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Population ecology of American marten in New Hampshire: Impact of wind farm development in high elevation habitat

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Population ecology of American marten in New Hampshire: Impact of wind farm development in high elevation habitat

Abstract
This study examined marten ecology relative to wind farm development using radio-marked marten, camera trapping, and snow track surveys to meet study objectives. The local population was mostly breeding adults and was considered near carrying capacity. Mortality (predation) was biased towards females and young. Seasonal home ranges were small overall, and largest during summer and when marten used more regenerating and softwood forest. Selection at the landscape scale was more pronounced than at the stand scale; regenerating forest was selected against year-round. Stand selection for mature mixed-wood and softwood occurred in winter. Disturbance from wind farm construction resulted in less use and periodic displacement of marten, although marten maintained presence in the study area. Winter access by competitor canids was enhanced by maintained roads and snowmobile trails at high elevation. A balanced approach is encouraged to minimize developmental impacts in prime, high elevation habitat of recovering marten populations.

Keywords

This thesis is available at University of New Hampshire Scholars' Repository: https://scholars.unh.edu/thesis/837
This thesis has been examined and approved.

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ABSTRACT

POPULATION ECOLOGY OF AMERICAN MARTEN IN NEW HAMPSHIRE: IMPACT OF WIND FARM DEVELOPMENT IN HIGH ELEVATION HABITAT

By
Alexej P. K. Siren
University of New Hampshire, September 2013

This study examined marten ecology relative to wind farm development using radio-marked marten, camera trapping, and snow track surveys to meet study objectives. The local population was mostly breeding adults and was considered near carrying capacity. Mortality (predation) was biased towards females and young. Seasonal home ranges were small overall, and largest during summer and when marten used more regenerating and softwood forest. Selection at the landscape scale was more pronounced than at the stand scale; regenerating forest was selected against year-round. Stand selection for mature mixed-wood and softwood occurred in winter. Disturbance from wind farm construction resulted in less use and periodic displacement of marten, although marten maintained presence in the study area. Winter access by competitor canids was enhanced by maintained roads and snowmobile trails at high elevation. A balanced approach is encouraged to minimize developmental impacts in prime, high elevation habitat of recovering marten populations.
INTRODUCTION

Forest patch size, arrangement, and proximity to large contiguous forests are important criteria for maintaining local populations of American marten (marten; *Martes americana*) (Chapin et al. 1998). Marten require forests with trees >6 m in height, with complex structure to establish home ranges (Katnik 1992, Payer and Harrison 2003). They are sensitive to landscape fragmentation (Thompson et al. 2012), with occupancy rate dropping sharply in landscapes comprised of >30% non-forested habitat (Fuller 2006). Seasonal use patterns indicate marten require forests with greater canopy cover during winter (Buskirk and Ruggiero 1994, Fuller and Harrison 2005). In northern New Hampshire contiguous forest is common at higher elevations (WAP 2005), and distribution patterns and habitat use models predict that marten prefer high elevation mixed and coniferous stands where deep snow exists (Kelly 2005).

Anthropogenic disturbances generated by wind development, logging, and climate change present serious threats to marten populations in New Hampshire (WAP 2005). Wind farm development is identified as the greatest immediate threat to high elevation habitat (WAP 2005). These forests are characterized by long, harsh winters, short growing seasons, shallow and acidic soils, and frequent natural disturbances (Sprugel 1976). Impacts of wind farm development within these forests could be substantial as the rate of forest succession is slower compared to lower elevation habitats, and the associated fragmentation might reduce occupancy by marten (Hargis et al. 1999, Fuller 2006). Much of the current and proposed wind farm development in the northeast occurs along high elevation ridgelines where measurable disturbance could destabilize the fragile forest community. Additionally, climate change models predict these forests to
either disappear (Iverson and Prasad 2001) or become reduced (Tang and Beckage 2010) in the long term.

To date, there are no studies that document the impact of wind farm development on marten. This is important, as an increasing number of wind farms are being constructed in the northeast and marten are listed as threatened in New Hampshire, endangered in Vermont, and projected to decline long term in New York and Maine (Carroll 2007). This study evaluated impacts on marten by the Granite Reliable Power Windpark (GRP Windpark; 33 turbines) built along the high elevation ridgeline in Millsfield and Dixville, Coos County, New Hampshire. Further, this study provides valuable ecological data concerning population density, home range, and habitat use that is lacking in New Hampshire (Kelly 2005). Such information is required to address regional concerns of marten and complements current research in the Adirondack Mountains in New York (Jensen 2012). The objectives of this research were to 1) estimate marten populations in New Hampshire and develop a cost effective method to index abundance and distribution, 2) measure seasonal home ranges, movements, and habitat use of marten to compare with regional populations, and 3) assess the potential impacts of wind development on marten populations.
STUDY AREA

The study area was located in Coos County, New Hampshire within the towns of Millsfield, Dixville, Odell, Columbia, Colebrook, and Ervings Location; Mt. Kelsey, Owlhead Mountain, and the surrounding lowlands delineated the study area (Fig. 1). The high elevation study site was >823 m elevation – the upper half of Owlhead and Kelsey Mountains – and dominated by mature red spruce (*Picea rubens*), balsam fir (*Abies balsamea*), yellow birch (*Betula alleghaniensis*) and sugar maple (*Acer sacharrum*) with mature spruce-fir stands interspersed with spruce-fir waves along ridgelines (950-1060 m). The majority of habitat found below 823 m was a northern hardwood-conifer mix composed of yellow birch, sugar maple, beech (*Fagus grandifolia*), red maple (*A. rubrum*), aspen (*Populus* spp.), white birch (*B. papyrifera*), red spruce, and balsam fir with the valley bottoms consisting primarily of white spruce (*P. glauca*) and balsam fir. Lower elevation forests were extensively harvested in the last 20 years and stands were typically pole size and small sawtimber with several large clearcuts <10 years old; mature stands along stream corridors were typically dominated by spruce-fir.

The climate of northern New Hampshire is characterized by warm and wet summers and cold winters with deep snow. Annual precipitation ranges between 91-178 cm (36-70 in) and snowfall varies 244-406 cm (96-160 in), with deeper snow at higher elevations and in the northern part of the state (McNab and Avers 1994). Temperature varies considerably with July being the warmest month averaging 18 °C (11 °C and 27 °C), and January being the coldest averaging -11 °C (-15 °C, and -2 °C; McNab and Avers 1994). The lowest recorded temperature (-44 °C) in Coos County was in Pittsburg in 1994.
Fig. 1. Kelsey Mountain Study Area (~100 km²), in the towns of Millsfield, Dixville, Odell, Ervings Location, Colebrook, and Columbia in Coos County, New Hampshire, USA.
CHAPTER 1

AMERICAN MARTEN DEMOGRAPHY IN NORTHERN NEW HAMPSHIRE

Introduction

American marten (*Martes americana*) are forest sensitive species generally requiring older forests with low tolerance for fragmentation at several spatial scales (Thompson et al. 2012). They have small body size, high metabolic rate, and spatial requirements 3-4 times larger than similar sized carnivores (Buskirk and McDonald 1989), with populations naturally unstable due to fluctuating prey availability. Low population growth rates and environmental change are often reflected in their demographic rates making them good indicators of forest health and productivity (Buskirk and Ruggerio 1994, Powell 1994). They are slow to reach sexual maturity (effective breeding ≥ 2 years old) and have only 1 small litter annually (Mead 1994; Strickland and Douglass 1987, $\bar{x} = 2.85$, range = 1-5). Annual pregnancy rates vary considerably, often due to fluctuating prey populations (Strickland and Douglass 1987, Poole and Graf 1996) resulting in an unstable age structure that inhibits population growth (Powell 1994). Additionally, female marten attain peak fecundity at ~6 years old and reach senescence at >12 years (Mead 1994).
Adult male marten are polygynous with home ranges overlapping ≥1 breeding female (Powell 1994, Powell et al. 2003). They do not wander to find females as do fisher (*Martes pennanti*) (Katnik et al. 1994); therefore, home range overlap with females is a necessity (Buskirk and Powell 1994). Trapping and logging that affect spacing patterns possibly disrupt breeding opportunity (Payer 1999). However, male home ranges within a trapped and harvested population in Maine were arranged strategically to meet energetic and breeding requirements (Katnik et al. 1994, Payer 1999); yet, landscapes with more fragmentation and/or located away from a source population might disrupt spacing patterns and reduce breeding potential (Payer and Harrison 1999).

While untrapped marten populations in second growth and mature forests typically maintain stable breeding populations (Hodgman et al. 1997), trapping, logging (Hodgman et al. 1994), and prey declines (Thompson and Colgan 1987) can cause demographic stochasticity, slow population growth (Powell 1994), and reduce carrying capacity (Chapin et al. 1998). For example, clear-cut forests in Ontario were dominated by juveniles with low survival (Thompson 1994), and high turnover rates were recorded in regenerating burns (<30 years old) in Alaska (Paragi et al. 1996) that were dominated by juveniles with few breeding females. Productivity in the Northwest Territories corresponded with the snowshoe hare (*Lepus americanus*) cycle (Poole and Graf 1996), and populations declined in British Columbia in response to temporary lulls in small mammal abundance (Poole et al. 2004).

Van Horne (1983) cautions about using density to infer habitat quality, and suggests that measures of fitness (i.e., survival and reproduction) be incorporated with density estimates to better understand habitat quality, and that current density might be
indicative of other factors (e.g., past prey density, habitat condition, competition, predation, or climate). For example, a high density population in fire-regenerating stands in Alaska were mostly non-breeding juveniles (Paragi et al. 1996). The effects of logging and trapping tend to lower density of marten (Soutiere 1979, Strickland 1994, Thompson 1994, Payer 1999), as logging fragments suitable habitat which reduces occupancy (Bissonnette et al. 1997, Fuller 2006), increases risk of predation from reduced canopy cover (Thompson 1994), reduces access to prey (Hargis et al. 1999), and increases trapping via road access (Hodgman et al. 1994). Removal of animals through trapping can disrupt breeding potential (Hodgman et al.1994, Payer et al. 2004) and reduce density (Thompson and Colgan 1987, Katnik et al. 1994).

In a comparison of landscapes with varying levels of fragmentation in Utah, marten density declined significantly with >25% fragmentation, whereas high-density landscapes with intact forest had the highest capture and recapture rates, reproducing females, and highest body weights (Hargis et al. 1999). Similarly, females were more productive and marten had higher survival rates in uncut forests in Ontario (Thompson 1994). In Maine, logged areas and trapped populations had lower densities, yet females were as productive as those in a nearby forest reserve (Katnik et al. 1994). Density decreases in response to declining prey populations, with the decrease more pronounced in logged landscapes (Thompson and Colgan 1987).

Providing accurate and precise density estimates is important to effectively manage vulnerable species (Sharma et al. 2010). Surveys should be conducted at a frequency that will allow managers to detect population trends (Zielinski and Kucera 1995); however, live-trapping is expensive and requires considerable effort. A
photographic mark-recapture (PMR) method provides distinct advantages over live-trapping for many reasons. It is minimally invasive, reduces "trap shyness", is cost effective, and allows for multiple visits; yet, it is only useful for species with identifiable field marks (Long and Zielinski 2008). Marten have unique ventral patches that allow for individual identification providing opportunity for PMR. Live-trapping and PMR surveys for wide-ranging, rare, and/or remote species often lack sufficient data required for traditional mark-recapture analyses and suffer from the same ad hoc assignments of trapping area (Royle et al. 2009). Recent advances in spatial capture-recapture (SCR) analyses effectively address both issues through use of Bayesian statistics and incorporating activity centers of animals to provide biologically relevant estimates of density (Royle et al. 2009).

