=1\text{♀}$, 4♂) in dense shrub cover on ridgelines where previous wildfire activity has presumably altered the stand composition from trees to shrubs. Shrub cover is typically not considered resting habitat in Lassen National Forest, but this cover type may provide resting areas for martens (Buskirk and MacDonald 1984, Martin 1987, Slauson and Zielinski 2009). In addition, shrubs can provide food for marten and their prey (Martin 1994, Roth and Vander Wall 2005, Moore and Vander Wall 2015). Further, dense cover that can prevent access to competitors or predators such as Pacific fishers (*Pekania pennanti*) and bobcats (*Lynx rufus*).

2.4.4 Rest structure management considerations

When planning management activities, our data suggest martens selected larger structures. Considering the recruitment of live trees may be important since it takes decades to centuries for trees to grow large and for cavities to develop (Hennon and Mulvey 2014). Such large-tree recruitment may be helpful for future populations of snag-dependent species (North et al. 2009). Creating and maintaining structures used by martens has additional ecological value for other species of vertebrates such as primary cavity-nesting bird species (Martin and Eadie 1999), and for species of conservation concern like the Pacific fisher (Purcell et al. 2009). Larger snags have a greater amount of wood volume than smaller diameter snags and therefore will typically last longer on the landscape (Bull et al. 1997). These would be used, based on our data, by multiple generations of martens. Being able to cut snags for firewood may conflict with preservation of existing snags. For example, current guidelines for fuelwood collection on federal lands allows for falling lodgepole snags regardless of size. Cutting snags is also a common practice for road hazards and during fires (A. Bianchi, USDA Forest Service, personal communication), and therefore policy changes to decrease loss may be warranted if conserving wildlife habitat is a priority.

We observed martens resting in all woody structures from large diameter trees, snags, logs, stumps – each along a progression of decay and succession. Based on the diversity of structures used, a variety of rest structures is likely needed to sustain marten habitat. While our microsite comparisons found no statistically significant differences, we believe our data demonstrate the value of considering activity patterns throughout the day and year when studying species habitat use and this will benefit subsequent management and conservation plans. Further distinctions between rest structure use and activity patterns can be improved with increased monitoring frequency of rest structures. We attempted locations every 3 days. Lower

monitoring rates can result in underestimates of rest structure use and daily locations maybe needed to effectively evaluate resting site use patterns (Carvalho et al. 2015).

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3 | Using fine scale resolution vegetation data from LiDAR and ground based sampling to describe Pacific marten resting habitat

3.1 Introduction

Mitigating habitat loss by identifying areas where habitat protection or restoration is needed requires knowledge of how a species uses an area. However, habitat use is scale-dependent, and is often described at smaller spatial scales and extrapolated across larger scales. Biologically, species use multiple scales as their behaviors occur both locally (e.g., foraging, predator avoidance) and broadly (e.g., territory maintenance) within a landscape (Johnson 1980, McGarigal et al. 2016). Our interpretations of habitat use patterns vary drastically depending on the observed scale (Wiens 1989); conversely, lack of patterns at one scale does not mean lack of selection at another scale (Mayor et al. 2009). Habitat selection is a scale-sensitive process; however, the choice of scale might not be intuitive. A literature summary by McGarigal et al. (2016) found that less than 25% of published analyses used multiple scales, such as including both data at a home range scale and landscape scale. Further, less than 5% of published habitat selection analyses optimize scales, which directly tests which scale is most informative in describing habitat use (McGarigal et al. 2016). As such, the interpretation of results may not reflect how species perceive important features across the landscape and thus the scale used may directly affect interpretations and suggested results (Boyce et al. 2003, Mayor et al. 2009).

Opportunities to analyze data and optimize multiple scales have advanced with the advent of light detecting and ranging technology (LiDAR). LiDAR can inform habitat use in forested ecosystems (Vierling et al. 2008) as the three dimensional output of the plant community from LiDAR can correlate with commonly used vegetation characteristics such as measures of canopy cover and basal area (Lefsky et al. 2002). LiDAR and field-based sampling are comparable at the

stand level for structural attributes (e.g., basal area) (Hummel et al. 2011); however, LiDAR can provide more information across a much larger area (Hyde et al. 2006) and can be a tool to describe wildlife habitat use relationships (Martinuzzi et al. 2009, Goetz et al. 2010, García-Feced et al. 2011, Zhao et al. 2012).

North American martens (*Martes americana*, *M. caurina*) are carnivore species typically associated with forest patches that include older structural elements (e.g., large diameter live trees and snags) and areas of increased structural complexity (Buskirk and Ruggiero 1994, Zielinski and Kucera 1995), and have been an icon for multi-scale habitat selection (Bissonette and Broekhuizen 1995). Martens are considered forest specialists due to large spatial requirements relative to their body size, and thus are often used as an indicator for conservation planning (Buskirk and Zielinski 2003). One area of recent conservation concern includes high elevation regions within the southern Cascades and northern Sierra Nevada Mountains where populations have become fragmented and clustered (Zielinski et al. 2005) and where predicted habitat may decline by as much as 85% with a warming climate (Spencer et al. 2015). Changes in forest stands (e.g., harvest, high severity wildfire) can result in the direct loss of habitat, (Moriarty 2010) increasing marten energetic costs due to avoidance of openings (Moriarty et al. 2016b) and maintenance of larger home ranges (Potvin et al. 2000). Martens may use managed landscapes where sufficient cover (Fuller and Harrison 2005, Godbout and Ouellet 2008) and structures important to fitness are retained (Payer and Harrison 2003). However, marten populations have been shown to avoid areas where more than 25-33% of forest cover has been removed (Bissonette et al. 1997, Hargis et al. 1999, Potvin et al. 2000). The degree to which disturbance affects the distribution of marten populations differs by geographic region (Sturtevant et al. 1996, Hargis et al. 1999, Thompson et al. 2012), therefore, regionally specific

data for martens are desired to guide management decisions. Accurate habitat data is critical for biologists to develop conservation and management plans for martens, which can be accomplished using a multiscale approach (Shirk et al. 2012, Wasserman et al. 2012, Shirk et al. 2014).

At finer spatial scales, martens rely on structures for resting that provide protection from predation and thermoregulatory benefits (Buskirk et al. 1989, Taylor and Buskirk 1994). Suitable rest structures may be a limiting habitat element (Buskirk and Zielinski 2003, Porter et al. 2005) and are often associated with complex vertical and horizontal structure in combination with dense canopy cover and large trees (Spencer et al. 1983, Spencer 1987, Moriarty et al. *in review*). We believe that using rest structures as a focal point for building a multiscale habitat selection model will be more precise for estimating rest site use than using traditional telemetry techniques, as telemetry error can lead to inaccurate habitat use models (Montgomery et al. 2011).

We quantified marten resting habitat using covariates derived from LiDAR and ground-based measurements. First, we optimized the scale for each covariate by running a suite of generalized linear mixed models to test whether resting habitat selection is scale-dependent. Second, we used prior literature and field experience to develop and test habitat suitability models using the optimized scale results for each covariate. Lastly, we created spatially explicit maps using our top model to depict predictive resting habitat. We hypothesized that rest structures would be located in areas of structurally complex forest with dense canopy cover, which provide suitable habitat for foraging and reducing predation risk. Further, we hypothesized that vegetation and topographical covariates would be represented in a hierarchical scale response when compared to randomly sampled locations.

3.2 Methods

3.2.1 Study area

We collected marten rest site data in Lassen National Forest, which is approximately 130 km east of Red Bluff, California. Lassen National Forest is comprised of 3 ecoregions: the northern Sierra Nevada Mountains, the southern Cascade Mountains, and the high desert of the Modoc Plateau. Our study area included both the southern extent of the Cascade and northern extent of the Sierra Mountain Ranges (area ~490 km², elevation 940 – 2180 meters; Figure 3.1). Forested stands included red fir (*Abies magnifica*), white fir (*Abies concolor*), and lodgepole pine (*Pinus contorta*) with a sparse understory of chaparral whitethorn (*Ceanothus leucodermis*) and manzanita (*Arctostaphylos spp.*). Average minimum and maximum temperatures in July are 6.9°C and 29.5°C respectively, and –6.9°C and 5.3°C in January (Western Regional Climate Center, 1948-2005). Average annual precipitation is 96-253 cm, depending on the location in our study area, and typically occurs as snow (Western Regional Climate Center, 1948-2005).

3.2.2 Marten capture and handling

We radio tracked Pacific marten from 2009 – 2013 and 2015 – 2017. Tomahawk® live traps (106, 108 models, Hazelhurst, Wisconsin, USA) were used to capture martens and were modified with an enclosed waterproof plywood box opposite the trap door. We baited traps with raw chicken legs, bacon, or beaver and applied a commercial scent lure (Gusto, Minnesota Trapline Products Inc., Pennock, Minnesota, USA) above the trap. During winter, traps were covered in a plastic case (Coroplast) with tree bark and fir boughs to shield against snowfall and predators. We placed fleece blankets inside the wooden box for protection from cold

temperatures. During summer, we placed traps in shaded areas and added water (e.g., hamster bottle). We checked stations daily to minimize the amount of time martens spent in traps.

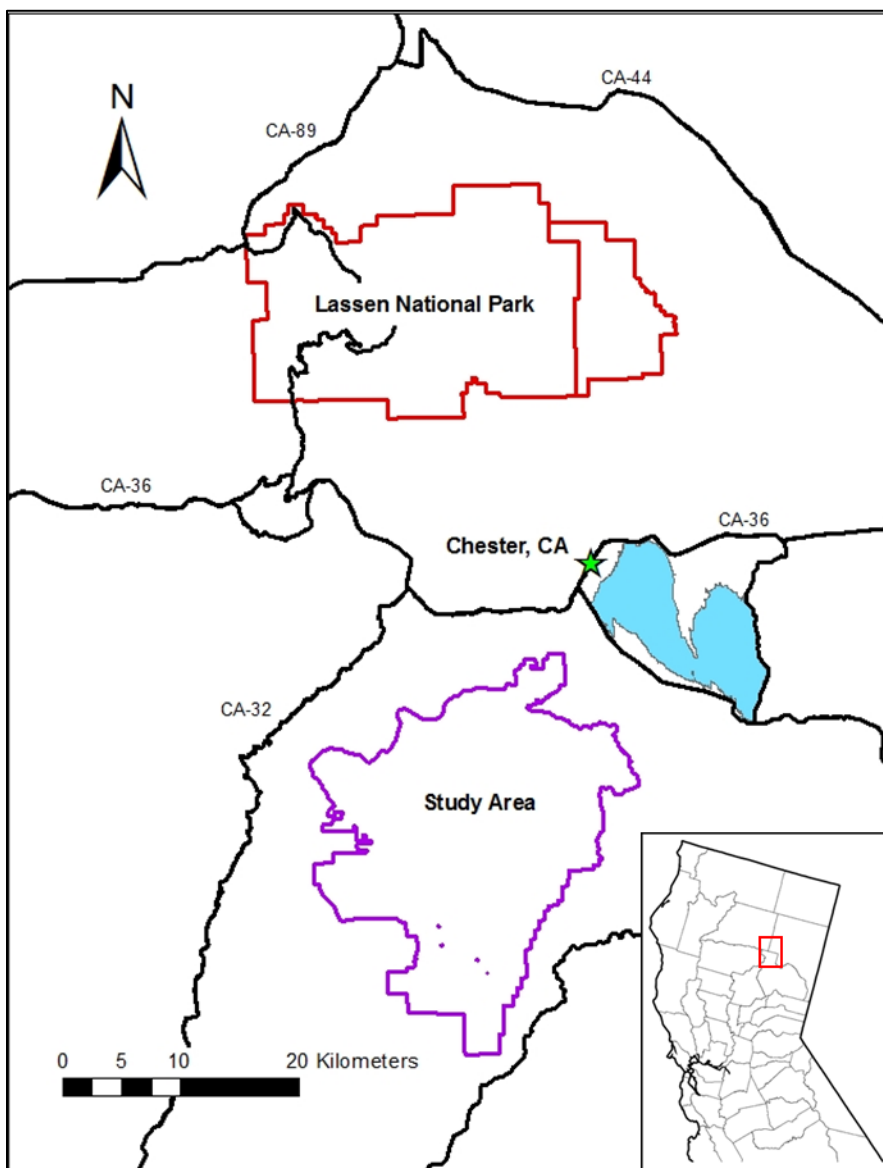


Figure 3.1. Study area was located south of Lassen National Park, California. Study area was $\sim 490\text{km}^2$. In comparison, Lassen Volcanic National Park is 431km^2 .

Captured martens were chemically anesthetized with a combination of ketamine (25 mg/kg) and midazolam (0.2 mg/kg) (Mortenson and Moriarty 2015) and were fitted with a VHF collar (MI-

2, Holohil Systems LTD., Carp, Ontario, Canada; M1800, Advanced Telemetry Systems Inc., Isanti, Minnesota, USA).

Animal capture and handling protocols were established following guidelines from the American Society of Mammalogists (Sikes 2016). Our methods for capturing and processing martens were approved by Oregon State University's Institute for Animal Care and Use Committee (2009 – 2013, Permits: 3944, 4367) and the USDA Forest Service's Institute for Animal Care and Use Committee (2015 – 2017, Permit: USFS-003).

3.2.3 *Rest site collection*

We acoustically determined whether telemetered martens were resting using a telemetry receiver (R-1000, Communication Specialists, Orange, California, USA). If the marten was inactive for >1 minute, we attempted to locate the resting marten on foot and only continued to find the marten if it remained inactive. We recorded information about the structure (e.g., tree type, size) and attempted to determine the resting microsite, or location within or on the structure using either visual identification or signal strength. We only attempted to locate rest sites every 3 days on average to avoid harassment and increase independence between samples. If martens were found reusing the same structure, the site was only included once for these analyses. We pooled all locations for both sexes and seasons because further subsetting the data would decrease the sample size between groupings and therefore reduce the power of our inference for habitat selection.

3.2.4 *Forest vegetation covariates*

To create a predictive model for marten resting habitat, we considered 14 *a priori* covariates (Table 3.1). We restricted covariates to those described in prior literature (Spencer et al. 1983, Spencer 1987, Zielinski et al. 2004, Kirk and Zielinski 2009, Purcell et al. 2009, Rustigian-Romsos and Spencer 2010, Moriarty et al. *in review*) and included covariates forest managers commonly use when surveying stands (e.g., basal area, trees per acre). We used fine-scale vegetation metrics created from LiDAR (30-m resolution) collected in 2013 and 2015. Both LiDAR flight data and field-based plots were used to validate vegetation covariates for the raster layers. From these data we used 7 covariates: basal area, canopy cover, canopy cover², standard deviation of canopy cover, quadratic mean diameter, stand density index, and trees per acre (Table 3.1). We included a quadratic term for canopy cover to test for a threshold in which further increases in percent cover would not increase predicted resting habitat suitability (Purcell et al. 2009). Also, forest stands with increased structural complexity are often associated with a higher probability of use (Spencer et al. 1983). Therefore we created a structural complexity metric by calculating the standard deviation of the canopy cover across 18 5-m estimates from the ground to the tallest portions of the canopy. This structural complexity raster (i.e., standard deviation of height within a 30-m pixel) was created using the Cell Statistics tool in ArcMap (Environmental Systems Research Institute Inc., Redlands, California, USA).

Using LiDAR allowed us to sample vegetation across a broader area, nonetheless, LiDAR does not characterize stand types. As such, we used the USDA Forest Service Existing Vegetation (EVEG) to classify stand type (Northern California Interior, CalVeg Existing Vegetation (EVEG) 2009) and U.S. Census Bureau TIGER, USGS, and U.S. National Atlas for linear features (Table 3.1, Rustigian-Romsos and Spencer 2010). These covariates are distance to meadow, distance to road, distance to water, elevation, road density, slope, and stream density.

Table 3.1. We considered 14 *a priori* abiotic and biotic predictor covariates to create a predictive model for marten resting habitat. Covariates were selected based on prior literature and local field-based knowledge. We tested each covariate with a univariate analysis comparing used versus random locations to determine which spatial scale had the most predictive power for further development of multivariate resting habitat models.

Covariate	Abbreviation	Units	Source
Basal area	ba	ft ²	LiDAR; Pacific Northwest Research Station, USDA Forest Service
Canopy Cover	cc	%	LiDAR; Pacific Northwest Research Station, USDA Forest Service
Standard Deviation of Canopy Cover	cc_sd	%	LiDAR; Pacific Northwest Research Station, USDA Forest Service
Canopy Cover ²	cc ²	%	LiDAR; Pacific Northwest Research Station, USDA Forest Service
Distance to Meadow	mdw	m	USGS 1-Arc Second National Elevation Dataset, 2009; Combination of Ward Assoc. (in process), Vestra Co. (2004), and USDA Forest Service - Pacific Southwest Region - Remote Sensing Lab, Existing Vegetation tile, 2005 – 2009; Rustigian-Romsos and Spencer 2010
Distance to Road	road	m	U.S. Census Bureau TIGER, California Major Roads, 2007; Rustigian-Romsos and Spencer 2010
Distance to Water	wtrdist	m	U.S. National Atlas, Water Feature Lines, 2008; USDA Forest Service - Pacific Southwest Region - Remote Sensing Lab, WaterBodies07_2, 2008; Rustigian-Romsos and Spencer 2010
Elevation	elev	m	USGS 1-Arc Second National Elevation Dataset; Rustigian-Romsos and Spencer 2010
Quadratic Mean Diameter	qmd	in	LiDAR; Pacific Northwest Research Station, USDA Forest Service
Road density	rdden	km/km ²	U.S. Census Bureau TIGER, California Major Roads, 2007; Rustigian-Romsos and Spencer 2010
Slope	slope	%	USGS 1-Arc Second National Elevation Dataset, 2009; Rustigian-Romsos and Spencer 2010
Stand Density Index	sdi	N/A	LiDAR; Pacific Northwest Research Station, USDA Forest Service
Stream Density	strmden	km/km ²	U.S. National Atlas, Water Feature Lines, 2008; Rustigian-Romsos and Spencer 2010
Trees Per Acre	tpa	N/A	LiDAR; Pacific Northwest Research Station, USDA Forest Service

For each location and each covariate, we calculated the mean at the sample location around the rest structure (30-m) and increased the spatial scale in 90 m radius increments to a maximum of 990 m, resulting in 12 spatial scales. Our finest scale represented 4th order selection

(Johnson 1980), and we assumed it would represent characteristics immediately surrounding the rest structure. Our broadest scale (990 m radius) was chosen because we assumed any values larger than this distance can potentially obscure the heterogeneity of the landscape. We used a moving window (i.e., Focal Statistics tool) to obtain the vegetation layer's average value within the 12 spatial scales (ArcMap 10.2.2, Environmental Systems Research Institute Inc., Redlands, California, USA).

3.2.5 *Random sampling*

In order to understand whether martens were selecting rest sites, as opposed to using areas in proportion to their availability, we compared marten resting locations to generated random points. We sampled random points across the entire the study area, including regions without known marten home ranges for two reasons: (1) we detected uncollared martens adjacent to known marten home ranges but were unable to capture individuals due to lack of resources and; (2) portions of the study area without known marten home ranges still fell within the predicted marten habitat suitability model created by Rustigian-Romsos and Spencer (2010) suggesting martens could occupy a majority of the region (Figure 3.2). We created two random sampling points for every unique rest site (Northrup et al. 2013). As such, we generated random points throughout the study area specifying that no two points could be within 100 m of each other and all locations were within 1 km of the edge of our spatial information (Create Random Points tool, ArcMap 10.2.2, Environmental Systems Research Institute Inc., Redlands, California, USA).

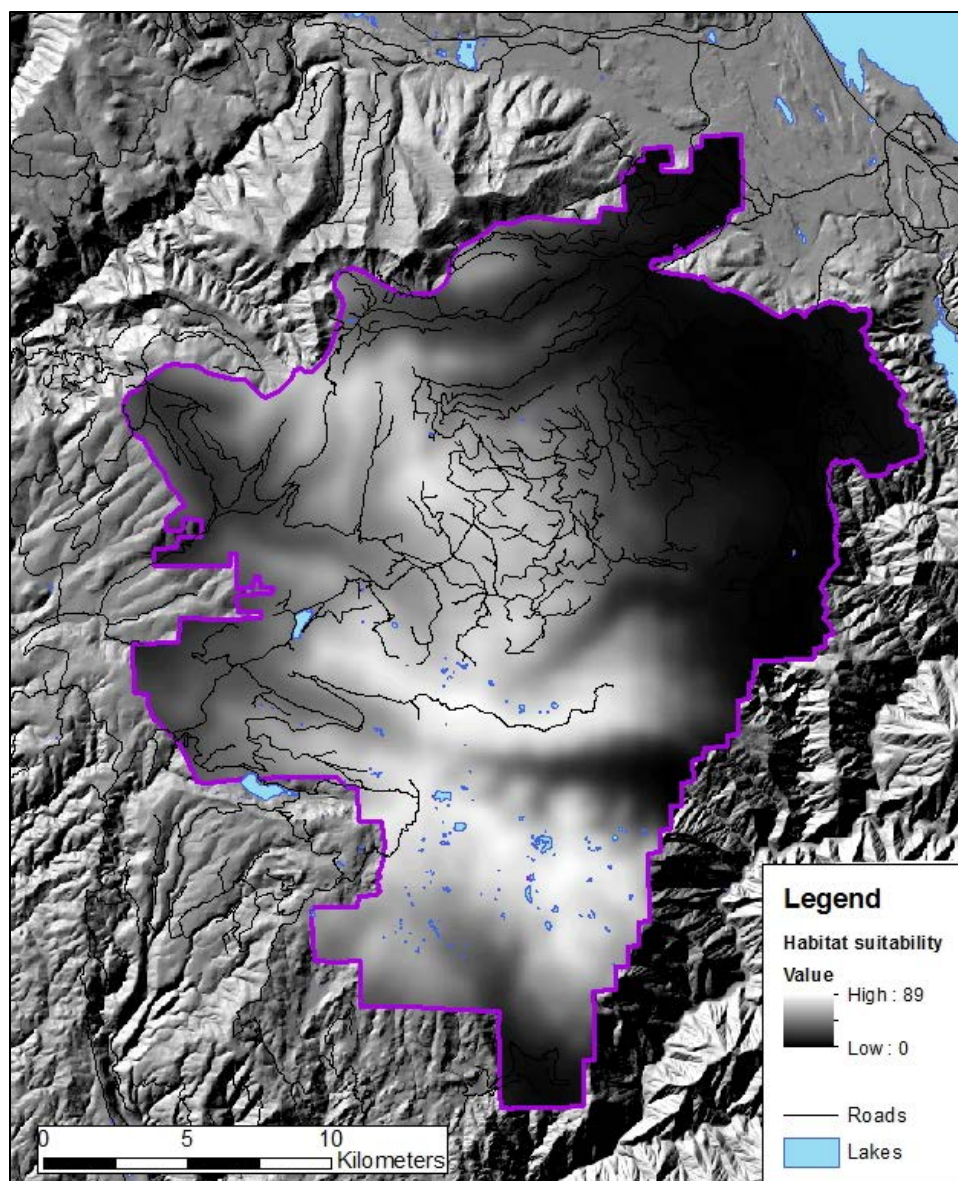


Figure 3.2. Pacific marten habitat suitability model created by the Conservation Biology Institute (Rustigian-Romsos and Spencer 2010). The model was created from marten detections over the entire Lassen National Forest and Lassen National Park area. The figure displays predicted marten habitat suitability within our study area.

3.2.6 Statistical analysis

We used resource selection functions with generalized linear mixed models to optimize the spatial scale for each covariate. We used the lme4 package (Bates et al. 2015) in program R (R Development Core Team 2016) for each covariate using the model:

$$g(x) = \beta_0 + \beta_1 x_i + \gamma_{0g}$$

where $g(x)$ is the relative probability of rest site use given the combination of a covariate (x_i) and slope (β_1) with individual marten as a random effect (γ_{0g}) (Gillies et al. 2006, Shirk et al. 2014).

We were unable to collect an equal amount of rest sites for each radio-collared marten, so we treated individual martens as a random effect to ensure representation of the entire population.

When generating regression models, we proportionally weighted the assignment of martens to random sampling points according to the amount of rest sites identified for each individual (Gess et al. 2013).