Marten are a state threatened species in New Hampshire (WAP 2005) and are projected to decline long-term due to anthropogenic disturbances (Krohn et al. 2004, Carroll 2007). Importantly, climate change models predict that the remaining boreal conifer forest will be concentrated in mountainous and northern regions of New Hampshire by the end of the 21st century (Tang and Beckage 2010). Further, wind power development is considered an immediate threat as it is increasing in areas considered prime marten habitat (WAP 2005).

To better understand the status of marten in New Hampshire, the sex ratio, age structure, morphology, mortality, reproduction, breeding potential, and density were documented through capture, radio-telemetry, PMR, and live-trapping during a 2-year study in northern New Hampshire. Population size was estimated by projecting local density estimates statewide using a recent probability of occurrence model (Kelly 2005).
Additionally, a minimally invasive camera trapping technique was developed to identify individual marten to be used for PMR. Density was estimated for winter 2011 and 2012 using a combination of PMR and live-trapping, and efforts were compared to determine the effectiveness of the PMR technique to estimate density. It was predicted that recaptures would be greater with PMR, which would increase the precision of density estimation.

**Methods**

**Capture**

Live-trapping was conducted primarily in winter and summer to maintain a sample size of 6-10 radio-collared marten for measurements of home range, movement, seasonal home range overlap, and habitat use. Tomahawk traps (Model #102; Tomahawk Live Trap, Hazelhurst, WI, USA) were weatherproofed and baited with sardines and/or raspberry jam, and a commercial skunk lure was applied near the entrance to lure marten into traps. Traps were spaced 300-1000 m apart and located in suitable habitat to maximize capture (trap density ranged between 1.4-7.0 traps/km²). Traps were checked daily, often twice to minimize time spent in trap. Recaptured marten and non-target captures were given an electrolyte drink and raspberry jam, and released immediately after identification.

Marten were restrained using a handling cone and injected intramuscularly (rear thigh) with a 5:1 mixture of ketamine hydrochloride:xylazine hydrochloride (10.0-18.0 mg/kg body weight; P. Jensen, New York State Department of Environmental Conservation, Division of Fish, Wildlife, and Marine Resources, pers. commun.). After
immobilization (~2 min), sex was determined and age (juvenile or adult) was estimated by examining teeth for wear and coloration. Scars, injuries, ectoparasites, body, coat, tooth condition, and lactation were noted. Weight (nearest 5 g), head length, neck circumference, body length, tail length, and hind foot length were measured (nearest 0.5 cm), and a numbered ear tag (Monel no. 1; National Brand and Tag Co., Newport, KY) was placed in each ear. Marten were uniquely marked using a passive integrated transponder (AVID Friendchip Identification System P-N AVID 2028) placed subcutaneously between the shoulder blades (York and Fuller 1997). A hair sample (tip of tail; >10 hairs with follicles) was collected, placed in an envelope, and frozen that day. Photo documentation of marten included teeth (front and side) and distinctive markings (e.g., throat patch). VHF radio-collars (Advanced Telemetry Systems (ATS), Insanti, MN) were fitted using a protocol developed in New York (P. Jensen, pers. commun.); 3 sizes (20, 27, and 36 g) were used to ensure that marten were fitted with collars <5% of their body mass.

After processing, marten were wrapped in a protective blanket, placed back into the trap, and monitored for recovery. A recuperative mixture of raspberry jam and an electrolyte drink were provided and the animal was released once fully recovered. During handlings animals were wrapped in blankets with hand warmers to aid thermoregulation. Trapping and handling procedures were approved by The Institutional Animal Care and Use Committee, University of New Hampshire (#100807, Appendix A).

Telemetry
Telemetered animals were located weekly to obtain ≥48 annual locations (24 per leaf-off [16 November-15 May] and 24 per leaf-on season [16 May-15 October]) to measure intersexual home range overlap, home range size, movements, seasonal home range overlap, and habitat use. The seasonal periods were defined by local conditions with respect to leaf emergence and senescence (i.e., leaf-on = 16 May-15 October and leaf-off = 16 October-15 May) with 2 leaf-off and 2 leaf-on seasons occurring over 2 continuous years of monitoring (Table 1-1). Marten were triangulated using ≥3 bearings taken ≤30 min apart; outermost bearing angles were ≥60° and ≤145°, with a minimum of 30° between each adjacent bearing. The maximum distance of each bearing vector was typically ≤1 km. Locations were separated by >12 h to reduce autocorrelation (Katnik 1992). A handheld GPS was used to mark the location of any observed marten. LOAS (Location Of A Signal) software (LOAS 2010) was used to calculate locations using a Maximum Likelihood Estimator (MLE).

Telemetry Error Testing

Telemetry error was calculated to determine the accuracy of location data. Angular error from ground telemetry was calculated by conducting field tests (n = 91 trials) using the estimated bearings of field technicians on the actual location of hidden beacons throughout the study area. Observers were required to obtain bearings following the telemetry protocol described above. Angular error and location estimates were calculated using telemetry software (LOAS 2010). Mean angular error was 9°, and was incorporated to provide an ellipse error (i.e., location error) for each estimated location.

Breeding Potential (Intersexual Home Range Overlap)
Table 1-1. Seasonal dates and lengths (days), and sample size of radio-collared marten for 4 leaf seasons (1 November 2010-15 October 2012) in northern New Hampshire.

<table>
<thead>
<tr>
<th>Seasonal Periods</th>
<th>days</th>
<th># of marten</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaf-off 1 (5 December 2010-15 May 2011)</td>
<td>162</td>
<td>6</td>
</tr>
<tr>
<td>Leaf-on 1 (16 May 2011-15 October 2011)</td>
<td>153</td>
<td>10</td>
</tr>
<tr>
<td>Leaf-off 2 (16 October 2011-15 May 2012)</td>
<td>212</td>
<td>9</td>
</tr>
<tr>
<td>Leaf-on 2 (16 May 2012-15 October 2012)</td>
<td>153</td>
<td>8</td>
</tr>
</tbody>
</table>
Intersexual home range overlap provides a simple yet useful measure of breeding potential (Katnik et al. 1994, Payer et al. 2004); therefore, overlap of adult male and female marten was documented for marten monitored during the same leaf season. Overlap was measured for both seasons because adult marten typically exhibit high home range fidelity throughout the year (Payer et al. 2004). A 95% minimum convex polygon (MCP) was calculated for adult (>1 yr) marten that met seasonal location requirements, and a 100% MCP was calculated for 5 marten with ≥15 but <24 locations (Poole et al. 2004); all marten were monitored for >80 days. Home range polygons were calculated using BIOTAS home range software (BIOTAS 2010). The percent overlap between female-male and male-female marten was calculated and compared to that measured in adjacent Maine (Katnik et al. 1994, Payer and Harrison 1999).

Telemetry Monitoring

Radio-collars were equipped with a mortality sensor that triggered when the collar remained stationary for 6 h. A site investigation was conducted immediately upon a mortality signal unless conditions precluded access. The investigation site was triangulated and the collar was homed in on after identifying the general area. When the marten or collar was located, site evidence (i.e., carcass, tracks, hair, and disturbed vegetation) and habitat were documented and a GPS location taken. All carcasses were inspected, abnormalities noted, and the carcasses were frozen immediately that day.

Necropsy

Necropsies were performed by a veterinary pathologist at the New Hampshire Veterinary Diagnostic Laboratory. Standard operating procedure included an external
and internal examination to assess body condition and determine cause of death; tooth condition was noted and the upper first premolar or canine was extracted for cementum aging. The liver, spleen, kidneys, heart, lungs, and reproductive tracts of females were extracted and preserved in formalin, stomach contents and fecal samples were obtained and stored in a whirl pack, and a histopath was performed on all marten of unknown cause of death. If puncture wounds and pre-mortem hemorrhaging were present, measurements were taken (e.g., intercanine width), and trauma type (i.e., localized or gross) and location of trauma (e.g., neck or abdomen) were documented to compare with available literature to help identify the predator. Also, site evidence was used to support the necropsy investigation if predation was suspected. Tissue samples were obtained for a genetic analysis of marten in the northeastern United States. All remaining samples were stored in the UNH necropsy freezer and carcasses were disposed.

**Camera Trap Method**

The camera trap method was developed during 2 winter seasons (2011 and 2012) to determine the best trap configuration, and camera make and settings for photo-capturing marten. The distinct ventral patches (throat and chest) of uncollared animals and artificial markings placed on radio-collars were used to identify individual marten for PMR analysis (Fig. 1-1). This procedure was adapted from a technique used to estimate wolverine (*Gulo gulo*) density with camera traps (Magoun et al. 2011).

Four camera models (7 Bushnell 8 megapixel (MP) Trophy Cams™, 3 Moultrie GameSpy™ 4 MP I-40 cameras, 5 Moultrie GameSpy™ 4 MP I-45 cameras, and one custom built 4 MP game camera) were used and tested to determine the best performing
Fig. 1-1. Ventral patches of collared (including unique artificial markings on collars) and uncollared marten. Trap on the bottom left was used during PMR 2011 and traps on top and right were used for PMR 2012. The positioning for marten in the top picture was both up1 and both up2 for the marten in the bottom right; both received a signature score of 2 as throat and chest ventral markings were visible.
camera. All brand name cameras had passive infrared flashes and the custom built camera a white flash; flash filters were applied to the infrared cameras because they were too bright for subjects closer than 1 m. Additionally, the capture mode was set to either video or photo, and the camera trigger was set to the minimum allowed factory setting to maximize capture (60 sec for the Moultrie GameSpy™ cameras, 10 sec for the Bushnell Trophy Cams™, and 3 sec for the custom camera). The performance was evaluated qualitatively by comparing image quality, features, reliability, and cost.

A pilot effort was conducted in November 2010 to evaluate the possibility of identifying ventral patches of individual marten. The initial design included a sardine can fastened to a tree branch, a platform that allowed marten to access the bait, and a camera positioned ~1 m in front of the platform to view feeding marten (left picture; Fig. 1-1). This method performed reasonably well and was used in winter 2011 to estimate density using PMR and to evaluate the camera trap design.

For the 2011 PMR effort, most remote cameras were set to video mode as this setting was thought to increase the likelihood of detecting the ventral patches of feeding marten. A comparison between video and photo modes was available for Moultrie GameSpy™ cameras, as a single picture was taken to provide a date/time stamp before the video initiated. Because the video mode proved unreliable for 2 Bushnell Trophy Cam™ models, they were reset to only take photos for the majority of winter 2011. To compensate, the settings of these cameras were changed to take 3 simultaneous photos (maximum factory setting) and the trigger reset every 10 sec.

The winter 2011 data was time consuming to analyze as videos were 15-30 sec,
the resolution of screen captures from video files was poor, and occasionally files were inoperable; further, the database required considerable computer memory (33 GB). Additionally, because the camera and bait configuration varied, marten would often face the camera at different angles, complicating identification. Further, because marten were identifiable at an equal rate (26%) from either one video or photo file, photos were used exclusively in winter 2012.

The camera trap design was changed before winter 2012 to improve identification of individual marten. Each trap was fitted with footholds, a bait corral, a hood, and a 20 cm ruler (Fig. 1-2). The footholds gave marten leverage to access bait, the bait corral kept the sardine can secure, the hood forced marten to access the bait from the front, and the ruler was inscribed into the front of the trap to measure morphology to differentiate gender. Each trap was built identically to reduce variation, with foothold spacing adjustable. All camera models were set to take 3 continuous pictures with the trigger set to the lowest allowable; photo data were easier to manage than video and used less memory.