To determine the scale that had the most predictive power from the univariate generalized linear mixed model for each covariate, we selected the scale with the lowest AIC score and a p -value ≤ 0.05 (Wasserman et al. 2012, Shirk et al. 2014, Wan et al. 2017). To avoid problems associated with multicollinearity between selected scales and covariates in our multiscale models, we computed Pearson's correlation coefficients. Covariates with a Pearson's correlation value of $|r| \geq 0.7$ were not included in the same model (Wiens et al. 2008).

We developed a set of 23 multivariate logistic regression models, each with a specific hypothesis that we thought was biologically reasonable for predicting marten resting habitat. We created our *a priori* hypotheses based on an extensive literature review and from our local field expertise, using only covariates at their optimized spatial scale (Burnham and Anderson 2002). All models had seven or less covariates to avoid overfitting, with marten as a random effect. As an example of our framework, Moriarty et al. (2016b) suggested martens avoided areas with reduced canopy cover, possibly due to an increased risk of predation. Areas of reduced canopy cover can be created from either natural (e.g. meadows) or anthropogenic (e.g. forest thinning) activities. Therefore, canopy cover and an additional vegetative covariate (e.g., basal area, trees

per acre) were used in each model. Furthermore, we limited the number of topographical covariates within any given model because we assumed that vegetation structure would be more influential than topography, and we felt having vegetation covariates within a model would be more important for interpretation by forest managers.

To evaluate candidate models, we calculated Akaike's Information Criterion adjusted for small sample size (AICc) (Burnham and Anderson 2002). Top candidate models with $\Delta\text{AICc} \leq 2$ were considered to be competing models (Burnham and Anderson 2002) but we were unable to average models due to correlation between covariates in the different models (Cade 2015). We tested the models' ability to distinguish between rest site and random locations by plotting the receiver operating characteristic curve using the R package ROCR (Sing et al. 2005). From this curve, we calculated the area under curve (AUC) metric. An AUC value of 1 indicates that the model perfectly predicts rest site use whereas values below 0.5 indicates a poorly-fitted model and an increased false positive rate (Type I Error). Finally, we created a predictive resting habitat map from our final top model informed by our estimated beta coefficients for each covariate (Raster Calculator tool in ArcMap 10.2.2, Environmental Systems Research Institute Inc., Redlands, California, USA).

3.3 Results

3.3.1 *Marten captures*

We captured and radio-collared 31 martens (18♂, 13♀) during our study. We located 312 unique rest structures (10.06 ± 8.16 rest structures per marten, $\bar{x} \pm \text{SD}$) which were paired with 624 randomly sampled locations for analyses.

3.3.2 *Scale optimization and model testing*

First, we chose a spatial scale that was most informative for each of the selected 14 covariates. We excluded two covariates, quadratic mean diameter ($p = 0.06$) and road density ($p = 0.32$), from further testing of habitat selection because they were not statistically significant at any scale. The optimized scale varied from the area around the site (30 m) to 990 m (Table 3.2), suggesting a single scale would not accurately represent predicted marten habitat. Using only the optimized spatial scale for each covariate, we tested our 23 multivariate hypothesized models. Our top model predicted positive correlations with canopy cover with a mean of $63 \pm 17\%$ ($\bar{x} \pm \text{SD}$, Table 3.2) at the smallest scale (30 meters), standard deviation of canopy cover (19 ± 1) at 270 meters, and trees per acre (252 ± 58) at 990 meters. These forest structure attributes were selected at an average of $1,940 \pm 71$ meters in elevation in a 900 meter radius from sampling locations. The top model also includes a negative correlation of distance to roads (441 ± 328 meters) at 990 meters.

Our top model accounted for 83% of the AICc weight and was not within $\Delta\text{AICc} \leq 2$ of the next model (Table 3.3). All covariates included in the top model were statistically significant (Table 3.4). For our binary mixed effects model, we evaluated the estimated change of the probability of our response variable with a one unit change in each predictor variable when the remaining predictor variables were set to the mean (i.e., marginal effect). We observed that predictor variables including canopy cover, standard deviation of canopy cover, and trees per acre had a positive exponential relationship with predicted probability of use (Figure 3.3). Distance to roads had a negative exponential relationship and elevation had a logistic curve pattern suggesting possible threshold values (Figure 3.3). Further, the indication of model fit was extremely high ($\text{AUC} = 0.909$, Figure 3.4a).

3.3.3 *Predictive resting habitat suitability maps*

We depicted our results spatially to show where resting habitat existed on the landscape (Figure 3.5). Our top predicted habitat model included elevation, and when elevation was included as a predictor variable in any model there was consistently better fit (lower in AICc value) compared to similar models without elevation (Table 3.3). Because we were specifically interested in providing guidance for managers, we created two additional predictive habitat suitability maps where we statistically controlled elevation (Figure 3.6) and roads (Figure 3.7) by setting those values at their mean (1,940 m and 441 m respectively). Using the top model, 41% of the landscape within our study area had 65% predicted probability of available resting habitat. When controlling for elevation in the top model, the amount of suitable resting habitat with at least 65% predicted probability of availability increased in size by 15%. We believe this is an effect of increased road density at lower elevations where frequent timber operations are conducted on private timberlands. When controlling for elevation and roads, areas with at least 65% predicted probability of use decreased by 27%. Thus, we created a predicted map based on forest structure while accounting for elevation and roads, which most accurately depicts available predicted availability of resting habitat (Figure 3.7).

3.3.4 *Testing model fit*

We evaluated model fit for a model controlling for elevation (AUC = 0.761, Figure 3.4b) and distance to roads (AUC = 0.760, Figure 3.4c). The AUC values suggests elevation and distance to roads strongly influenced our model fit, but covariates only including vegetation

structure (i.e., canopy cover, trees per acre, structural complexity) can accurately predict marten resting habitat.

Table 3.2. Univariate statistics for the 14 habitat covariates tested for inclusion into multivariate habitat models. Habitat covariates were selected based on prior literature and relevance for forest surveying. Rasters of vegetation covariates were created from LiDAR. Rasters of topographic covariates were created from ground-based sampling (Table 3.1).

Covariate	Units	Scale	Rest sites ($n = 312$)	Random sites ($n = 624$)	AIC	Coefficient	p -value
			$\bar{x} \pm \text{SD}$	$\bar{x} \pm \text{SD}$			
Basal area	ft ²	180	55.59 \pm 13.07	38.15 \pm 18.46	988.8	0.066	< 0.001
Canopy Cover	%	Site	63.01 \pm 16.69	43.73 \pm 25.54	1056.9	0.038	< 0.001
StDev Canopy Cover	%	270	19.49 \pm 0.63	19.17 \pm 0.83	1160.1	0.567	< 0.001
Canopy Cover ²	%	90	3780.65 \pm 1706.17	2378.48 \pm 1812.40	1080.7	0.0004	< 0.001
Distance to Meadow	m	990	1039.3 \pm 544.15	1373 \pm 923.40	1160.3	-0.001	< 0.001
Distance to Road	m	990	441.2 \pm 328.11	712.48 \pm 824.76	1160.7	-0.001	< 0.001
Distance to Water	m	990	498.31 \pm 167.66	459.62 \pm 198.02	1189.0	0.001	0.003
Elevation	m	900	1939.75 \pm 71.46	1740.13 \pm 194.89	858.4	0.012	< 0.001
Quadratic Mean Diameter	in	90	14.23 \pm 2.34	13.79 \pm 3.90	1194.1	0.037	0.06
Road Density	km/km ²	450	1.07 \pm 0.92	1.00 \pm 1.10	1196.6	0.066	0.32
Slope	%	990	16.28 \pm 6.06	22.0 \pm 9.83	1100.6	-0.092	< 0.001
Stand Density Index	N/A	180	397.22 \pm 100.46	268.02 \pm 132.34	986.2	0.009	< 0.001
Stream Density	km/km ²	990	0.49 \pm 0.30	0.6 \pm 0.38	1177.9	-0.886	< 0.001
Trees Per Acre	N/A	990	251.88 \pm 57.75	191.85 \pm 79.26	1059.9	0.012	< 0.001

Table 3.3. Multivariate logistic regression models with individual marten as a random effect. Variable acronyms correspond with the habitat covariates in table 3.1. Numbers underscored with variable acronyms represent the scale tested. The top five models from AICc model selection analysis are shown (see Appendix C.2 for all models tested). Models were built using variables tested with univariate analyses and subsequent p -value ≤ 0.05 . All models were built using *a priori* hypotheses using previous literature and field based knowledge from the study area.

Model	AICc	ΔAICc	AICcWt
cc_site + cc_sd_270 + tpa_990 + road_990 + elev_900	703.23	0.00	0.83
cc_sd_270 + sdi_180 + slope_990 + elev_900	706.53	3.30	0.16
cc_site + cc_sd_270 + waterdist_990 + road_990 + elev_900	712.86	9.64	0.01
cc_site + tpa_990 + road_990 + elev_900	717.04	13.81	0.00
cc_sd_270 + ba_180 + slope_990 + elev_900	719.95	16.72	0.00

Table 3.4. Variable coefficients and 95% confidence intervals of the top model selected using Akaike Information Criterion corrected for small sample size (AICc).

Variable	Coefficient	95% Confidence Interval	p-value
Canopy Cover	0.027	0.0163, 0.0374	< 0.001
StDev Canopy Cover	0.552	0.2767, 0.8367	< 0.001
Trees Per Acre	0.01	0.0056, 0.0140	< 0.001
Distance to Road	-0.0015	-0.0021, -0.0009	< 0.001
Elevation	0.013	0.0112, 0.0161	< 0.001

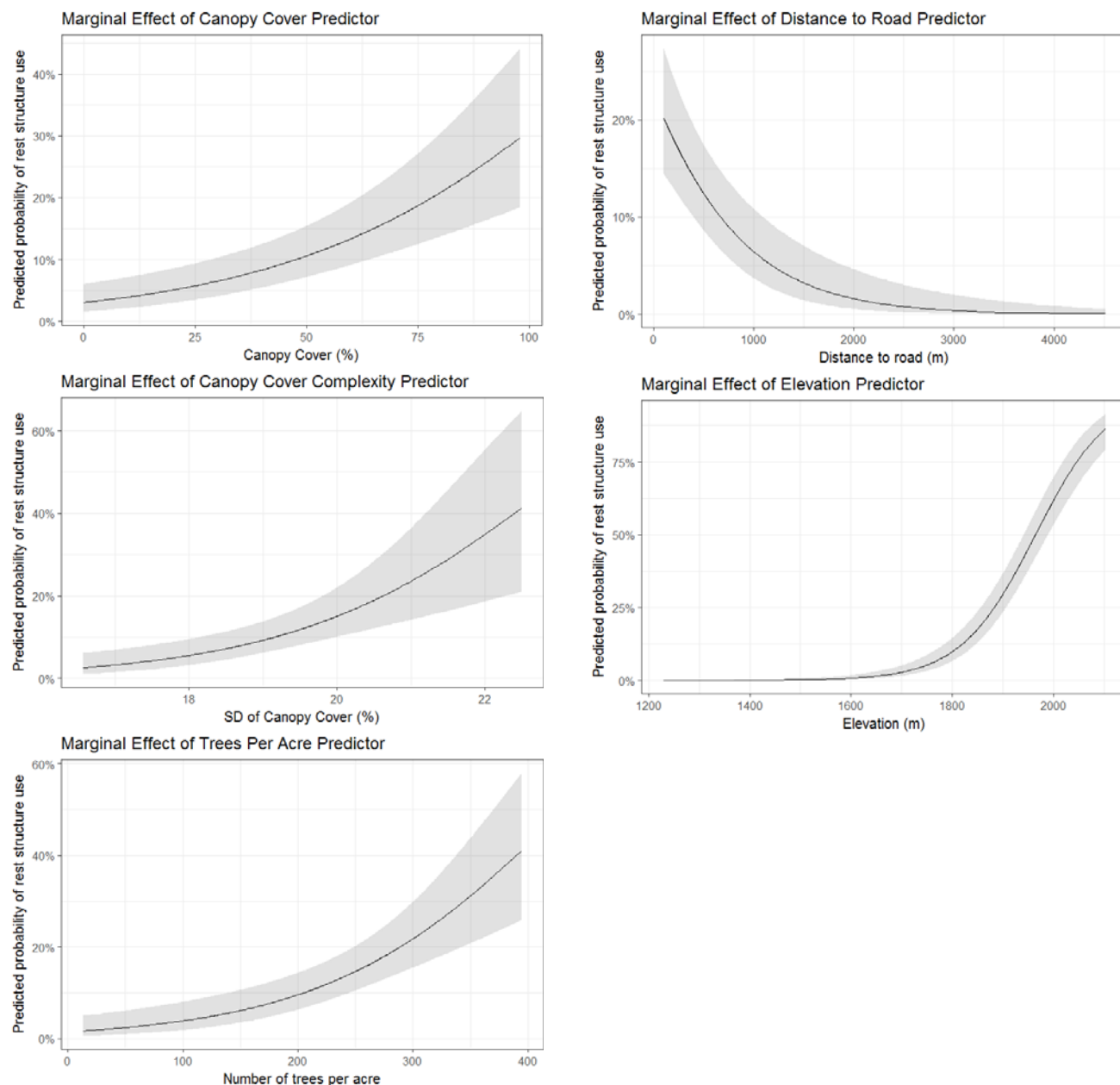


Figure 3.3. To understand the relationship of our predictor variables to the predicted change in habitat suitability, we calculated the marginal effects of the predictor variables from the top model. Marginal effects calculates the change in predicted rest structure suitability for every one unit change in the predictor variable with the remaining covariates set to the mean. The 95% confidence interval is represented by the gray shading around the line.

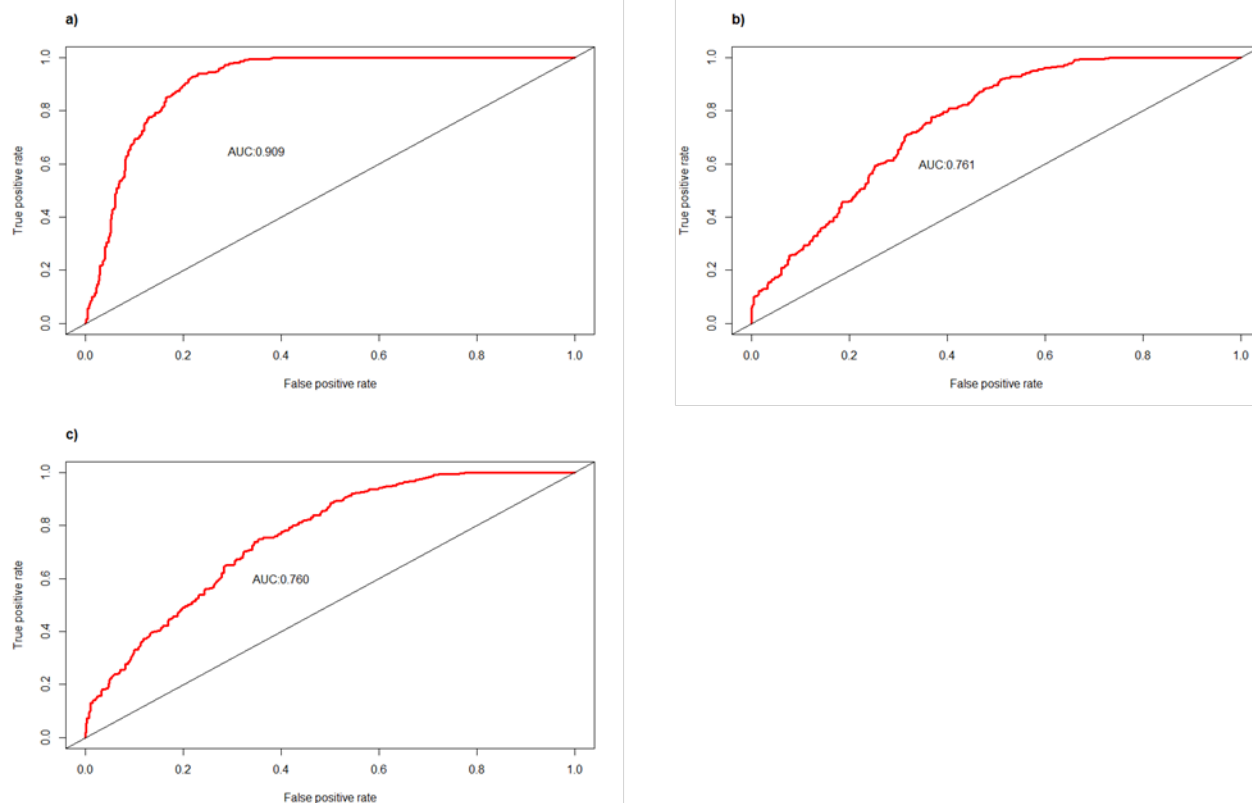


Figure 3.4. **a)** Area under the receiving operating curve (AUC) for the top model calculated from AICc model selection (AUC = 0.909). **b)** AUC for the top model controlled for the elevation predictor variable (AUC = 0.761). **c)** AUC for the top model controlled for the elevation and distance to road predictor variables (AUC = 0.760). This model focuses only on vegetation covariates for predicting rest structure use. An AUC value of 1 indicates that the model perfectly predicts rest site use whereas values below 0.5 indicates a poor fitting model and an increased false positive rate.

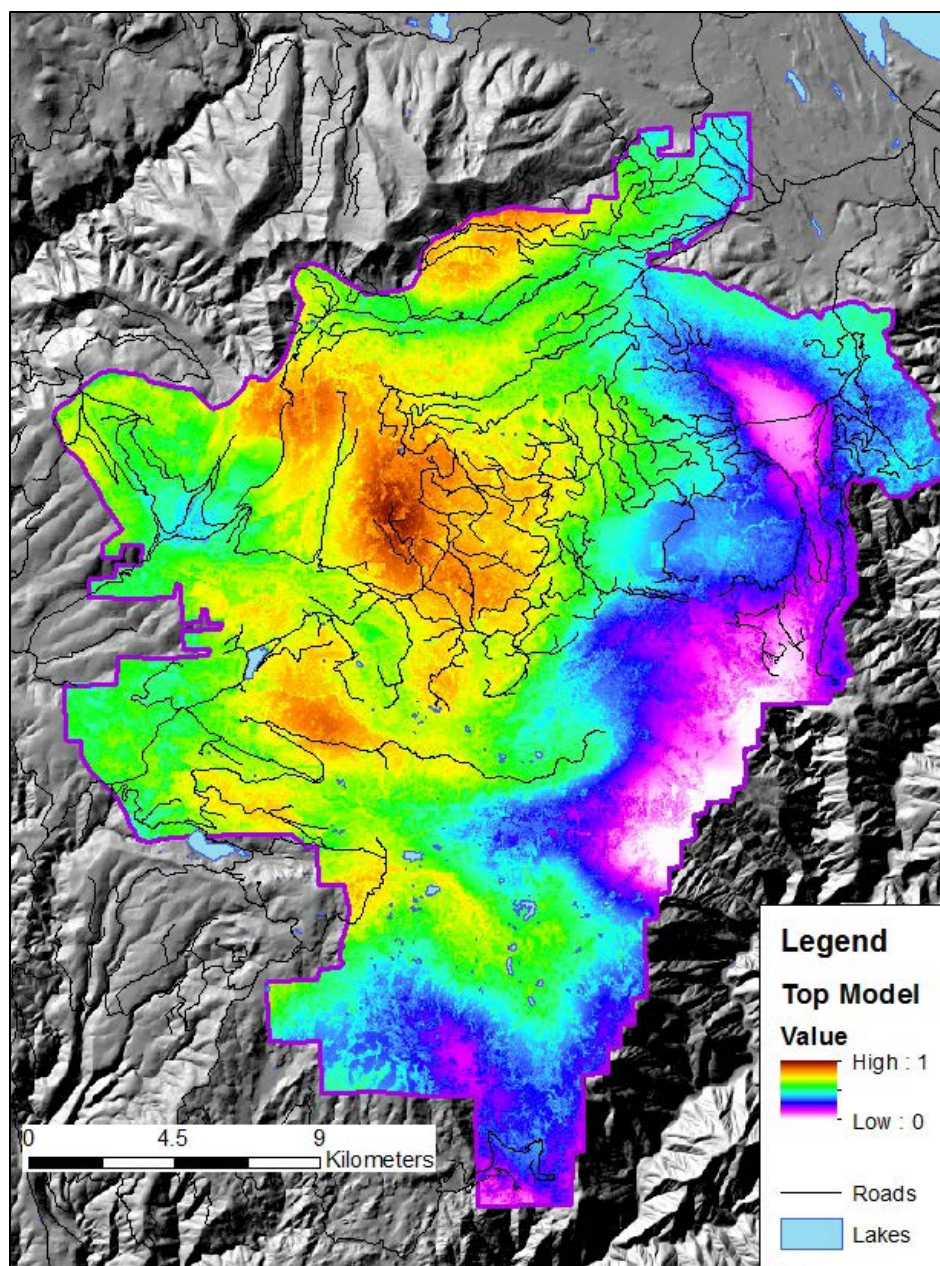


Figure 3.5. Predicted habitat suitability map created from the full top model.

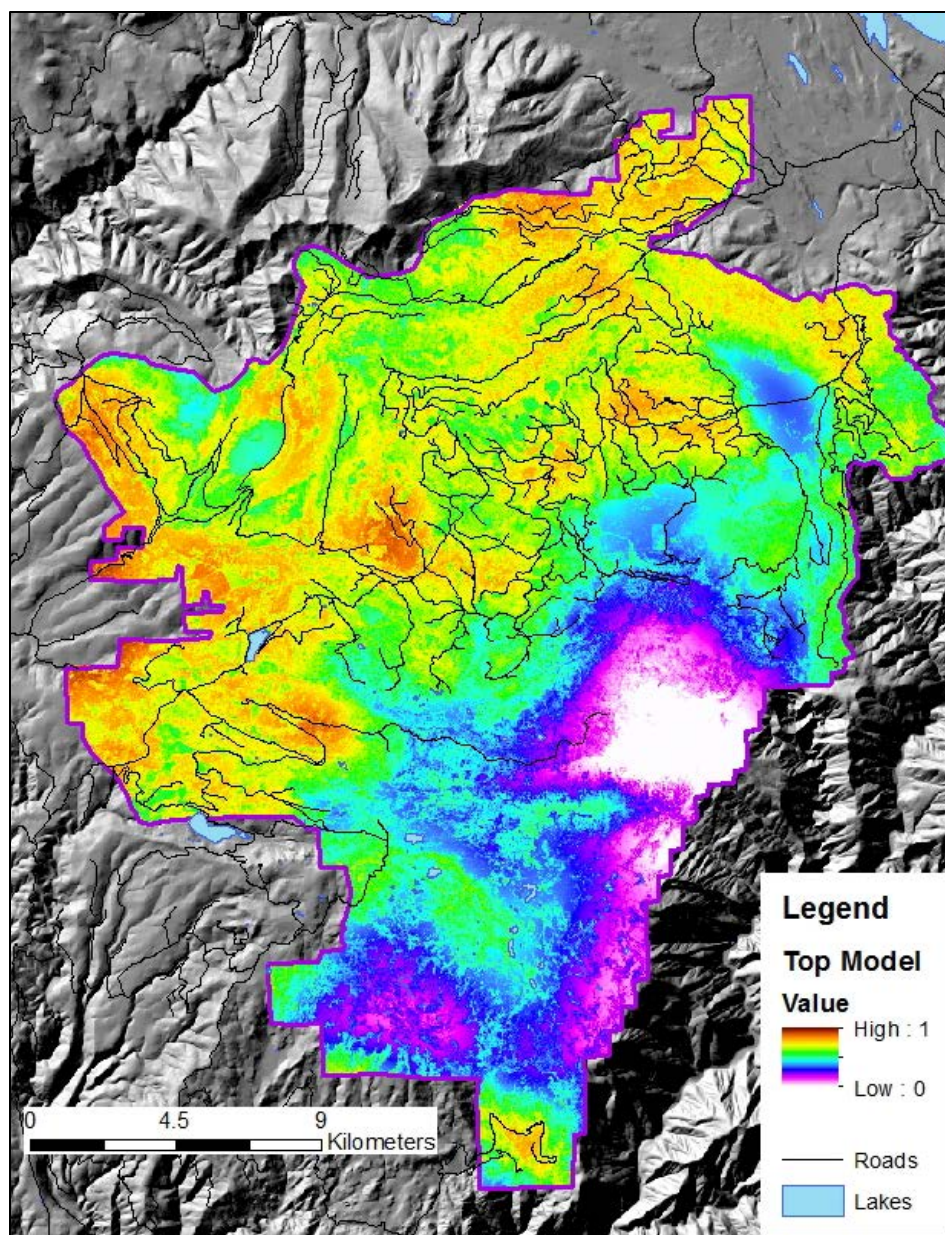


Figure 3.6. Predicted habitat suitability map created from the top model controlling for elevation by setting the elevation parameter equal to 1,940 meters (average elevation).