**Camera Trap Configuration (Signature)**

Because camera position and trap placement influenced the ability to photo-capture ventral patches, the following parameters were varied during winter 2012 to determine a configuration that would best maximize identification. Traps were screwed into trees ~70-150 cm above the snow surface and cameras were positioned on a post or tree 48-88 cm away, a ramp (log) measuring 4-12 cm in diameter was angled up to a supportive branch below each camera trap, and the trap height above the log varied 15-30
Fig. 1-2. Camera trap design used for winter PMR 2012 to maximize capture probability.
Fig. 1-3. Camera trap setup for PMR 2012. Camera distance, trap height, foothold spacing, ramp angle and diameter varied to determine the best configuration for capturing ventral patches.
cm to determine a height that would best accommodate both sexes (Fig. 1-3).

Foot positioning and visibility were recorded to compare with camera configuration because the front foot positioning of marten influenced the visibility of ventral patches. Foot positioning was quantified as: both down = both feet below shoulder height; one up = one foot above shoulder height and the other below; both up0 = both feet above shoulder height but none touching footholds; bothup1 = both feet above shoulder height and one or both feet touching one foothold; bothup2 = both feet above shoulder height touching each foothold separately (Table 1-2). An ordinal scale was used to quantify the visibility of ventral patches. A “signature” score was given to rate the visibility of the throat and chest patches for each photo-capture: 0 = no marks visible; 1 = chest or throat patch visible; 2 = chest and throat patch visible (Table 1-2). For example, the photo-capture of the uncollared marten in Fig. 1-1 received a signature score of “2”, and the foot positioning was “both up1”. The camera on this trap was 70 cm from the trap, the trap height was 30 cm from the ramp, and the foothold spacing was 7.6 cm.

A partition regression model was used to determine which parameters most influenced signature. Partition analyses utilize regression to split datasets based on how factors influence a response. Often several splits, or partitions, are performed to measure the contribution of a predictor variable to a response. In this partition analysis, signature was treated as an ordinal response variable and there were 6 fixed-effects variables (trap height, camera distance, foothold spacing, ramp angle, ramp diameter, and foot positioning; Table 1-2). JMP Pro 10 statistical software was used to perform all partition analyses (JMP 2012).
Table 1-2. Description of variables used for partition analysis to determine effects of marten hand positioning and trap configuration on signature scores.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Categories</th>
<th>Variable Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signature*</td>
<td>0</td>
<td>No throat and/or chest patch visible</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Chest or throat patch visible</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Both chest and throat patch visible</td>
</tr>
<tr>
<td></td>
<td>both down</td>
<td>both feet below shoulder height</td>
</tr>
<tr>
<td></td>
<td>one up</td>
<td>one foot above shoulder height and the other below</td>
</tr>
<tr>
<td>Positioning</td>
<td>both up0</td>
<td>both feet above shoulder height and none touching footholds</td>
</tr>
<tr>
<td></td>
<td>both up1</td>
<td>both feet above shoulder height and one or both feet touching one foothold</td>
</tr>
<tr>
<td></td>
<td>both up2</td>
<td>both feet above shoulder height touching each foothold separately</td>
</tr>
<tr>
<td>Trap Height</td>
<td>15-31 cm</td>
<td>Height above ramp base</td>
</tr>
<tr>
<td>Ramp Angle</td>
<td>25-39°</td>
<td>Angle of ramp leading up to base of trap</td>
</tr>
<tr>
<td>Ramp Diameter</td>
<td>3.5-12 cm</td>
<td>Width of ramp below trap</td>
</tr>
<tr>
<td>Foothold Spacing</td>
<td>6.4-10.2 cm</td>
<td>Width of footholds on trap</td>
</tr>
<tr>
<td>Camera Distance</td>
<td>48-87.5 cm</td>
<td>Distance of camera to trap</td>
</tr>
</tbody>
</table>

* Signature was the response variable for the partition analysis.
Camera Data Processing

Because marten are territorial and would presumably exclude other marten from simultaneously visiting the same camera trap, photos that were clustered temporally were examined because identification was not always possible from a single picture (O’Brien et al. 2003, Gerber et al. 2012). An analysis of 2011 (n = 183 captures) and 2012 (n = 64 captures) data revealed that individual radio-collared marten visited camera traps for 12 ± 1 min (11 ± 1 videos) and 17 ± 3 min (84 ± 17 photos) respectively, providing ample opportunity for identification. There was no evidence that marten were captured in the same camera trap simultaneously; the mean time between visits at the same trap was 1,048 ± 163 min and visits <15 min by different marten at the same trap occurred infrequently (n = 4, both years). The least time between visits at the same trap by the opposite sex was 1 min, and the least time between visits of marten of the same sex was 6 min. Further, differentiating between individual marten was uncomplicated, as ventral patterns were recognizable.

Therefore, camera trap data for both years were aggregated from each visit into a cluster and this was considered a capture event. The best candidate photos from each capture were compared with all other captures to determine individual marten and capture history. Photo captures were evaluated by 2 independent observers and the number of identifiable marten and capture history were determined based on consensus; marten that were unidentifiable were excluded from the capture history (Gerber et al. 2012). The proportion of marten identified during each capture was summarized to evaluate the accuracy of the PMR technique and to compare with the effort of the previous year.
For uncollared marten, gender was determined by comparing foot morphology (marten are sexually dimorphic) from a sample of 6 radio-collared marten identified during PMR (4M, 2F), as marten readily used the 30 mm wide trap footholds (Fig. 1-4). The front feet of males were as wide as or wider than the footholds, whereas female feet only spanned 3/4 of the foothold (Fig. 1-4). This was verified by comparing foot morphology measurements (10 M, 9 F) taken during actual captures; male front feet were 30 ±1 mm wide whereas females were 25 ±0.5 mm. Further, because juvenile and adult marten cannot reliably be differentiated, PMR analyses for both years reflect density of all age classes.

Density Estimate

Camera and live-trapping data were used to estimate density in winter 2012, and camera trap data only in winter 2011 as live-trapping was infrequent; identification was less reliable in 2011 as the technique was being evaluated. PMR and live-trapping were conducted consecutively in winter 2012 to compare the techniques. Marten were often caught multiple times daily at the same trap during camera trapping; this was counted as a single daily capture for density analyses (Royle et al. 2009), yet was quantified to determine the accuracy of the technique.

In winter 2011 (14 February-2 April), 30 camera traps were deployed on Kelsey and Owlhead Mountains in an attempt to use identification of ventral patches to estimate density. Three traplines of 10 traps were staggered to maximize trap density due to resource and time constraints. Sites were chosen in a nonrandom pattern, and spaced
Fig. 1-4. Comparison of female (top) and male (bottom) front foot width. Female marten had narrow front feet and would typically only span 3/4 of width of the foothold, whereas male marten front feet were as wide as or wider than footholds.
500-1000 m apart (>1 trap/km²) to reduce capture heterogeneity (White et al. 1982) (Fig. 1-5). Each trapline was set for 12 d, and sites were visited midway to add bait (sardines), download pictures, and ensure cameras were working properly. Sardine cans were fastened to a tree branch, and cameras were positioned within 1 m and at an angle that would provide a view of the ventral patches (left picture; Fig. 1-1).

During winter 2012 (3-19 January), 30 camera traps were deployed at the same locations as winter 2011 (Fig. 1-5); only 2 traplines were set as 15 traps were available and the effort was restricted to the month of January. Each trapline was set for 8 days, and sites were visited midway to add bait, download pictures, and ensure cameras were working properly.

Live-trapping occurred during the end of the PMR 2012 efforts and lasted 6 days (17-22 January). Twenty-one live-traps were set at the PMR sites to compare density estimates between PMR and live-trapping (Fig. 1-5). This effort was shorter and fewer traps were deployed due to personnel and weather limitations; to compensate, traps were only set at camera trap sites that were visited by marten during PMR. Live-trapping followed the same protocol described above.

Statistical Analyses (Density)

Density analyses for PMR and live-trapping efforts were performed using the SPACECAP package (Gopalaswamy et al. 2013) in R (R Core Team 2013). The capture histories and locations of trapsites for both efforts were summarized and stored in a database file. A spatial grid (i.e., sampling area) was then created in ArcGIS 10 (ESRI
Fig. 1-5. Trapsite locations for camera and live-traps during PMR and live-trapping CMR efforts from winter 2011-2012 on Kelsey and Owlhead Mountains in northern New Hampshire.
2011) to provide the background for SPACECAP to measure activity centers for individual marten; it consisted of a minimum bounding rectangle that encompassed all traps to which a 3,750 m buffer (3 x the radius of an average marten home range) was added and equidistant sampling points (500 m) were included within the buffered rectangle using the Fishnet tool to achieve a density of 4 points/home range. Suitable and unsuitable habitat points within the grid were assigned a value of “1” and “0”, respectively; unsuitable habitat was considered to be early regenerating forest and ponds as these were avoided by marten at the study site during winter. The capture history, trapsite location, and spatial grid database files were loaded into SPACECAP software and a model that included trap response, spatial capture-recapture, half-normal detection function, Bernoulli encounter process, 50,000 iterations (1st 1,000 were discarded), a thinning rate of 1, and a data augmentation value of 100 were selected. The sampling grid and model parameters were chosen based on statistical considerations and marten biology (A. Royle, USGS Patuxent Wildlife Research Center, Laurel, MD, pers. commun.).

Statewide Population Estimate

A statewide population estimate was conducted using the density estimates from PMR efforts in 2011 and 2012 in context with a GIS probability of occurrence model for marten in New Hampshire that consisted of occurrence data from 1980-2004 (Kelly 2005). Marten distribution in New Hampshire was best predicted by a logistic regression multimodel that included deep snow, mature mixed and coniferous forest, fisher absence, and low population/road density. The use of the distribution model was justified for extrapolating density estimates statewide as resource selection at finer scales (i.e.,
selection for mature mixed forest at stand and landscape scale) in this study was similar to that in the probability of occurrence model (Kelly 2005). The model consisted of 1 km pixels that contained associated probabilities of marten occurrence based on multimodel predictions. The spatial grid (i.e., the sampling area) from the density analysis was used to extract the pixel values (i.e., probabilities) from the GIS model. The mean, and 1 and 2 standard deviations from the mean of the pixel values (n = 381) were calculated to determine low probability threshold values to project density estimates statewide. It was assumed that pixels containing higher probability values than the mean of the study area would support similar or higher density, because the study area contained unsuitable habitat (i.e., open areas) and these were removed from the density analysis. The -1 and -2 standard deviations of the mean were calculated to include area in the statewide distribution model where marten could possibly occur, but at lower density. The raster calculator tool was used in GIS to calculate the area of the distribution model that was greater than these 3 probability threshold values. Finally, the density estimate (marten/km²) and 95% Bayesian confidence limits for both winters were multiplied by the total area of habitat calculated for the mean, -1 SD, and -2 SD probability thresholds, and this was considered the potential statewide population.

Results

Capture

A total of 34 marten (17M, 17F) were captured 121 times from 28 October 2010-9 August 2012; 29 were adult (>1 yr old; 16 M, 13 F) and 5 were juvenile (<1 yr old; 1 M, 4 F) (Table 1-3). Additionally, 2 unmarked kits were found at the den of F5. Four
marten were not collared because collars were unavailable and 1 juvenile male was deemed too small (<600 g). Overall, adult males weighed 59% more ($\bar{X} = 831 \pm 21$ g) than females ($\bar{X} = 522 \pm 15$ g), and male and female marten weighed 9 and 11% heavier during summer than winter, respectively (Table 1-3). Reproduction was documented on 7 occasions either directly (i.e., kits were observed) or indirectly (i.e., teats of adult female marten were swollen and milk could be expressed): 1 kit was observed at the capture site of F4; 2 dead kits were found at the mortality site of F5; 2 kits were captured during summer 2011; and teats were enlarged with milk evident for 3 female marten trapped in summer.