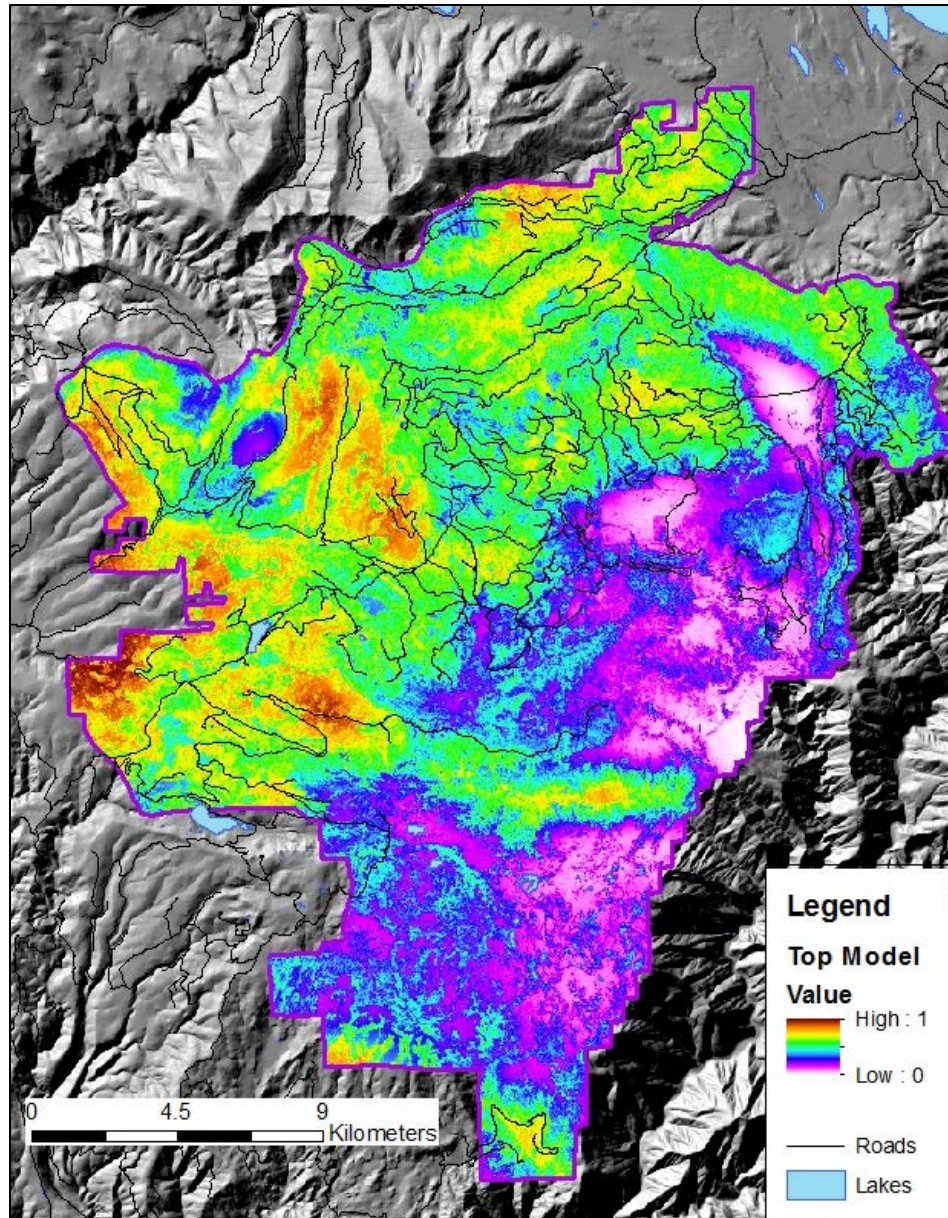


Figure 3.7. Predicted habitat suitability map created from the top model, controlling the elevation parameter equal to 1,940 meters (average elevation) and the distance to road equal to 441 meters (average distance to a road from a used rest structure). This model focuses on forest structure covariates for predicting probability of resting habitat use.

3.4 Discussion

3.4.1 Significance of top model

Martens have been highlighted as a focal species for multi-scale management considerations for decades; for example, Bissonette and Broekhuizen (1995) described how

marten populations could act as a habitat indicator of forest management if considered at multiple spatial scales. Our data also suggests the benefits of considering multiple scales – from the site (30m), area within a stand (270m), and within a home range (900-990m). We interpret the positive relationship with trees per acre (990 meter scale) and elevation (900 meters) as evidence of martens selecting for increased tree cover at higher elevations at the home range scale (Johnson 1980). Similarly, increased elevation was correlated with marten rest site use detections at 990m scale (Shirk et al. 2012, Wasserman et al. 2012, Shirk et al. 2014) and at the 3 km scale (Kirk and Zielinski 2009). Our results demonstrate that higher canopy cover surrounding rest structures and increased structural complexity at broader scales (30 m and 270 m, respectively) increased the probability of selection. Structural complexity has been described as an essential component of marten habitat (Bissonette and Broekhuizen 1995) as it provides protection from predation (Spencer et al. 1983, Payer and Harrison 2003, Zielinski et al. 2005) and habitat for prey (Buskirk and Powell 1994, Fuller and Harrison 2005, Vanderwel et al. 2010).

3.4.2 Topographic influence of predicted resting habitat

While some previous research suggests that martens avoid areas with increased road densities (Robitaille and Aubry 2000, Shirk et al. 2012, Wasserman et al. 2012) and that roads can be a barrier to movement (Moriarty et al. 2016a), the negative relationship of distance to roads in our model may be indicative of sampling bias rather than avoidance. For our study, we typically conducted telemetry from roads. Mountainous topography and exposed rock faces can often deflect or block radio collar signals, lessening the likelihood of detecting martens further away from the road. Roadless areas can be attributed to maintaining ecosystem processes and

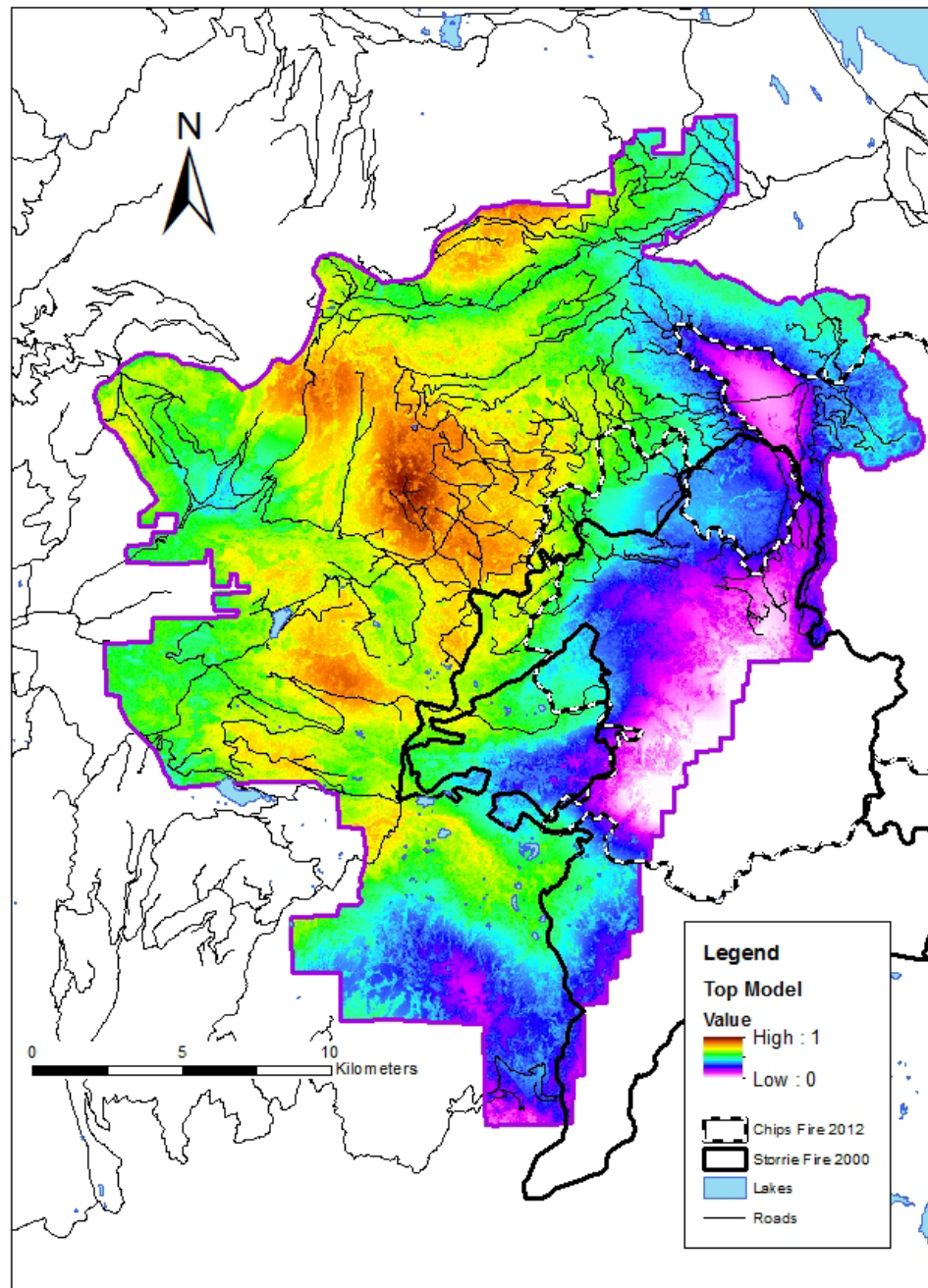
increased biodiversity (Crist et al. 2005). We suggest that suitable rest structures, regardless of the distance to a road, be considered as potential marten habitat in conjunction with the other covariates in our model.

Elevation at the 900-m scale is the only covariate that was consistently within our top models (Table 3.2). Martens have long, thin bodies and proportionally large feet, allowing martens to efficiently travel in deep snow (Krohn et al. 2004). Deep snow likely excludes other predators such as bobcats (*Lynx rufus*) and coyotes (*Canis latrans*) from higher elevations in winter months which could explain the presence of elevation in the top models (Krohn et al. 2004, Moriarty et al. 2015). If the ability to occupy forest stands at higher elevations is mitigating predation via climate, then we may expect a decrease in predicted habitat in the future. Using current climate model projections and their associated impacts on vegetation conditions, Spencer et al. (2015) predicts up to an 85% reduction in future marten population distributions and habitat in California due to elevation shifts from a decreased snow pack prior to the year 2100. Similar reductions in predicted habitat are expected elsewhere (Halofsky et al. 2017, Suffice et al. 2017).

We included both topographic (e.g., elevation) and linear features (i.e., streams, roads) in all *a priori* models, yet martens require specific forest structures for resting. Martens in the Lassen National Forest primarily used trees, snags, and logs as rest structures (Moriarty et al. *in review*) and during our study (Tweedy et al., Chapter 2). Inclusion of elevation and roads increased the probability of predicted habitat suitability (Figure 3.5), but 3% of these areas were located within the perimeter of past wildfires and subsequent salvage logging activities (Figure 3.8a, 3.8b) where little to no forest structure remains. Our model accurately depicted this - when

including canopy cover, trees per acre, and a structural complexity index, predicted resting habitat was minimal in areas without forest cover such as areas that have been previously

a)



b)

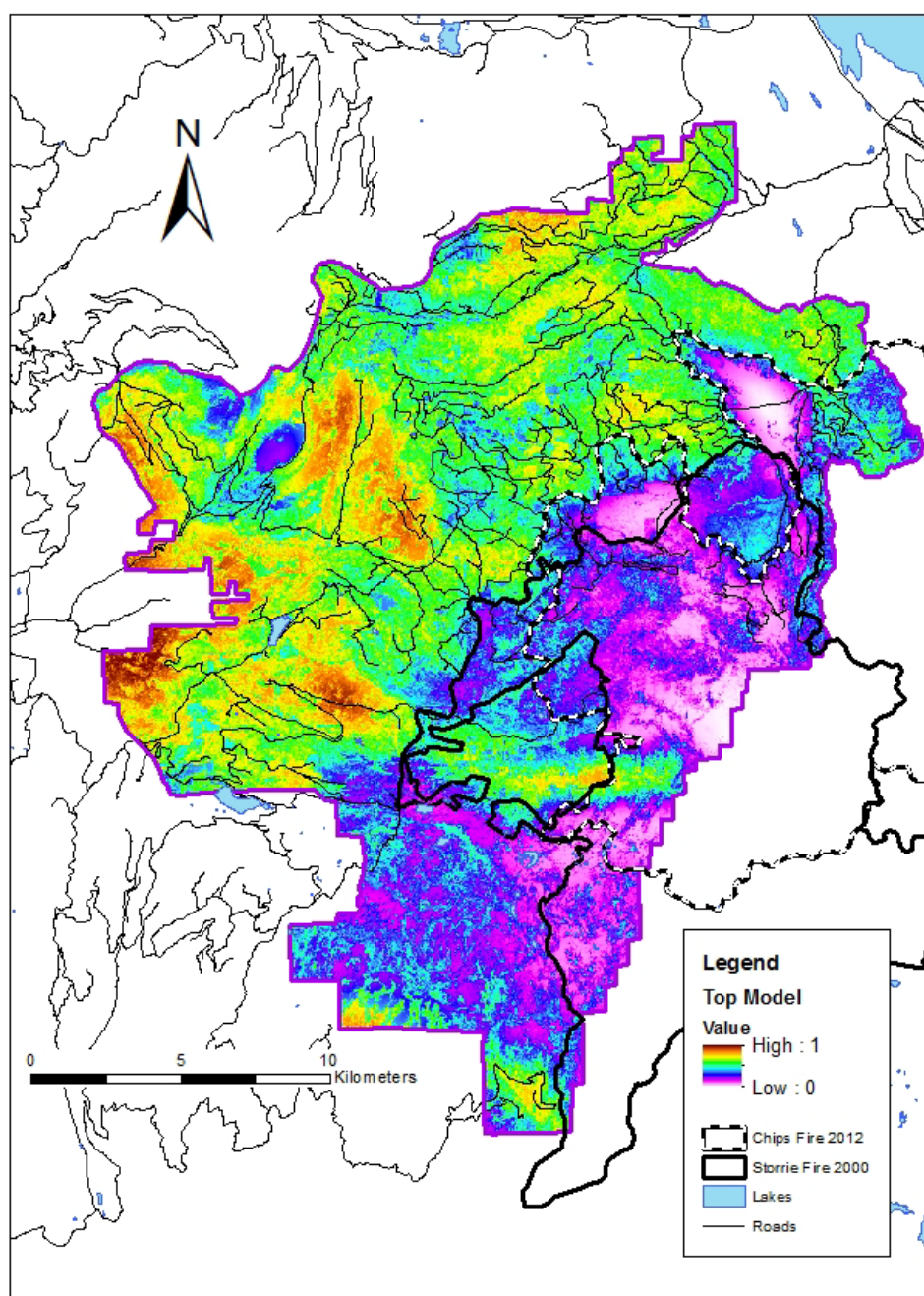


Figure 3.8. a) Predictive resting habitat suitability map of the top model. Portions of the Storrie Fire and Chips Fire footprints are located within our study area (99.7km² and 99.5km², respectively). Portions of the Storrie Fire and Chips fire and subsequent salvage logging reduced the amount of marten resting habitat available, however, elevation and distance to roads predictive parameters increased the probability of resting habitat located with the perimeters of the fires. **b)** Controlling for elevation and distance to roads reveals where forest structure related to resting habitat exists within the study area. Previously higher predicted probabilities of resting habitat decreased within the boundaries of the wildfires while newer areas with suitable forest structure increased.

burned at high severity. Our modeling efforts also identified areas of predicted resting habitat in the western portion of the study area that were previously identified as inadequate due to its presence below an elevational limit of 1940 m (i.e., our mean elevation value at the 900 m selected scale). These areas overlap with predicted high-quality fisher (*Pekania pennanti*) habitat, where recently reintroduced fishers have been documented to occur (Facka et al. 2016). Fishers are larger than martens are potential predators as well as competitors for prey items. Thus, neither map may be accurate – areas with increased elevation may lack forest structure but areas with forest structure at lower elevations may not be available to martens due to competition.

3.4.3 Understory limitations

While our finest scale (30 m resolution with LiDAR) is an appropriate resolution for measuring forest stand features at broader scales, it remains difficult to distinguish between extremely fine scale habitat components, such as individual structures, shrubs, and woody material (e.g., logs) on the forest floor. Shrub cover is typically not considered resting habitat in Lassen National Forest with the presence of other resting structures available. We observed nine marten resting and foraging events in dense shrub cover on ridgelines where previous wildfire activity has presumably altered the stand composition from trees to shrubs (Tweedy et al., unpublished data). Shrubs can be an important source for cover and food for marten and their prey (Martin 1994, Roth and Vander Wall 2005, Moore and Vander Wall 2015). Similarly, large woody material such as logs provide cover and complexity for martens and their prey (Bull et al. 1997, Andruskiw et al. 2008, Vanderwel et al. 2010, Fauteux et al. 2012). We measured woody material and shrub cover to assess marten resting habitat for another aspect of our research; the

number of logs was included in the top model, but was only measured at a 30 m² sampling area around the rest structure (Moriarty et al. *in review*). Although we do not include these understory components in this analysis, other data suggest both logs and shrub cover may increase suitability for marten resting habitat.

3.4.4 *Temporal limitations*

While LiDAR allows sampling of vegetative and abiotic factors over a large spatial extent, it does not provide insight into temporal aspects influencing marten rest selection, such as temperature and snow cover. In the Tahoe National Forest, ~120 km southeast of our study area, martens exclusively used under-snow (“subnivean”) rest structures during the winter and above-ground locations in live trees during the summer (Spencer 1987). We observed martens exclusively using cavities at night during summer, suggesting that martens may seek out more thermally insulated locations when temperatures are colder (Tweedy, Chapter 2). Snow cover affects marten movement (Moriarty et al. 2015, Moriarty et al. 2016b), and likely also affects the availability of rest structures. Further, juvenile dispersal primarily occurs during winter, when martens may be easier to detect (Zielinski et al. 2015), and may be more likely to rest in areas outside our predicted model. As such, we consider our model a conservative representation of predicted resting habitat that is most relevant to territorial adult martens, which are the most sensitive for population stability.

Similar to changes expected in seasons or temperature, alteration to vegetative composition or distribution (e.g. wildfire, harvest, thinning, etc.) would likely influence our predicted scales of importance. Here our results suggest that martens select areas ~270m from a rest structure and up to 990m. If disturbance occurs at those scales we would expect changes in

both marten use of rest structures and marten movements within their home ranges. For instance, female marten home ranges were 212% larger in logged forests compared to uncut forests Ontario, Canada which the authors attributed to decreased encounter and success rates in capturing prey (Thompson and Colgan 1987, 1994). In Lassen National Forest, fuel reduction treatments in the form of thinning disrupted marten movement patterns and habitat use (Moriarty et al. 2016b). We found that 3.5% of rest structures were within recent fire boundaries (Chips Fire 1, Storrie Fire 10; Figure 3.8). Because martens in this region occupy high elevation areas that are within their normal fire rotation intervals, we predict a negative impact with increased forest loss, reduced canopy cover, or reductions in structural complexity due to either fire or harvest activity. Recent simulations by Credo (2017) suggest treatment within predicted marten habitat was not necessary to achieve significant reductions in large fire spread rates. Further, at a landscape scale, treatment on 20% of the land area, in the form of reducing small diameter trees and woody debris at lower elevations, significantly reduced the potential for large fires (Credo 2017). We hypothesize that increased disturbance in areas of high predicted resting habitat would increase the size of marten home ranges, and decrease overall suitability.

3.4.5 Importance of multiscale for quantifying habitat suitability

When comparing multi-scale models to single scale models, multiscale methods consistently performed better when predicting habitat suitability (Shirk et al. 2012, McGarigal et al. 2016, Wan et al. 2017). Management decisions at landscape scales, extrapolated from results at finer spatial scales, can produce ineffective conservation strategies (Bissonette 2013). The availability of satellite imagery (e.g. Landsat) and increasing use of LiDAR has made it easier to consider scale relationships across the landscape (Ackers et al. 2015). We used scales that we

considered biologically relevant to the life history needs of martens (e.g. breeding, dispersal, etc.), but our techniques can be used for other species. For instance, Fisher et al. (2011) describes the direct relationship between body mass and scale of habitat selection in terrestrial mammals. Using this model, analysis of habitat selection for a grizzly bear might be more appropriate to examine at relatively large spatial scales (2-4 km, 5-10 km, and 40+ km; Nams et al. 2006) compared to habitat selection for birds and moths where selection of scale focused on areas less than 1.2 km from locations (Grand et al. 2004). Predictive habitat models, even those incorporating multiple scales, are most effective within the study area where data were observed. Shirk et al. (2014) identified dissimilar multiscale habitat models when comparing marten habitat selection in xeric and mesic forest stands. In mesic stands, top models indicated that martens were more likely to select areas based on topography particularly valleys bottoms of large drainages that correspond to riparian areas where the largest trees grow. Riparian areas are lacking in xeric stands, therefore top models included habitat attributes related to patch size with the largest quadratic mean diameter (Shirk et al. 2014). Similarly, scale selection of habitat features for predicting nest and roost sites differed between two Mexican spotted owl (*Strix occidentalis lucida*) populations in Arizona and New Mexico. Percent canopy cover was selected at a finer scale in New Mexico than in Arizona (100 m and 2,700 m respectively) (Wan et al. 2017) which would affect how the landscape is managed in the two areas. The importance of considering scale relationships when examining habitat relationships is widely recognized, yet in a review of >800 research papers published between 2009 and 2014, only 20% adequately addressed multiscale habitat associations (McGarigal et al. 2016).

Because of its emerging use, very few studies have used LiDAR to assess predictive habitat for wildlife. Here, we uniquely obtained spatially-explicit information characterizing

vegetation during our study that encompassed a large area and were highly accurate, matching the resolution of our marten rest locations. Our goal was to provide information that could be used to identify areas for restoration or to minimize negative effects on martens. Given our data, areas of high predicted marten resting habitat may be considered as predicted movement corridors. At a stand or home range scale, increased number of trees per acre – especially in areas around 1940 m elevation and above – appears to be correlated with marten rest site use. Areas around rest structures could act as “leave islands”, or areas of limited or no management activity within treated stands. With our multi-scale optimization, our data suggest that 270 m may be an appropriate distance perceived by martens (i.e., 22 ha, 56 acres) and we observed an average of 63% cover at the 270 m scale.

We conclude that the hierarchal habitat selection process is an important consideration when managing for species that may be sensitive to forest management practices. Similar multiscale habitat studies highlight the importance of developing management strategies adapted to local landscape characteristics (Shirk et al. 2014, Wan et al. 2017). When considering conservation of species, one broad management plan over multiple landscapes could be inadequate, and our methods could be a useful tool when developing local forest management plans.

3.5 Literature Cited

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4 | Conclusions

With increasingly frequent high-severity wildfires in California (Miller et al. 2009), there is an urgency to return forest ecosystems back to their natural fire regimes through a combination of thinning and prescribed fire treatments (North et al. 2015). However, forest management goals may conflict with species sensitive to forest management activities, especially in areas of late-seral, old-growth forest stands (Jones et al. 2016). The degree to which disturbance affects the distribution of marten populations may differ across their geographic range (Sturtevant et al. 1996, Hargis et al. 1999, Thompson et al. 2012); therefore, regionally-specific data for martens are desired to guide management decisions within Lassen National Forest, California. Accurate habitat data can help biologists develop conservation and management plans for marten populations. At the beginning of this research, we had two objectives: (1) evaluate whether the proportion of use for microsite and rest structure selection was dependent on the diel period, and (2) understand the relationship between scale and resting habitat selection.