**Catch Per Unit Effort (CPUE)**

The sampling area for live-trapping efforts from 2010-2012 provided coverage of Kelsey and Owlhead Mountains and the surrounding valley (Fig. 1-5). Catch-per-unit-effort (CPUE) was >4 x higher during leaf-off seasons (31 marten/100 trap nights) and similar in the same season (Table 1-4). CPUE was highest during both leaf-off seasons (33 and 30 marten/100 trap nights), and lowest during both leaf-on seasons (7 and 8 marten/100 trap nights; Table 1-4). Sampling effort (i.e., trap nights) was purposely lower in some areas as target marten were captured early and traps were moved.

**Breeding Potential (Intersexual Home Range Overlap)**

Home range overlap (HRO) was documented for 5 potential breeding pairs (M7 and F4, M1 and M5, M11 and F9, M3 and F9, and M16 and F17) during 4 seasons. Mean HRO was $87 \pm 6\%$ for females-males and $48 \pm 8\%$ for males-females. It is likely
Table 1-3. Morphology of adult and juvenile male (M) and female (F) marten captured over 4 seasons in Millsfield, Odell, Ervings Location, and Dixville townships in northern New Hampshire. Mean (+SE) weights (rounded to the nearest 10 g) are summarized below in **bold** for each season (juveniles are not included in means). Measurements were averaged for marten captured >1 time per season.

<table>
<thead>
<tr>
<th>Season</th>
<th>Id</th>
<th>Age</th>
<th>Capture</th>
<th>Weight (g)</th>
<th>Id</th>
<th>Age</th>
<th>Capture</th>
<th>Weight (g)</th>
</tr>
</thead>
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<td><strong>Leaf-off 1</strong></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M1</td>
<td>A</td>
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<td>800</td>
<td>F1</td>
<td>J</td>
<td>10/29/2010</td>
<td>420</td>
<td></td>
</tr>
<tr>
<td>M6</td>
<td>J</td>
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<td>720</td>
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<td>1/12/2011</td>
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<td></td>
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<td></td>
</tr>
<tr>
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</tr>
<tr>
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<td>2/4/2012</td>
<td>1020</td>
<td>F5</td>
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<td>560</td>
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</tr>
<tr>
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<tr>
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<td>560</td>
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</tr>
</tbody>
</table>

**Leaf-off:** 827 (±32) 478 (±17)

**Leaf-on:** 904 (±31) 533 (±36)

**Leaf-off:** 833 (±36) 511 (±15)

**Leaf-on:** 887 (±38) 615 (±55)
Table 1-4. Capture data for 4 seasons and pooled for leaf-off and leaf-on seasons (2010-2012). Trap nights are the total # of nights traps were set per trapping period; captures are # of marten captured; and CPUE is the Catch per unit effort (catch/100 trap nights). CPUE was higher during leaf-off periods.

<table>
<thead>
<tr>
<th>Trapping Season</th>
<th>Trap Nights</th>
<th>Captures</th>
<th>Recaptures</th>
<th>CPUE (per 100 T.N.)</th>
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<td>14</td>
<td>33</td>
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<tr>
<td>Leaf-on 1</td>
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<td>19</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
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<td>47</td>
<td>7</td>
<td>30</td>
</tr>
<tr>
<td>Leaf-on 2</td>
<td>393</td>
<td>27</td>
<td>16</td>
<td>7</td>
</tr>
<tr>
<td>Combined Leaf-off</td>
<td>243</td>
<td>75</td>
<td>21</td>
<td>31</td>
</tr>
<tr>
<td>Combined Leaf-on</td>
<td>621</td>
<td>46</td>
<td>22</td>
<td>7</td>
</tr>
</tbody>
</table>
that there were at least 2 more breeding pairs (M5 and F7, and M3 and F6); however, since telemetry data for these female marten were sparse, their breeding can only be confirmed via subsequent genetic analysis (offspring from at least 2 females are available).

Telemetry Monitoring

At the end of monitoring (3 January 2013) 6 marten in the study area were alive, 15 mortalities had occurred, and the fate of 13 was unknown (Table 1-5). There were 8 instances of radio-collar failure resulting in a loss of 2-247 monitoring days; radio-collars were replaced on 5 marten with the other 3 censored due to lack of data. There were 22 mortality/dropped collar investigations; carcasses were recovered for 15 (5 M: 10 F), only a radio-collar was recovered for 6, and no physical evidence was recovered in 1 instance. Of the 15 documented mortalities, predation was suspected for 8 based on site evidence (crushed vegetation, tracks, hair, and visible trauma on carcass). A slipped collar was confirmed for M2, as it was detected during subsequent 2011 camera trapping. The fate of the remaining 7 marten was unknown with no evidence of mortality.

Necropsy

Necropsies were performed on 17 recovered marten, with predation confirmed for 10 based on puncture wounds and pre-mortem hemorrhaging (2 red fox [Vulpes fulva], 2 coyote [Canis latrans], 1 fisher or marten, and 5 unidentified predators; Table 1-6); totals include 2 unmarked female kits. There were 2 human-related mortalities; M13 was an incidental capture by a trapper and F2 was likely shot based on wound evidence (Table 1-6). Three mortalities were attributed to handling stress as they occurred within 1 week
Table 1-5. Marten id, age, initial capture date, status as of end of monitoring (1/3/2013), censor date, mortality date, and total days monitored for 34 marten (17 M, 17 F) captured on Kelsey and Owlhead Mountains in northern New Hampshire. Male marten were monitored for 304 ±66 days and females were monitored 87 ±38 days.

<table>
<thead>
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<th>Id</th>
<th>Age</th>
<th>Initial Capture</th>
<th>Collared</th>
<th>Status</th>
<th>Censor Date</th>
<th>Mortality Date</th>
<th>Days monitored</th>
</tr>
</thead>
<tbody>
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<td>797</td>
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<td>1/28/2012</td>
<td>198</td>
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<td>-</td>
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<td>-</td>
</tr>
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<td>12/5/2012</td>
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<th>Status</th>
<th>Censor Date</th>
<th>Mortality Date</th>
<th>Days monitored</th>
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* These marten were never radio-collared
Table 1-6. Mortality summary for 17 marten (4 M, 13 F) at the Kelsey and Owlhead Mountain study site in northern New Hampshire.

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<th>Predator</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>M3</td>
<td>Suspected Predation</td>
<td>marten or fisher</td>
<td>Punctures found on neck/head match the intercanine width of a large marten/small fisher</td>
</tr>
<tr>
<td>M7</td>
<td>Suspected Predation</td>
<td>unknown predator</td>
<td>Gross trauma on torso and neck (multiple punctures). Likely a large predator</td>
</tr>
<tr>
<td>M8</td>
<td>Handling/Starvation</td>
<td>n/a</td>
<td>Poor body condition/possible pneumonia. Found dead 10 days post capture</td>
</tr>
<tr>
<td>M10</td>
<td>Predation</td>
<td>coyote</td>
<td>Gross trauma on torso and neck. Intercanine width of punctures matches coyote and found coyote hair at site investigation.</td>
</tr>
<tr>
<td>M13*</td>
<td>Incidental Take</td>
<td>n/a</td>
<td>Incidentally trapped by a recreational fisher trapper ~8 km north of original capture location.</td>
</tr>
<tr>
<td>F2</td>
<td>Shot by human</td>
<td>n/a</td>
<td>Trauma to torso consistent with gunshot wounds (likely shotgun).</td>
</tr>
<tr>
<td>F3*</td>
<td>Suspected Predation</td>
<td>unknown predator</td>
<td>Found buried at the base of a fir tree ~7 km west of original capture location.</td>
</tr>
<tr>
<td>F4</td>
<td>Predation</td>
<td>unknown predator</td>
<td>Puncture wounds on torso and neck (too many punctures to determine predator).</td>
</tr>
<tr>
<td>F5</td>
<td>Predation</td>
<td>red fox</td>
<td>Found at den site with 2 kits. Gross trauma on torso and neck. Intercanine width of punctures matches red fox.</td>
</tr>
<tr>
<td>F5K1*</td>
<td>Predation</td>
<td>n/a</td>
<td>Found partially consumed lying next to F5 at den site. Predator was likely red fox.</td>
</tr>
<tr>
<td>F5K2*</td>
<td>Predation</td>
<td>n/a</td>
<td>Found partially consumed lying next to F5 at den site. Predator was likely red fox.</td>
</tr>
<tr>
<td>F6</td>
<td>Unknown</td>
<td>n/a</td>
<td>Found underground curled up in nesting material. Cause of death undetermined.</td>
</tr>
<tr>
<td>F7</td>
<td>Handling</td>
<td>n/a</td>
<td>Found under rock pile 3 days post-capture.</td>
</tr>
<tr>
<td>F8*</td>
<td>Predation</td>
<td>coyote</td>
<td>Gross trauma on torso and neck. Intercanine width of punctures matches coyote.</td>
</tr>
<tr>
<td>F9</td>
<td>Starvation</td>
<td>n/a</td>
<td>Found underground curled up in nesting material. Necropsy findings suggest starvation.</td>
</tr>
<tr>
<td>F12*</td>
<td>Handling/Starvation</td>
<td>n/a</td>
<td>Died 2 days post-capture. Found underground curled up in nesting material. Necropsy findings suggest animal was starving.</td>
</tr>
<tr>
<td>F16</td>
<td>Predation</td>
<td>red fox</td>
<td>Gross trauma on torso and neck. Intercanine width of punctures matches red fox and found fox hair at site investigation.</td>
</tr>
</tbody>
</table>

* Marten <1 yr old.
post-capture; 2 of these marten were in poor condition and with starvation contributing to mortality, as with F9 during the same season (leaf-off 2; Table 1-6). Cause of death was undetermined for F6 (Table 1-6). The mean and median age of all recovered marten (n = 15) were 1.4 ± 0.3 and 1.0 yr, respectively. All were ≤3 yr old and all juveniles (n = 3, <1 yr old) were females. The mean age of females (n = 10, 1.4 ± 1.4 yr) was similar to males (n = 5, 1.4 ± 0.2 yr) but more variable.

**Camera Trap Method**

In winter 2011 there were a total of 3,130 files (1,624 photos, 1,506 videos) of marten during 45 trap nights. There were 247 recognizable captures (i.e., clusters), and marten were identifiable on 202 (82%) visits; unrecognized marten were not included in the PMR density analysis. In winter 2012 there were a total of 11,499 photos of marten in 16 trap nights. There were 144 recognizable captures and marten were identifiable on 130 (90%) visits.

**Camera Trap Configuration (Signature)**

There were 8,948 photos from the 2012 PMR effort available for the signature analysis (southern line = 4,216, northern line = 4,732) to determine the optimal trap configuration for capturing marten. The data were partitioned (split) 5 times, and the 4 variables that contributed to the signature response were positioning, foothold spacing, height of trap, and camera distance; ramp angle and diameter did not contribute to the signature scores (Table 1-7). There was a 92% chance of a signature score ≥1 when the foot positioning was “both down”, “one up”, or “both up2” and traps were <19cm tall,
Table 1-7. Factor contributions, number of splits, and associated $G^2$ values (estimated proportions) that contributed to the signature scores. Higher $G^2$ values indicate greater contribution. Positioning, foothold spacing, and trap height had the greatest influence on signature scores.

<table>
<thead>
<tr>
<th>Factor Contributions</th>
<th>Splits</th>
<th>$G^2$ Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positioning</td>
<td>2</td>
<td>1424</td>
</tr>
<tr>
<td>Foothold Spacing</td>
<td>1</td>
<td>556</td>
</tr>
<tr>
<td>Height of Trap</td>
<td>1</td>
<td>504</td>
</tr>
<tr>
<td>Camera Distance</td>
<td>1</td>
<td>162</td>
</tr>
<tr>
<td>Ramp Angle</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ramp Diameter</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Table 1-8. Partition splits, total observations (n) per split, and the associated probabilities of signature scores (0-2) for a partition regression analysis to determine the best camera trap configuration for photo-capturing marten ventral patches. The highest probability of capturing a ventral patch (i.e., a signature score >1) occurred when traps were <19 cm (but ≥15 cm) and when both feet were up, down, or when one only one foot was up.