4.1 Principle findings

4.1.1 *Diurnal and nocturnal rest structure use*

Because martens predominantly rest at night during the summer, but data is often collected during the day, we predicted there could missing information for managers to consider. Nonetheless, we did not observe differences between the sizes of woody structures used by martens throughout the diel period. However, these rest structures are considerably larger than the available structures located within the random plots suggesting that martens prefer these unique features. Further, we did not observe statistical differences in microsite use between the nocturnal and diurnal periods. We did observe martens primarily using cavities and burrows at night, possibly due to associated thermoregulatory properties and protection from predation

within the study area. We suspect that our nocturnal sample size was not large enough to detect a statistical difference between the diel periods. In Lassen National Forest, martens used snags as rest structures more than any other structure type. This may suggest martens would benefit from retention and recruitment of large snags (>89 cm, lower 95% confidence interval, Table 2.3).

We observed significant variation of marten rest structure use in California. For instance, martens selected stumps more than other structure types in the Tahoe National Forest. Martens used snags more than any other structure type in Six Rivers National Forest, but also used logs, rock piles, and slash piles more frequently than Lassen and Tahoe National Forest. Martens are likely adapted to local forest conditions; thus, we caution extrapolating information between studies when creating marten conservation strategies. Instead, land managers can identify large structures with microsite features used by martens, like cavities, to retain. If there are a deficiency of structure types (e.g., large live trees), then recruitment would occur by allowing such trees to grow larger.

4.1.2 Multiscale resting habitat selection

With the acquisition of LiDAR and ground-based data, we used accurate location data of marten rest structures to analyze the selection of resting habitat at multiple spatial scales. We generated a series of hypothesis-based multivariate logistic regression models built from the optimized scale of 14 habitat covariates. Our top model included variables that were significant for predicted marten resting habitat, and we also described the scale at which martens may perceive these features. During our study, martens selected for increased tree cover at higher elevations as well as structural complexity with dense canopy cover around rest structures. At the site scale (30m) martens used structures with increased canopy over, similarly at the stand scale (270m) martens selected areas with increased trees per acre. Selection at multiple scales may

suggest martens perceive both local conditions at the structure location while selecting for specific stands.

We noticed increased elevation and decreased distance to road predictor variables increased the amount of suitable resting habitat even when such areas contained little to no vegetation. Therefore, we also modeled predicted habitat while keeping elevation and distance to road at their average used values, and we observed a reduction in the amount of predicted suitable resting habitat. We suggest managers review each model carefully, and that the depiction of habitat primarily focused on vegetation characteristics may be the most meaningful for assessing marten connectivity and assigning areas for future restoration.

We highlight the importance of both hierarchical habitat selection and portraying results geographically to assess biological relevance. We both observed martens selecting predicted habitat at different scales and our assessment of predicted vegetation appeared more relevant after standardizing the effects of road and elevation to our model. The availability of processed LiDAR data into values pertaining to silviculture (e.g., trees per acre, basal area) was necessary for our evaluation of multiscale habitat relationships.

4.2 Limitations

4.2.1 Diurnal and nocturnal rest structure use

Our observational period and sample sizes would have benefited from a higher sample size. Data collection of nocturnal rest structures was performed from June – September 2016 and we located 32 unique rest structures, which was meager compared to the 140 summer and 198 winter diurnal structures located during the project. We could have increased sample size with a larger field team or with multiple summers of data. Because of martens' elusive nature, we were unable to collect unique rest structure data for 2 individuals and only 1 or 2 rest structures for

four other individuals representing 46% of the total martens radio collared during the 2016 summer. With few locations per individual and total sample size, our nocturnal data may not be representative for comparisons between the two diel periods. Also, if nocturnal cavity use (47%, Chapter 2, table 2.4) was influenced by thermoregulation, we would benefit from sampling during multiple years to increase the variation in conditions between years.

4.2.2 *Multiscale resting habitat selection*

Although we used high resolution location and vegetation data, our multiscale models do not account for all vegetative features that may influence martens. Specifically, we lacked data on shrub cover and log density due to the inability of the laser from LiDAR equipment to consistently reach the ground in dense canopy cover. This may limit our inferences; martens used dense shrub sites for resting for nine events during our study. Shrub cover and large logs have been emphasized as a critical component of marten habitat for both resting (Buskirk et al. 1989, Slauson and Zielinski 2009) and foraging for prey (Martin 1994, Bull et al. 1997, Roth and Vander Wall 2005, Andruskiw et al. 2008).

In addition, we were unable to account for temperature variations during the day, seasonality of rest structure use, or future scenarios such as large scale disturbance. Previous studies have demonstrated how forest loss and fragmentation can change how martens use the landscape. For instance, martens will avoid clearcuts (Potvin et al. 2000) and often increase the size of their home ranges to improve foraging success in areas of forest fragmentation (Thompson and Colgan 1987). Within Lassen National Forest, marten movements were slower and more sinuous in complex stands while movements in openings were more erratic and linear (Moriarty et al. 2016). Fragmentation can also have lasting temporal effects due to amount of

time it takes before harvested stands become suitable habitat again (Sturtevant et al. 1996).

Therefore we predict that our multiscale selection results would likely change as well.

Our models were focused on vegetation and topography, but suspect including biotic factors, such as the presence of prey influences rest site selection. Mustelids consume prey and use the prey's shelter for resting. For example, squirrel middens were the majority of rest sites in Alaska (Buskirk 1984). Thus, rest structures that aid martens to safely consume prey could be beneficial, and we predict higher prey densities could influence marten resting habitat.

Finally, our scope of inference is limited to our study area in Lassen National Forest. We know that martens occupy other areas of Lassen National Forest (Moriarty et al. 2016) and Lassen Volcanic National Park (Zielinski et al. 2005). Even though habitat characteristics might be similar at the landscape level, local conditions may vary between regions. We caution extrapolating our findings elsewhere, but suggest our techniques could be readily applied if similar data were available.

4.3 Future research and management considerations

4.3.1 Diurnal and nocturnal rest structure use

Because marten activity patterns appear seasonal, sampling during periods when martens are most vulnerable may better inform limiting factors. We suspect these periods include temperature extremes (e.g., extreme heat, cold). Our nocturnal sample size may have been too low for comparisons. Additional locations would provide the ability to test whether rest structure selection was different at night. We hypothesize that cavities and subterranean microsites were necessary features providing martens with refugia from lower nocturnal temperatures and protection from specialized predators.

Individual rest structures might not be restricted to diurnal or nocturnal use. For instance, we found 39 unique nocturnal rest structures; however, seven of those structures were also used by martens during the day. We deployed remote cameras to monitor rest structures. Preliminary results from the 24 hour surveillance showed that martens reused rest structures 79% of the time while our VHF telemetry efforts only detected a reuse rate of 30% (M. Delheimer, USDA Forest Service, unpublished data). We have not processed the remote camera data prior to the completion of this thesis, and we suspect that some rest structures were used during both diurnal and nocturnal periods. When comparing selection throughout the day, future research focus on the degree to which microsite use is dependent on the diel period while accounting for temperature. Due to the marten's seasonal activity patterns, future research could also devote efforts during winter to evaluate the 24 hour and year round selection of habitat structures, perhaps through remote camera surveillance, as rest structure selection appears to change seasonality (Spencer 1987, Bull and Heater 2000).

4.3.2 *Multiscale resting habitat selection*

Our largest information gap was from the inability to predict understory vegetation, which has been successful in interior ponderosa pine forests (Wing et al. 2012). We hypothesize shrub and log cover strongly influenced martens' selection of resting habitat. Further, we hypothesize that snag distribution might also influence resting habitat selection. Similar to the prediction of understory vegetation cover, using LiDAR methods to detect individual snags has improved (Wing et al. 2015). Snags represented over 50% of rest structures used (Chapter 2, Table 2.4) and understanding the spatial pattern of snags could help foresters and biologists identify areas on the landscape for protection or restoration.

One goal from these efforts was to describe the relationship between scale and resting habitat selection. Martens selected areas at 30 and 270m, and each could be considered for establishment of buffers or “leave islands” in areas with predicted suitable habitat. For instance, a minimum of 30m could be considered around each resting structure and 270m around marten dens and rest structures used on multiple occasions, which were presumably more important. Nonetheless, such strategies would benefit from considering other life history characteristics to sustain marten occupancy on the landscape with subsequent implementation of forest management activities. For instance, connectivity between rest locations would benefit from retaining understory cover in stands where martens can both avoid predation and forage as depicted from movement data (Moriarty et al. 2016).

4.3.3 Management considerations

Locating marten rest structures is not currently possible without radio telemetry and intensive monitoring. This work presented in this thesis represents one of the largest datasets for marten rest structures in the western United States. However, the costs associated with this type of monitoring is typically not available for continuous long-term research. Our work is a snapshot in time, and changes to the landscape are expected from management activities, natural disturbances, and a slow attrition is expected.

Meanwhile, our research can provide information and tools for future management plans. For instance, we found that martens often used large woody structures for resting. If these structures are thermally beneficial and are limited on the landscape, we predict that martens will continue to use large woody structures in the future. The lower diameter (95% confidence intervals) of used trees, snags, logs and stumps were 87cm, 89cm, 51cm, and 90cm, respectively

(Chapter 2, Table 2.2). These sizes could inform structure guidelines for wildlife tree retention. Retaining large structures is not a permanent solution as these features will eventually decay beyond functional suitability for martens. Therefore, the recruitment of live trees that can grow and die, becoming large snags and eventually logs, is an important consideration for long term marten persistence. Areas of predicted low quality marten habitat may benefit from thinning or prescribed burning as these treatments can often increase the size of trees within the management units.

Size can be an informative guideline for mapping potential marten rest structures; however, microsites can be particularly difficult to survey especially in dense, structurally complex stands. Surveying for other species or observation of particular environmental elements can assist with identifying resting areas. For example, tree damage or mortality can begin the process of decay and subsequent cavity formation created by heart rot fungi and/or woodpeckers. Although not tested during our study, pileated woodpeckers (*Dryocopus pileatus*) and heart rot fungi are linked in forming cavities for many species (Remm and Löhmus 2011, Cockle et al. 2012) including mustelids (Green 2017). Further researching indicating whether the presence of woodpecker activity or heart rot fruiting bodies (i.e., conks) can serve as an indicator of possible resting habitat could help inform management strategies. For instance, trained surveyors could return to known resting structures and random locations to assess whether features can be remotely identified.

Retaining large structure with suitable microsites should not be the only consideration when managing marten species as we observed a hierarchal scale response of the vegetation surrounding the rest structures. We observed dense canopy cover ($\bar{x} = 63\%$) at the rest structure and increase structural complexity at a radius of 270 meters. Buffers or “leave islands” of 270

meters may be appropriate when planning management activities around rest structures. Our scale optimization is a way of estimating how martens perceive the landscape when selecting resting habitat, and we observed that this perception can start at the largest scale tested (i.e., 990 meters). We observed how the presence of other predictor variables had the potential to increase predicted resting habitat when the presence of suitable vegetation characteristics was missing. Therefore, field-based knowledge of the vegetation conditions may be needed as creating the same buffers around every snag may not advantageous for conservation planning. Here, a minimum radius of 30 m (our smallest scale), with marten-specific management actions within 270 m and 990 m could be considered. Only using one distance for creating buffers ignores the scale selection we observed when testing other vegetation covariates. For example, the selection of increased tree cover at higher elevations at a distance of 990 meters around structures likely represents home range selection. Hence, other life history characteristics influences the selection of resting habitat and should be considered when creating management plans. Ultimately, reducing large openings as well as maintaining connectivity throughout a marten range would be highly beneficial. Marten social dynamics, predator-prey interactions, and movement patterns likely influence habitat selection but such activities were not considered for this research. Careful consideration of the spatial distribution of “leave islands” across the landscape while accounting for the connection to other suitable habitat patches may be beneficial. Further, the monitoring of these “leave islands” for marten use could provide further insight for adapting management techniques.