<table>
<thead>
<tr>
<th>Partition Splits</th>
<th>n</th>
<th>Signature &quot;0&quot;</th>
<th>Signature &quot;1&quot;</th>
<th>Signature &quot;2&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positioning (both up0, both up1) &amp; Foothold Spacing ≥10.2cm &amp; Camera Distance &lt;65cm</td>
<td>823</td>
<td>0.34</td>
<td>0.51</td>
<td>0.15</td>
</tr>
<tr>
<td>Positioning (both up0, both up1) &amp; Foothold Spacing ≥10.2cm &amp; Camera Distance ≥65cm</td>
<td>2159</td>
<td>0.57</td>
<td>0.39</td>
<td>0.05</td>
</tr>
<tr>
<td>Positioning (both up0, both up1) &amp; Foothold Spacing &lt;10.2cm</td>
<td>3351</td>
<td>0.78</td>
<td>0.21</td>
<td>0.02</td>
</tr>
<tr>
<td>Positioning (one up, both up2, both down) &amp; Height of Trap &lt;19cm</td>
<td>774</td>
<td>0.08</td>
<td>0.42</td>
<td>0.50</td>
</tr>
<tr>
<td>Height of Trap ≥19cm &amp; Positioning (both down)</td>
<td>921</td>
<td>0.64</td>
<td>0.17</td>
<td>0.19</td>
</tr>
<tr>
<td>Height of Trap ≥19cm &amp; Positioning (one up, both up2)</td>
<td>920</td>
<td>0.30</td>
<td>0.55</td>
<td>0.15</td>
</tr>
</tbody>
</table>
and a 22% chance of a signature score ≥1 when the foot positioning was “both up0”, or “both up1” and the foothold spacing was <10.2 cm (Table 1-8).

**Density Estimate**

During the 2011 PMR effort, 13 marten were captured 120 times and density was estimated at 46 marten/100 km² (95% Bayesian C.L. = 27-69; Table 1-9); in the 2012 PMR effort, 15 marten were captured 89 times and density was estimated at 61 marten/100 km² (95% Bayesian C.L. = 35-90). The 2012 live-trapping yielded 15 marten captured 30 times and density was estimated at 41 marten/100 km² (95% Bayesian C.L. = 16-95; Table 1-9). The proportion of marten recaptured during PMR was 93% versus 53% for live-trapping.

**Statewide Population Estimate**

The mean, -1 SD, and -2 SD probability values of the distribution multi-model within the density study area was 0.56, 0.42, and 0.29, respectively (Fig. 1-6). The range for the total area of the probability values was 1,524 km²-4,849 km², and the associated population estimates ranged between 701-2,958 marten (Table 1-9). The population estimate for the mean probability value was 701 (range = 411-1,052) marten in winter 2011 and 930 (range = 533-1,372) in winter 2012; 1332 (range = 782-1,998) marten in winter 2011 and 1,766 (range = 1,013-2,606) in winter 2012 for the -1 SD probability value; and 2,231 (range = 1,309-3,346) marten in winter 2011 and 2,958 (range = 1,697-4,364) in winter 2012 for the -2 SD probability value (Table 1-9).
Table 1-9. Density estimates (PMR and live-trapping) for winter 2011 and 2012 and statewide population estimates based on mean, -1 SD, and -2 SD probability of occurrence within the density sampling area of northern New Hampshire. Low and high population estimates are based on 95% Bayesian confidence intervals from PMR density estimates.

### Density Estimates 2011-2012

<table>
<thead>
<tr>
<th>Year</th>
<th>marten/100 km²</th>
<th>Low 95% Bayesian C.L.</th>
<th>High 95% Bayesian C.L.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter 2011 (PMR)</td>
<td>46</td>
<td>27</td>
<td>69</td>
</tr>
<tr>
<td>Winter 2012 (PMR)</td>
<td>61</td>
<td>35</td>
<td>90</td>
</tr>
<tr>
<td>Winter 2012 (Live-Trapping)*</td>
<td>41</td>
<td>16</td>
<td>95</td>
</tr>
</tbody>
</table>

### Population estimate based on area ≥ mean probability

<table>
<thead>
<tr>
<th>Year</th>
<th>Estimate</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population Estimate 2011</td>
<td>701</td>
<td>411</td>
<td>1,052</td>
</tr>
<tr>
<td>Population Estimate 2012</td>
<td>930</td>
<td>533</td>
<td>1,372</td>
</tr>
</tbody>
</table>

### Population estimate based on area ≥ -1 SD of the mean

<table>
<thead>
<tr>
<th>Year</th>
<th>Estimate</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population Estimate 2011</td>
<td>1,332</td>
<td>782</td>
<td>1,998</td>
</tr>
<tr>
<td>Population Estimate 2012</td>
<td>1,766</td>
<td>1,013</td>
<td>2,606</td>
</tr>
</tbody>
</table>

### Population estimate based on area ≥ -2 SD of the mean

<table>
<thead>
<tr>
<th>Year</th>
<th>Estimate</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population Estimate 2011</td>
<td>2,231</td>
<td>1,309</td>
<td>3,346</td>
</tr>
<tr>
<td>Population Estimate 2012</td>
<td>2,958</td>
<td>1,697</td>
<td>4,364</td>
</tr>
</tbody>
</table>

* Not used to estimate statewide population; only used to compare with PMR 2012.
Fig. 1-6. NH occurrence multi-model describing probability of occurrence for marten in New Hampshire (upper left, Kelly 2005). Three potential areas to estimate statewide population based on probabilities (Mean, -1 SD, and -2 SD) of marten occurrence within the sampling area. Statewide area ≥ mean probability value was 1,524 km², area ≥ -1 SD probability value was 2,895 km², and area ≥ -2 SD probability value was 4,849 km².
Discussion

Capture

Body weights were similar to those measured in New Hampshire (Kelly 2005), Maine (Hearn 2007), New York (Jensen 2012) and Minnesota (Mech and Rogers 1977) but less than those recorded in western United States and Canada (Spencer 1981, Smith and Schaefer 2002, Poole et al. 2004, Hearn 2007); in all studies males weigh more than females throughout their geographic range (Smith and Schaefer 2002). The adult sex ratio slightly favored males (1.3) and was reasonably similar to that in trapped (1.0) and untrapped (1.0) industrial forests in Maine (Payer 1999). Males represented a greater proportion of captures in forest reserves in New York (3.6; Jensen 2012) and Maine (Payer and Harrison 1999) which is likely due to reduced trapping pressure and higher natural mortality of females (Hodgman et al. 1997, Jensen 2012); however, the ratio may be biased due to limited access at remote study sites (Payer 1999). The even sex ratio in trapped and cut Maine forests was attributed to male-biased harvest (Hodgman et al. 1994) and less intrasexual territoriality in low density populations (Payer 1999). Marten trapping is illegal in New Hampshire and density in this study was comparable to that in the forest reserve in Maine (Payer 1999). It is unknown if high elevation habitat imparts a unique advantage for females, or if the observed ratio was influenced by the relatively short sampling period; however, mortality was biased towards females as in Maine (Payer 1999) and New York (P. Jensen pers. commun.). Young males were more common in an earlier study in New Hampshire presumably because the population was expanding and some trapsites were adjacent to unsuitable habitat (Kelly 2005, J. Kelly,
pers. commun.); in general males disperse farther (Johnson et al. 2009) and occupy a wider range of habitats (Thompson 1994, Paragi et al. 1996, Chapin et al. 1998).

**Catch Per Unit Effort (CPUE)**

The CPUE was markedly higher during leaf-off (i.e., winter) than leaf-on seasons which is consistent with most studies (except see Poole et al. 2004), presumably because resources are limited during winter (Jensen 2012). The summer CPUE was higher (7 marten/100 trap nights) than in an earlier study in New Hampshire (1.05 marten/100 trap nights; Kelly 2005) and in Utah (1.06 marten/100 trap nights; Hargis et al. 1999). However, the latter study purposefully trapped in suboptimal habitat (i.e., clear-cut and partially harvested stands) that contributed to lower CPUE; at one site with <25% canopy cover only 1 marten was captured in 937 trap nights (0.11 marten/100 trap nights; Hargis et al. 1999). Similarly, CPUE was higher in spring and fall in uncut forests in Ontario (10 marten/100 trap nights) compared to cut forests (1.05 marten/100 trap nights) (Andruskiw et al. 2008), indicating that suboptimal habitat clearly reduces CPUE (Soutiere 1979, Hargis et al. 1999, Andruskiw et al. 2008).

**Breeding Potential (Intersexual Home-Range Overlap)**

Although sample size was smaller, breeding potential (i.e., intersexual home range overlap) was somewhat higher than that documented in a trapped industrial forest in Maine where female-male overlap was 71.4% and male-female was 37.1% (Katnik et al. 1994), and lower than in an untrapped industrial forest and reserve where female-male overlap was 94.9 and 100%, respectively (Payer and Harrison 1999). Further, reproduction was documented during live-trapping in both summers and juvenile marten were captured during both winters. The incidence of lactating females was similar for all
study sites in Maine, likely because marten select high quality habitat ensuring
reproduction (Payer and Harrison 1999). Similarly, in this study marten positioned home
ranges to include mostly mature forest (see Chapter 2).

Mortality

Mortality was biased toward females and predation was the leading cause of
mortality; higher natural mortality of females was also documented in Maine (Hodgman
et al. 1997, Payer 1999) and Newfoundland (Hearn 2007). Further, mortality was biased
towards younger marten as occurs elsewhere in North America (Bull and Heater 2001,
Shults 2001, Hearn 2007). Avian predators were not associated with mortality; rather,
red fox and coyotes were the primary predators. Although the concern was that fisher
would predate on marten (Hodgman et al. 1997), there were few camera detections or
tracks of fisher compared fox and coyote (see Chapter 4). Red fox were the primary
terrestrial predator in Ontario (Thompson 1994) and Newfoundland (Hearn 2007) where
8 of 9 suspected or documented predations involved fully intact carcasses suggesting
interference competition. Interestingly, live captures of marten increased with the
elimination of red fox in Newfoundland (Hearn 2007) and populations increased
following their decline in Scandinavia (Lindström et al. 1994, Helldin 1998).

Several marten were in poor condition during winter 2012 and starvation likely
ccontributed to their mortality. Because small mammal abundance was not documented
during the study, it is unknown if it was a contributing factor. Density was highest in
winter 2012, and could have been at carrying capacity when higher mortality of females
is common (Hodgman et al. 1997). Further, starvation occurred for 2 yearlings (1 M, 1
F) occupying suboptimal winter habitat (i.e., regenerating forest) relative to adult marten;
the home range of the other juvenile female mortality was unknown, but it was recovered in similar habitat. It is possible that these animals were excluded from optimal habitat and their survival was compromised. Winter survival was lower for female marten in a forest reserve in Maine and was speculated as due to high density, reduced prey availability, or capture inefficiency (Hodgman et al. 1997, Payer 1999).

Human-related mortality was minimal (n = 2) but has the potential to limit population growth, especially where roads provide easy access for trapping (Hodgman et al. 1994, Payer 1999); both mortalities were ≤200 m of a road. Trapping-associated mortality typically involves young males (Strickland and Douglass 1987, Fortin and Cantin 1994, Hodgman et al. 2004, Hearn 2007) and has been the case for incidental captures in New Hampshire (NHFG, unpublished data). Given that natural mortality is higher in females (Hodgman et al. 1997), human-related mortality might be compensatory in certain situations (Hearn 2007). It is interesting to note that an adult female mortality was attributed to gunshot, as also occurred in Maine (Hodgman et al. 1994), and while such events are rare, they are likely associated with road access.