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5 | Appendices

Appendix A: Defining marten activity periods

Possible mechanisms influencing marten activity patterns include synchronization with prey activity patterns (Zielinski et al. 1983), thermoregulation (Arthur and Krohn 1991, Thompson and Colgan 1994), and avoidance of predators (Drew and Bissonette 1997). Zielinski et al. (1983) hypothesized in the Pacific states the martens were aligning their activity with primary prey species. Martens are described as generalist predators and during the summer there is an abundance of ground squirrels, insects, and birds – all of which would generally be more active during the day (Zielinski et al. 1983, Slauson and Zielinski 2017). During winter in the high elevation areas of the Sierra Nevada Mountains, many of the prey species available during summer hibernate or migrate. Thus, during the snow covered winters, martens may switch their diet to snowshoe hares (*Lepus americanus*) and northern flying squirrels (*Glaucomys sabrinus*) (Zielinski et al. 1983, Cumberland et al. 2001), both of which are suspected to be more active at night.

In contrast to the prey hypothesis, the temperature hypothesis stipulates that martens would be most active during periods to conserve energy. For instance, during summer martens in Ontario had a poly-phasic activity pattern during summer, moving at all times of the day (Thompson and Colgan 1994). At night when temperatures were as low as -15°C, martens were predominantly diurnal. In this region, prey items would be similar to the Pacific states, but it is stipulated that the energetic cost to forage at night would be too thermally detrimental (Thompson and Colgan 1994). High fidelity to resting areas with large woody material and structures with cavities during winter (Spencer 1987, Sherburne and Bissonette 1994) support the thermoregulatory hypothesis.

The predator avoidance hypothesis suggests that martens would avoid periods when their primary predators are active (Drew and Bissonette 1997). For instance, martens may be nocturnal despite low temperatures in winter. Diurnal movements would increase the risk of predation by predators (e.g., coyotes (Kitchen et al. 2000)) especially in areas with less vegetation and presumably less escape cover as experienced in Newfoundland, Canada (Drew and Bissonette 1997, Hearn et al. 2010). Because martens are small bodied predators (<1300g), martens may be sensitive to competition and predation and make movement decisions based on periods with the least risk (McCann et al. 2017). Lastly, these three hypotheses could interact or influence marten activity at different scales, such that broad activity patterns are influenced by weather but daily decisions better correspond with prey or predator activity (McCann et al. 2017).

We verified the diel period (i.e., diurnal, nocturnal, twilight) when martens were most active during summer (June-November) and winter (December-May). We attached Quantum 4000 micro-GPS collars with accelerometers (Telemetry Solutions, Concord, CA, 40-45g) to previously captured martens (see methods in Moriarty et al. 2016) and programmed the unit to assess activity every 4 seconds and to record data every 2 minutes. The collar output provided two correlated metrics: “maximum amplitude” which was the highest peak of movement during the 2 minute period and “energy” which reflected cumulative movement, or the volume of intensity values, in each 2-minute period. Both values were an index of movement on both the vertical and horizontal planes.

We established three categories for marten activity: inactive (sleeping), active (walking or running), and unknown (reflecting minor movements). We did not attempt to characterize type of behavior (e.g., foraging, walking, bounding), which would have required observation of

captive martens. Instead, we identified energy values clearly reflecting “inactive” or “active” behaviors by monitoring each collared marten during post-capture anesthetic recovery and immediately after release (while still in visual range). We used values recorded while the marten was sleeping in the cage to characterize the inactive state, and values recorded when the marten walked or ran after release as active. We combined data with known activity states during observation and determined whether our inactive or active differed by gender and if values for inactive and active accurately portrayed actual marten activity with 2-sample t-tests assuming unequal variance, then created a generalized linear model with marten as a random effect to assign predicted activity state to martens moving without observation.

We calculated the duration of each activity bout, or period when the marten was presumed to be walking or running. Activity bouts were only measured if the animal was active for a minimum of 8 consecutive minutes (4 data opportunities). Similarly, the activity bout was considered completed once the animal was inactive for a minimum of 8 minutes. Short periods (<6 minutes) of unknown activity were designated as the previous known activity. Unknown periods could include eating or stalking if the animal was previously active or stretching and slight movement if the animal was previously inactive.

We obtained daily nautical twilight, sunrise, and sunset from the United States Naval Observatory Calendar (<http://aa.usno.navy.mil/>) to accurately classify activity type (e.g., diurnal, nocturnal). We distinguished between diurnal and nocturnal time periods based on nautical twilight. Nautical twilight in the mornings and evenings occurs when the center of the sun is geometrically 12 degrees below the horizon (United States Naval Observatory, Astronomical Applications Department, Washington, D.C.). At this time of day stars are generally visible and polarized light is absent (Chernetsov et al. 2011).

The activity patterns of martens in our study are best explained by the prey synchronization hypothesis and the thermoregulatory efficiency hypothesis. We observed animals primarily active during the day during summer and at night during winter, which likely corresponds to similar periods of marten prey (Figure A.1). We also observed martens using cavities or subterranean chambers as microsites (74% of all locations) at night and much more predominantly than diurnal microsites, suggesting increased selection of these structures.

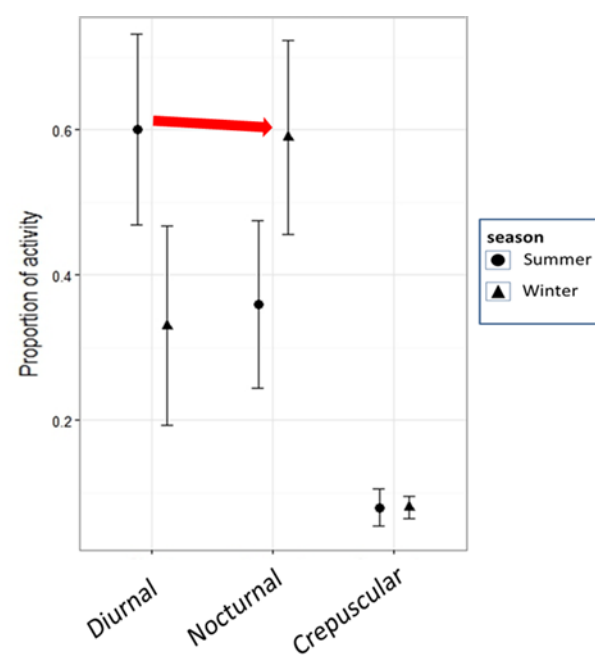


Figure A.1. We evaluated Pacific marten (*Martes americana*, *M. caurina*) activity patterns by quantifying the duration individual martens were presumed moving. We quantified activity from an accelerometer and movement data with GPS collars where we observed martens in known states (e.g., resting, running) and used linear regression to identify movement states for each 2-minute period of observation. Then, we used a moving window to classify activity bouts and presumed a marten was most active if >60% of activity was within a diel period (e.g., diurnal). We report the mean and 95% confidence interval during each season (n = 9 martens) (Lassen National Forest, California; 2010 – 2013; Moriarty, USDA Forest Service, unpublished data). Based on our assumptions, there was strong evidence that martens shifted from diurnal activity in the summer (circles) to nocturnal activity in the winter (triangles) with low but consistent amounts of activity during the crepuscular period (nautical twilight).

Appendix A Literature cited

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Appendix B: Figures



Figure B.1. Photographic Examples of Marten Rest Structure Types. Commonly-used marten rest structure types in the Lassen NF include (a) snags, (b) live trees, (c) stumps, and (d) logs.

Appendix C: Tables

Table C.1. Definition of the microsite types used in Lassen National Forest. If the microsite is unknown when it pertains to a snag or live tree, the microsite is labeled “arboreal” to indicate the marten was not using a ground feature. If the microsite is unknown when it pertains to a log, coarse woody debris, or rock pile, the microsite is labeled “ground”.

Microsite	Resting Structure	Microsite Definition
Cavity	Snag (>2m), live tree, stump (<2m)	Cavities are created by mechanical breakage/damage and subsequent heart-rot decay of the tree structure. Excavation of nesting holes by woodpeckers can create suitable cavity features as well.
Broken top	Snag, live tree	Broken tops are a platform feature created following the main stem of a snag or tree bole has been broken. Visual confirmation is often required as cavity entrances can exist at the top of these structures.
Branch platform	Snag, live tree	Branch platforms are typically a large diameter branch or complex branching feature forming a suitable platform. Complex branching may form naturally or as a result of a pathogen (e.g., mistletoe, <i>Arceuthobium spp.</i>).
Subterranean	Stump	Subterranean feature in which decayed root systems provide a chamber-like space for resting.
Basal hollow	Snag, live tree	Cavity-like feature at the base of a tree created by the individual or synergistic action of fire and decay. Careful consideration is needed as cavity microsites can be misidentified as basal hollows when the basal hollow is merely the entrance, not the microsite being used.
Subterranean, Interstitial space	Coarse woody debris	Interstitial space created from the grouping of either natural or human (slash pile) woody (e.g., stumps, logs, live trees) or rock features. Or an available subterranean space within the debris pile.
Ground	Shrub clump	Dense shrub feature in which the actual resting location is usually unknown. Possible microsite locations within the shrub clump can be a subterranean burrow, rock pile, or simply resting on the ground.
Subterranean	Burrow	Feature underground typically associated with rodent activity. This identification should only be used when there is no structural association.
Subterranean, Interstitial space	Rock pile	Whether the marten is using an interstitial space created by the arrangement of rocks or possible subterranean burrow within the rock pile is usually unknown, but we presume a chamber or spaces between rocks persist
Cavity	Log	Cavity-like space created from the decay of a log. No unique microsite feature is being used just the decayed structure as a whole.
Subnivean	Stump, saplings, logs, snag, rock pile (Subnivean)	Resting location is underneath the snow. This is typically associated with stumps, logs, live trees and branches, and/or saplings. Occasionally, trees or snags at an inclined angle may provide an adequate structure. Effort should be taken to identify the structure after the snow melts.

Table C.2. Multivariate logistic regression models with individual marten as a random effect. Variable acronyms correspond with the habitat covariates in table 3.1. Numbers underscored with variable acronyms represent the scale tested. All models from AICc model selection analysis are shown. Models were built using variables tested with univariate analyses and subsequent p -value ≤ 0.05 . All models were built using *a priori* hypotheses using previous literature and field based knowledge from the study area.

Model	AICc	ΔAICc	AICcWt
cc_site + cc_sd_270 + tpa_990 + road_990 + elev_900	703.23	0	0.83
cc_sd_270 + sdi_180 + slope_990 + elev_900	706.53	3.3	0.16
cc_site + cc_sd_270 + waterdist_990 + road_990 + elev_900	712.86	9.64	0.01
cc_site + tpa_990 + road_990 + elev_900	717.04	13.81	0
cc_sd_270 + ba_180 + slope_990 + elev_900	719.95	16.72	0
cc_sd_270 + ba_180 + slope_990 + elev_900	724.68	21.45	0
cc_sd_270 + ba_180 + tpa_990 + strmden_990 + elev_900	726.5	23.28	0
cc_sd_270 + ba_180 + tpa_990 + elev_900	741.54	38.32	0
cc_site + cc_sd_270 + elev_900	746.83	43.61	0
cc_sd_270 + elev_900	833.21	129.98	0
cc_sd_270 + sdi_180 + slope_990	861.00	157.78	0
cc_sd_270 + ba_180 + slope_990	868.28	165.05	0
cc_site + cc_sd_270 + waterdist_990 + slope_990	935.58	232.35	0
cc_site + cc_sd_270 + slope_990 + road_990	939.98	236.76	0
cc2_90 + cc_sd_270 + waterdist_990 + slope_990	943.04	239.82	0
cc_sd_270 + ba_180 + tpa_990 + strmden_990	953.26	250.03	0
cc_sd_270 + ba_180 + tpa_990	961.67	258.44	0
cc_sd_270 + ba_180 + tpa_990 + waterdist_990	963.63	260.41	0
cc_site + cc_sd_270 + tpa_990 + road_990	989.15	285.93	0
cc_site + tpa_990 + road_990	1012.74	309.51	0
cc_site + cc_sd_270	1033.15	329.93	0
cc_sd_270	1160.12	456.89	0
Intercept	1195.57	492.34	0