Of greater significance is the influence of roads on the predator community assemblage (Oehler and Litvaitis 1996, Buskirk et al. 2000). Although the gated roads to the wind farm limit vehicular access, fox and coyote used them extensively in winter (see Chapter 4) and presumably year-round. Two female mortalities (1 with kits) were attributed to red fox and one to coyote <200 m from the road in the high elevation habitat. An adult male was also predated <100 m from the high elevation road, and another was predated by a coyote on a logging road.

**Camera Trap Method**
Signature scores were greatly improved when the front feet of marten were either both down on the platform under the camera trap or positioned in a manner that allowed the ventral patches to be photographed. However, foot positioning was influenced by trap position, and signature scores were higher when camera traps were 15-19 cm above the platform; this height is recommended as it optimized capture of ventral patches of both sexes. Further, cameras performed well at intermediate distances (40-80 cm) from the trap as this distance provided recognizable ventral marks without sacrificing image quality. A camera hood should be used to keep snow from covering the lens. A trap design that integrates the camera and trap and encloses both would be ideal as distance would be standardized and lighting stable. Ultimately, increasing the probability of identifying marten from one picture will provide more candidate photos from each capture event (i.e., cluster of photos), and this is especially important when bait is depleted and the # of detections per visit declines.

Camera performance varied considerably with the custom built camera the most reliable, taking continuous pictures with high image quality. The Bushnell cameras were less reliable, but took continuous pictures with variable image quality. The 2 Moultrie Camera models were as reliable as the Bushnell cameras, but were limited to 3 pictures per minute, and photo quality was variable. It is possible that cold weather caused several cameras of both brands to occasionally malfunction. To contrast, custom built cameras withstood extreme cold temperatures, had longer battery life, and were very reliable. Although time and budget constraints may affect choices, custom built cameras can be relatively inexpensive to make (~$100) but require expertise. Alternatively, Bushnell Trophy Cams are reasonably priced (~$200), offer flexible settings, and
perform well at warmer temperatures; conducting PMR in late winter when temperatures are warmer would provide a compromise.

While the identification of unique individuals is achievable, the ability to correctly classify gender and distinguish between juvenile and adult marten is more complex. Gender differentiation is easier to accomplish with sexually dimorphic species and was attempted in this study. It might be improved by widening the capture zone to include the genital area as was done with wolverines (*Gulo gulo*) in Alaska (Magoun et al. 2011); however, it should not compromise the identification of ventral patches. Using landmarks that are readily captured (e.g., front feet) and in close proximity to the ventral patches may be more practical. Providing a ruler to make comparisons is important, and can be integrated to provide quantitative comparisons of morphology with photo analysis software. Thompson (2008) used the ratio of head morphology and camera trap landmarks (ear-width/treadle width) to classify the gender of fisher and correctly classified 82.5% of known males and 94.7% of known females. While identification of gender is possible, the greatest challenge is to distinguish juvenile and adult marten because they reach adult size their first winter.

The camera trap method proved to be accurate and a more reliable method to estimate density compared to live-trapping. Although both methods provided the same number of unique captures (*n* = 15), recaptures were more likely with PMR which improves the precision of the density estimate. Further, although starvation was a contributing factor, live-trapping can occasionally result in mortality (Paragi et al. 1996, Potvin and Breton 1997, Hodgman et al. 1997, Smith and Schaefer 2002, Poole et al. 2004, Hearn 2007, Erb et al. 2010, P. Jensen pers. commun.), and 4 marten identified
during camera trapping were not live-trapped until the following season. Camera trapping may require equal effort to establish trap sites and greater time to analyze data than live-trapping; however, traps do not need to be checked daily, it can be maintained longer, and because multiple captures occur continuously, there is increased opportunity to capture more individuals. Higher capture and recapture rates, longer sampling periods, and the reduction of trap shyness and trapping-associated mortality with camera trapping contributes to more precise density estimation, and because winter is energetically demanding for marten (Buskirk and Harlow 1989), it provides a minimally invasive alternative to traditional live-capture.

Density and Statewide Population Estimate

The average density during both winters (0.52) was similar to that estimated in a forest reserve (>0.52 marten/km²) considered near carrying capacity (Payer and Harrison 1999). Winter density fluctuated around this perceived threshold (0.42-0.62 marten/km²), with natural mortality biased towards females as occurred in Maine (Payer and Harrison 1999). To contrast, density in an untrapped industrial forest averaged 0.31 marten/km², and in a trapped industrial forest considered well below carrying capacity (0.19 marten/km²); both landscapes had nearly 50% regenerating forest (Payer and Harrison 1999). Similarly, density of marten in Ontario was lower in cut than uncut forest (Thompson 1994).

In New Hampshire the marten population has increased steadily since the 1980s and is likely re-colonizing much of its historical range (Kelly 2005). Assuming that the mean and -2 SD population estimates could be too conservative and liberal, respectively, the -1 SD estimate probably better reflects the statewide population. The area within the
-1 SD estimate includes peripheral areas where marten are known to occur and contains less developed habitat. Because the projected population estimates are limited to a single sampling location considered optimal habitat, density is undoubtedly lower in less suitable habitat, and the estimate should be considered conservative.

The local density estimate is considered high for the region and reflects good habitat based on a previous study (Payer 1999), and was characterized by a high proportion of adult reproductive marten. Dispersing (young) marten entered the population when adults died, providing evidence of a healthy regional population in northern New Hampshire. More importantly, these high density estimates provide evidence that elevation can be a powerful surrogate for latitude in the northeastern United States (Carroll 2007), and it is important that the ecological integrity of these landscapes remain intact from the perspective of optimal marten habitat. Marten populations fluctuate naturally, yet human disturbance often increases these fluctuations, potentially destabilizing local populations. Further, high elevation habitat in northern New Hampshire and northwestern Maine is predicted to be important long-term in the face of climate change (Tang and Beckage 2010), and is considered a critical linkage for marten in northern New England (Jensen 2012). It is important then, for population monitoring to occur regularly and that development and disturbance within these fragile ecosystems consider habitat use and dynamics of marten populations to ensure their sustainability.
CHAPTER 2

SPATIAL ECOLOGY AND RESOURCE SELECTION OF A HIGH ELEVATION AMERICAN MARTEN POPULATION IN NORTHERN NEW HAMPSHIRE

Introduction

American marten (*Martes americana*) are at the southern edge of their distribution in the northeastern United States (Gibilisco 1994). Snow, interactions with sympatric competitors (specifically fisher [*Martes pennanti*]), and forest fragmentation are factors thought to limit southward range expansion (Krohn et al. 2004, Kelly 2005, Carroll 2007, Jensen 2012). Distribution in New Hampshire is concentrated in the north where deep snow occurs at higher elevations with little development and few fishers (Kelly 2005). Similarly, more marten are associated with deeper snow (>48 cm per month) in northern Maine, whereas fisher represent the majority of furbearer records in southern Maine (Krohn et al. 1995). Additionally, recent models indicate that marten distribution in the northeastern United States is associated with mixed-wood forest canopy cover (Kelly 2005, Jensen 2012).

Marten have small body size, high metabolic rate, and large spatial requirements up to 3-4 times larger than similar sized carnivores (Buskirk and McDonald 1989). Home range size is related to energetic constraints (Kelt and Van Vuren 1999) as well as
age, sex, and trophic status (Lindstedt et al. 1986). Home range size can be used as a surrogate for habitat productivity (Harestad and Bunnel 1979) and many studies have used it as an indicator of habitat conditions (Powell et al. 2003). Indeed, prey fluctuations (Hawley and Newby 1957, Weckwerth and Hawley 1962, Thompson and Colgan 1987, Powell 1994, Gosse et al. 2005, Jensen 2012), habitat fragmentation (Potvin and Breton 1997, Payer and Harrison 1999), logging practices (Fuller and Harrison 2005), forest age (Thompson and Harestad 1994), season (Fuller and Harrison 2005), low forest productivity (Smith and Schaefer 2002, Gosse et al. 2005), social status (Payer and Harrison 1999), and breeding status (Katnik et al. 1994) influence the size of a home range.

The effect of timber harvesting on home range size is well documented and direct relative to increasing home range size (Thompson et al. 2012). In Maine, male and female marten with partially harvested stands in their home ranges had winter home ranges twice as large as those in uncut forests (Fuller and Harrison 2005). Possible explanations were that partially harvested stands had lower snowshoe hare (*Lepus americanus*) density (Fuller et al. 2004) and did not provide optimal winter canopy cover (Payer and Harrison 2003). In Quebec, marten occupying mature and partially cut forests had smaller home ranges compared to those in clear cuts, pre-commercially thinned forests, and forests with high road density (Godbout and Ouellet 2008).

Timber harvesting can also impact fitness through increased energy expenditure and exposure to predators (Fuller and Harrison 2005). Marten in logged and untrapped landscapes in Maine had larger home ranges, longer daily movements, and lower survival (Hodgman et al. 1994, Payer and Harrison 1999); however, females positioned their
home ranges to include greater residual forest and their reproduction was similar to that measured in a nearby forest reserve (Chapin et al. 1998). In logged, yet untrapped forests in Ontario, Potvin and Breton (1997) measured larger home ranges, longer movements, and lower survival in recently cut forests, and another Ontario study found that marten in cut forests were younger (<3 years old), had lower survival, larger home ranges, and no reproduction during a 5-year period; in contrast, marten in uncut forests had pregnancy rates of 22-67% (Thompson 1994). Further, a recent study in Quebec found female condition to be negatively correlated with the amount of regenerating forest within a home range, suggesting that harvested landscapes reduce fitness (Cheveau et al. 2013). Conversely, marten in uncut forests in Maine had smaller home ranges (Payer and Harrison 1999) and higher survival rates (Hodgman et al. 1997). Lower survival in logged landscapes can be attributed to greater energetic requirements (i.e., longer distances travelled), and perhaps marten traveling in fragmented landscapes are at higher predation risk because of reduced canopy cover (Thompson 1994, Potvin and Breton 1997, Fuller and Harrison 2005). However, home range fidelity was similar among industrial forest and forest reserve sites in Maine, suggesting that marten are required to maintain stable home range boundaries to fulfill a suite of life-history requirements (Payer et al. 2004).

Fluctuating resources can also influence home range size (Thompson and Colgan 1987, Powell 1994, McLoughlin and Ferguson 2000, Jensen 2012). In a 7-year study in Newfoundland, Gosse et al. (2005) documented smaller home ranges when snowshoe hare populations were high, although overall home range size was large due to low diversity of resource abundance. Further, Thompson and Colgan (1987) found that home
range size increased in cut and uncut forests in response to prey shortages. Though the increases were greater in cut forests, it is noteworthy that prey shortages affected home range size in uncut forests, suggesting that that is not always indicative of habitat conditions. During a 6-year study in the Adirondack State Park (forest reserve) in New York, home range size and movements fluctuated in response to masting events; home range size and movements were smaller during mast years (Jensen 2012). This study was important because it was long-term, evaluated spatial ecology in the absence of timber harvesting, and was set in a deciduous-dominated Acadian forest. In landscapes where prey diversity is higher, prey switching occurs, possibly allowing for more stable home range size (Poole and Graf 1996, Payer and Harrison 1999).

Home range fidelity is considered important because it provides familiarity with resources (Burt 1943) and increases survival (Phillips et al. 1998). If marten are required to increase home range size, or shift home range seasonally because of unsuitable habitat (O'Doherty et al. 1997), it may be energetically costly (Buskirk and Ruggeiro 1994), and increase predation risk (Payer 1999) and territoriality with conspecifics (Katnik et al. 1994). Home range fidelity for marten in Wyoming was considered high when there was >65% overlap between successive seasonal home ranges, as determined by a statistical bootstrap procedure that estimated the variance of expected home range overlap (O'Doherty et al. 1997).

Marten are traditionally associated with mature coniferous forests (Allen 1982, Buskirk and Powell 1994) but research over the past 20 years has indicated that they occupy a variety of forest types depending on region (Paragi et al. 1996, Payer 1999, Potvin et al. 2000, Poole et al. 2004, Dumahyan 2007, Jensen 2012). Many authors

Marten showed no preference for forest type at the stand scale in cut or uncut forests in New York or Maine (Payer 1999, Fuller and Harrison 2005, Jensen 2012). Although, they may not exhibit preference for forest types at the stand scale, it does not preclude selection at other scales (Jensen 2012). Recent research in the Northeast indicates that martens select for mixed-wood forest at the ecoregional and statewide scale (Kelly 2005, Jensen 2012), and a recent study in Quebec found that smaller home ranges contained a greater proportion of mixed-wood forest (Cheveau et al. 2013). Modeling suggests that the probability of occupancy in New Hampshire is <0.43 with >69% of the landscape composed of deciduous forest, and increases when mean canopy cover is ≥68% (Jensen 2012). No cover type selection occurred at the landscape scale in Maine; rather, martens responded negatively to fragmentation and positioned home ranges to include <40% of early successional forest (Payer and Harrison 1999). It is unknown if
these patterns persist at finer scales (e.g., stand and sub-stand scales) for marten in New Hampshire, but it is important to understand the influence of scale on resource selection to aid in management and conservation efforts (Nams et al. 2006).

In a recent study, topographic ruggedness was an important variable for predicting the presence of marten in the Adirondack Mountains of New York (Jensen 2012). New Hampshire has pronounced elevational gradients and the greatest proportion of high elevation habitat compared to other Northeastern states (Publicover and Kimball 2011), and its rugged terrain might influence spatial ecology of marten differently than adjacent states. Therefore, it is important to understand any unique spatial requirements and habitat selection by marten in New Hampshire to best assist their recovery.

Marten are a state threatened species in New Hampshire (WAP 2005) and are projected to decline long-term due to anthropogenic disturbances (Krohn et al. 2004, Carroll 2007). Importantly, climate change models predict that the remaining boreal conifer forest will be concentrated in mountainous and northern regions of New Hampshire by the end of the 21st century (Tang and Beckage 2010). Further, wind power development is an immediate threat as it is increasing and occurs in areas considered to be prime habitat for marten (WAP 2005).

Past research has focused on larger scale influences predicting marten distribution in New Hampshire (Kelly 2005, Jensen 2012); yet, finer scale resource use is required to understand proximal factors that affect local populations. Providing metrics such as home range size and resource selection will be useful to compare with regional studies in Maine and New York and to aid in management and conservation of marten. Further,
understanding how marten respond at multiple scales can aid in predicting their response to forest disturbance and aid in recovery efforts. The objectives of this research were to document home range size and fidelity, movements, and habitat selection at multiple scales (2nd and 3rd order; Johnson 1980) of radio-collared marten. It was predicted that marten would select for mixed-wood and coniferous stands and select against regenerating forests during winter at landscape and stand scale analyses.

**Methods**

**Telemetry, Home Range, and Movements**

Capture, telemetry, and error testing followed the protocol described in Chapter 1. Home range and seasonal movements were measured to provide comparison with other regional studies. A 95% minimum convex polygon (MCP) was calculated for adult marten >1 yr that met seasonal location requirements (see Chapter 1). The mean minimum distance (MINDIST) travelled between consecutive locations can be a reliable index for home range size, and is often used when limited locations are available to calculate standard home range (Katnik et al. 1994, Phillips et al. 1998). MINDIST was strongly correlated with home range size for males ($r = 0.721, n = 21$) and females ($r = 0.749, n = 6$); therefore, a MINDIST was calculated for all adults with >10 locations. For habitat use, home range overlap, and habitat composition analyses, a 100% MCP was calculated for 5 marten with ≥15 but <24 locations (Poole et al. 2004). Marten included in home range and movement analyses were monitored for >80 days. Home range and movement analyses were conducted using BIOTAS home range software (BIOTAS 2010).
Seasonal Home Range Overlap and Fidelity

Home range overlap (HRO) was calculated for individuals as the percentage of overlap with the previous season and between similar seasons to detect seasonal shifts and provide interpretation of habitat use and composition analyses. Previous research in Maine calculated the proportion of locations within the 95% MCP home range boundary of the previous season and corresponding season as an index (FIDEL) for marten with too few locations to measure seasonal and annual home range fidelity (Phillips et al. 1998); although this was weakly correlated \( r = 0.336, n = 21 \) for marten in this study, it was compared with that measured by Payer et al. (2004) as they used the FIDEL index without testing for correlation. Also, males and females were pooled because there were no statistical differences between their measures of fidelity (Fuller and Harrison 1999, Payer et al. 2004, Hearn 2007).

Landscape Scale Habitat Use

Habitat use was evaluated at the landscape scale (2nd order; Johnson 1980) using a design III study, where used units are compared to randomly generated units within a landscape (Manly et al. 2002). Because the delineation of a study area is especially important at the landscape scale (Johnson 1980), the study area boundary was defined by a minimum bounding concave polygon that encompassed all marten home ranges and trapsites to which a 1 km buffer was added (Potvin et al. 2000, Cheveau et al. 2013) (Fig. 2-1). The unique geometry of individual home ranges was used for the randomization process to provide a comparison between used and randomized home ranges, as the size, shape, and orientation of a home range on a landscape is ecologically meaningful (Potvin
et al. 2001). Home range polygons were randomly rotated and placed 100 x within the
delineated landscape using MATLAB software (MATLAB 2012b), and the habitat
composition within seasonal home ranges were compared to randomly generated home
ranges.

Stand Scale Habitat Use

Habitat use was evaluated at the stand scale (3rd order; Johnson 1980) using a
design III study, where used (telemetry) locations were compared to available (i.e.,
randomly generated) locations within an individual home range (Manly et al. 2002). For
used and available locations within a seasonal home range, an 80 m buffer (radius of the
2 ha median error ellipse; see Chapter 1) was applied to incorporate telemetry error
(Rettie and McLoughlin 1999). Available locations were generated by multiplying the
number of locations within each seasonal home range by 5 (Baasch et al. 2010) and
randomized using the “Generate Random Points” tool in ArcGIS (ESRI 2010). Similar to
the landscape scale analysis, the habitat composition within used locations areas (buffer)
was compared to that within randomly generated location areas, and selection was
measured using logistic mixed-effects models.

Resource Selection GIS Data

The New Hampshire Land Cover Assessment (NHLCA) data from 2001 (New
Hampshire GRANIT 2001) was used to generate GIS forest type layers and a
combination of statewide land cover data from 2001 and 2006, and orthophotos from
2009 were used to delineate regenerating forest <20 years old (NHFG, unpublished data)
to determine habitat composition within home ranges and the sampled landscape;
Fig. 2-1. Study area map for landscape and stand scale habitat selection (62 km²) study area. Landscape was determined by calculating a minimum convex polygon around all seasonal marten home ranges (n = 33) and adding a 1 km buffer influence zone.
resolution of all GIS data was 30 m and accuracy was 82%. Forest types were classified as softwood, mixed-wood, deciduous, and lowland conifer/shrub forest using a classification scheme similar to that described in Kelly (2005). Forest age was classified as either regenerating (<20 years) or mature, as most forest in the study area had been cut in recent years leaving easily identified residual mature forest. Partial harvests were not digitized as they were difficult to distinguish (NHFG, unpublished data).

Statistical Analysis (Habitat Use)

To test habitat selection hypotheses for landscape and stand scale during both seasons, logistic generalized linear mixed-effects models (GLMM) were performed using R statistical software (R Development Core Team 2013) using the lme4 package (Bates et al. 2012). Used units were compared to randomly generated units for both analyses and when top competing models were close (i.e., shared AICc weights (AICcWt)) and Delta_AICc scores were <2), model parameters were averaged using the MuMIn package (Barton 2013) in R. Model averaging can lead to more precise parameter estimates (Burnham and Anderson 2002, Bolker et al. 2009). Marten were treated as a random effect in all models. Logistic mixed-effects models are useful for resource selection analyses because they allow for repeated measures, provide inference into population level dynamics, and are useful for unbalanced designs (Hebblewhite and Merrill 2008, Hegel et al. 2010). Significance values for the parameter estimates of the best fitting models were calculated using the Wald z-statistic.

Home Range Composition Analysis
Generalized linear mixed-effects models (GLMM) were evaluated to determine the influence of forest composition on home range size (Cheveau et al. 2013). Since home range size varied seasonally, it was included as a predictor variable. The proportions of hardwood, softwood, mixed-wood, and regenerating forest within each seasonal home range were included as model predictors and marten was included as a random effect for model comparisons.

**Results**

**Telemetry, Home Range, and Movements**

Thirty-four marten (17 M, 17 F) were captured and 29 were radio-collared over the course of the study. A total of 1,000 telemetry locations were collected from 20 radio-collared marten from 14 November 2010-22 October 2012. Of these, telemetry location data was available for 16 marten (11 M, 5 F) for home range (n = 822), movement (n = 940), and habitat use (409 leaf-off, 492 leaf-on) analyses.

A 95% MCP was calculated for 28 marten (22 M, 6 F) and a MINDIST was calculated for 33 marten (25 M, 8 F) for 4 seasonal periods (Table 2-1). To compare differences in home range size and movements between males and females, data was pooled across seasons. Overall, male home range size ($\bar{x} = 2.95 \pm 0.27$ km$^2$) and movements ($\bar{x} = 1129 \pm 77$ m) were 44% larger ($P = 0.002$) and 32% longer ($P = 0.004$) compared to female home range size ($\bar{x} = 1.55 \pm 0.20$ km$^2$) and movements ($\bar{x} = 768 \pm 142$ m). Male home range size ($\bar{x} = 3.19 \pm 0.45$ km$^2$) increased 20% during leaf-on periods but was not different ($P >0.05$) than leaf-off periods ($\bar{x} = 2.54 \pm 0.30$ km$^2$); although sample size was low, female home range size was similar during both seasons.
(leaf-on $\bar{X} = 1.54 \pm 0.33$ km$^2$, leaf-off $\bar{X} = 1.79 \pm 0.28$ km$^2$; Table 2-1). Movements were similar ($P > 0.05$) during both seasons movements for male (leaf-off $\bar{X} = 1.043 \pm 102$ m, leaf-on $\bar{X} = 1.077 \pm 59$ m) and female (leaf-off $\bar{X} = 776 \pm 91$ m, leaf-on $\bar{X} = 761 \pm 132$ m) marten (Table 2-1).

**Seasonal Home Range Overlap and Fidelity**

HRO was high, yet variable ($\bar{X}$ overlap = $78 \pm 11\%$) between Leaf-off 1 and Leaf-on 1 seasons for 5 marten; these marten either expanded home ranges to encompass that of the previous season (M1, M3, M5) or shifted home range position to include new habitat (F5, M7; Table 2-2). From Leaf-on 1 to Leaf-off 2, HRO was low and variable ($\bar{X}$ overlap = $47 \pm 11\%$); 6 marten (F5, M1, M5, M6, M8, M10) contracted home range size shifted from lower to higher elevation habitat, and 2 marten maintained similar position at low elevation (F9, M11; Table 2-2). HRO was the highest and least variable ($\bar{X}$ overlap = $83 \pm 9\%$) for 5 marten from Leaf-off 2 to Leaf-on 2 as they expanded home range size to include that of the previous season (Table 2-2). The overall mean HRO between consecutive seasons was $66 \pm 6\%$ (Table 2-2, Fig. 3). Three marten (F5, M1, M5) exhibited low HRO ($\bar{X}$ overlap = $42 \pm 9\%$) between leaf-on seasons, and 4 marten (M3, M6, M10, M11) had higher HRO ($\bar{X}$ overlap = $67 \pm 16\%$) between leaf-off seasons (Table 2-2).

Home range fidelity between successive seasons was calculated for 18 marten. The mean proportion of leaf-off (winter) locations located within the home range of the previous leaf-on (summer) season was $51.4 \pm 9.6\%$, and similarly, fidelity of leaf-on locations within the home range boundary of the previous leaf-off season was $52.3 \pm 5.1$.
Table 2-1. Number of locations (locs), home range area (95% MCP), mean (±SE) home range size, MINDIST, and mean (±SE) MINDIST of male and female marten during 4 seasons (1 November 2010-15 October 2012) in northern New Hampshire. Male home range size was 44% larger and movements were 32% longer than females, and home range size and movements were 20% larger and 3% longer for males during leaf-on seasons.

<table>
<thead>
<tr>
<th></th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Id</td>
<td>locs</td>
</tr>
<tr>
<td><strong>Leaf-off 1</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M1</td>
<td>30</td>
<td>2.11</td>
</tr>
<tr>
<td>M3</td>
<td>32</td>
<td>2.7</td>
</tr>
<tr>
<td>M5</td>
<td>24</td>
<td>4.12</td>
</tr>
<tr>
<td>M6*</td>
<td>12</td>
<td>-</td>
</tr>
<tr>
<td>M7**</td>
<td>18</td>
<td>1.76</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Leaf-on 1</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M1</td>
<td>36</td>
<td>6.47</td>
</tr>
<tr>
<td>M3**</td>
<td>16</td>
<td>5.31</td>
</tr>
<tr>
<td>M5</td>
<td>29</td>
<td>5.55</td>
</tr>
<tr>
<td>M6</td>
<td>31</td>
<td>2.33</td>
</tr>
<tr>
<td>M7</td>
<td>27</td>
<td>1.98</td>
</tr>
<tr>
<td>M8</td>
<td>31</td>
<td>4.36</td>
</tr>
<tr>
<td>M10</td>
<td>26</td>
<td>2.22</td>
</tr>
<tr>
<td>M11</td>
<td>25</td>
<td>2.19</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Leaf-off 2</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M1</td>
<td>34</td>
<td>1.85</td>
</tr>
<tr>
<td>M5</td>
<td>28</td>
<td>2.75</td>
</tr>
<tr>
<td>M6</td>
<td>32</td>
<td>2.24</td>
</tr>
<tr>
<td>M8**</td>
<td>18</td>
<td>7.13</td>
</tr>
<tr>
<td>M10</td>
<td>37</td>
<td>1.42</td>
</tr>
<tr>
<td>M11</td>
<td>37</td>
<td>3.14</td>
</tr>
<tr>
<td>M15**</td>
<td>15</td>
<td>0.87</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Leaf-on 2</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M1</td>
<td>34</td>
<td>2.3</td>
</tr>
<tr>
<td>M6</td>
<td>32</td>
<td>3.54</td>
</tr>
<tr>
<td>M10</td>
<td>24</td>
<td>3.01</td>
</tr>
<tr>
<td>M11</td>
<td>31</td>
<td>4.37</td>
</tr>
<tr>
<td>M15</td>
<td>31</td>
<td>0.67</td>
</tr>
<tr>
<td>M16</td>
<td>31</td>
<td>2.53</td>
</tr>
<tr>
<td>M17**</td>
<td>20</td>
<td>0.95</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Were not included in summary statistics as M6 had not established residency and F8 was a juvenile
** 100% MCP (Only included in HRO and habitat selection analyses)
Table 2-2. Mean (±SE) home range overlap for marten between consecutive and corresponding leaf seasons from 1 November 2010-15 October 2012 in northern New Hampshire. The overall mean HRO between consecutive seasons was 66 ± 6% and between corresponding seasons was 57 ± 10%.

<table>
<thead>
<tr>
<th>Marten</th>
<th>Leaf-off 1</th>
<th>Leaf-on 1</th>
<th>Leaf-off 2</th>
<th>Leaf-on 2</th>
<th>Leaf-off 1</th>
<th>Leaf-on 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>F5</td>
<td>61%</td>
<td>5%</td>
<td>-</td>
<td>25%</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>F9*</td>
<td>-</td>
<td>87%</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>M1</td>
<td>100%</td>
<td>19%</td>
<td>77%</td>
<td>46%</td>
<td>23%</td>
<td></td>
</tr>
<tr>
<td>M3*</td>
<td>92%</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>M5</td>
<td>96%</td>
<td>49%</td>
<td>-</td>
<td>55%</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>M6</td>
<td>-</td>
<td>60%</td>
<td>100%</td>
<td>-</td>
<td>87%</td>
<td></td>
</tr>
<tr>
<td>M7*</td>
<td>42%</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>M8*</td>
<td>-</td>
<td>26%</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>M10</td>
<td>-</td>
<td>41%</td>
<td>100%</td>
<td>-</td>
<td>69%</td>
<td></td>
</tr>
<tr>
<td>M11</td>
<td>-</td>
<td>92%</td>
<td>86%</td>
<td>-</td>
<td>91%</td>
<td></td>
</tr>
<tr>
<td>M15*</td>
<td>-</td>
<td>49%</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

78 ± 11%  47 ± 11%  83 ± 9%  42 ± 9%  67 ± 16%

* 100% MCP
Table 2-3. Mean % (n, SE) of locations recorded within the 95% MCP home range boundaries of the previous and corresponding season for marten from 1 November 2010-15 October 2012 in northern New Hampshire. Data and table format was borrowed from Payer et al. (2004) for comparison between studies. Data from Maine included the average fidelity measures pooled across 8 years for 3 study sites. Measures in bold are highlighted for comparison with Payer et al. (2004).

<table>
<thead>
<tr>
<th>Study Area</th>
<th>Seasonal Home Range Fidelity</th>
<th>Annual Home Range Fidelity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Winter to previous summer</td>
<td>Summer to previous summer</td>
</tr>
<tr>
<td>New Hampshire</td>
<td>51.4 (8, 9.6)</td>
<td>58.1 (8, 4.1)</td>
</tr>
<tr>
<td>Maine</td>
<td>67.4 (131, 1.9)</td>
<td>52.3 (23, 4.8)</td>
</tr>
</tbody>
</table>
Fig. 2-2. Home range overlap for 3 martens during consecutive seasons. Seasonal shifts were considered normal and fidelity was high, leaf-off home ranges were smaller than leaf-on and martens minimized regenerating forest within their home range year-round.
% (Table 2-3). Home range fidelity in the same season was calculated for 7 marten: the mean proportion of leaf-on locations overlapping was 53.5 ± 5.4 %, and for leaf-off locations was 40.2 ±13.2 % (Table 2-3).

Landscape Scale Habitat Use

The landscape was comprised of 75% mature and 25% regenerating forest, with 51% hardwood, 32% mixed-wood, 15% softwood, and 2% lowland conifer/shrub forest. There were 33 seasonal home ranges (15 leaf-off, 18 leaf-on) available for the landscape selection analysis. Habitat composition within individual home ranges varied greatly; forest types within home ranges during leaf-off seasons were 11-94% hardwood, 0-71% softwood, 6-53% mixed-wood, 0-2% lowland conifer/shrub, and 1-26% regenerating stands (Table 2-4); home ranges during leaf-on seasons were comprised of 24-95% hardwood, 0-42% softwood, 5-52% mixed-wood, 0-5% lowland conifer/shrub, and 2-46% regenerating forest (Table 2-5). Female marten had 21% and 14% less regenerating forest than males within their home ranges during leaf-off ($\bar{X} = 8.3 \pm 1.9$ %) and leaf-on ($\bar{X} = 12.7 \pm 2.8$ %) seasons, respectively, but sample size was too small to make comparisons (Tables 2-4 and 2-5).

Resource selection at the landscape scale was not random during leaf-off and leaf-on seasons (Tables 2-6). The top models (i.e., models with $\text{AIC}_c < 2$) for the leaf-off season were “Full” (all forest types) and “Regenerating Forest” (Table 2-6). The “Regenerating Forest” model had the fewest number of parameters (3) indicating this variable alone best explained landscape selection during leaf-off seasons; top models were averaged to increase precision of parameter estimation (Table 2-6). Marten
Table 2-4. Forest composition (%) within individual leaf-off seasonal home ranges for 15 marten (11 M, 4 F) from 1 November 2010-15 October 2012 in northern New Hampshire. Mean (±) home range (HR) size, and percent forest type within male, female and combined home ranges during for 2 leaf-off seasons.

<table>
<thead>
<tr>
<th>Marten</th>
<th>Season</th>
<th>HR Size</th>
<th>Regen (%)</th>
<th>Lowland Conifer/Shrub (%)</th>
<th>Hardwood (%)</th>
<th>Mixed (%)</th>
<th>Softwood (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F4</td>
<td>Leaf-off 1</td>
<td>2.34</td>
<td>12</td>
<td>0</td>
<td>58</td>
<td>33</td>
<td>9</td>
</tr>
<tr>
<td>F5</td>
<td>Leaf-off 1</td>
<td>1.53</td>
<td>6</td>
<td>0</td>
<td>43</td>
<td>53</td>
<td>4</td>
</tr>
<tr>
<td>M1</td>
<td>Leaf-off 1</td>
<td>2.11</td>
<td>5</td>
<td>0</td>
<td>53</td>
<td>44</td>
<td>3</td>
</tr>
<tr>
<td>M3</td>
<td>Leaf-off 1</td>
<td>2.70</td>
<td>7</td>
<td>0</td>
<td>32</td>
<td>34</td>
<td>34</td>
</tr>
<tr>
<td>M5</td>
<td>Leaf-off 1</td>
<td>4.12</td>
<td>7</td>
<td>0</td>
<td>27</td>
<td>28</td>
<td>45</td>
</tr>
<tr>
<td>M7*</td>
<td>Leaf-off 1</td>
<td>1.76</td>
<td>6</td>
<td>0</td>
<td>72</td>
<td>21</td>
<td>7</td>
</tr>
<tr>
<td>F5</td>
<td>Leaf-off 2</td>
<td>1.49</td>
<td>4</td>
<td>0</td>
<td>47</td>
<td>34</td>
<td>19</td>
</tr>
<tr>
<td>F9*</td>
<td>Leaf-off 2</td>
<td>0.90</td>
<td>11</td>
<td>0</td>
<td>94</td>
<td>6</td>
<td>0</td>
</tr>
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<td>M1</td>
<td>Leaf-off 2</td>
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<td>M5</td>
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<td>11</td>
<td>19</td>
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<td>M6</td>
<td>Leaf-off 2</td>
<td>2.24</td>
<td>16</td>
<td>2</td>
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<td>52</td>
<td>21</td>
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<tr>
<td>M8*</td>
<td>Leaf-off 2</td>
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<td>40</td>
<td>25</td>
<td>35</td>
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<td>M10</td>
<td>Leaf-off 2</td>
<td>1.42</td>
<td>1</td>
<td>0</td>
<td>11</td>
<td>33</td>
<td>56</td>
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<tr>
<td>M11</td>
<td>Leaf-off 2</td>
<td>3.14</td>
<td>24</td>
<td>2</td>
<td>68</td>
<td>24</td>
<td>6</td>
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<tr>
<td>M15*</td>
<td>Leaf-off 2</td>
<td>0.87</td>
<td>26</td>
<td>0</td>
<td>84</td>
<td>16</td>
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</table>

<table>
<thead>
<tr>
<th>Sex</th>
<th>Season</th>
<th>HR Size</th>
<th>Regen (%)</th>
<th>Lowland Conifer/Shrub (%)</th>
<th>Hardwood (%)</th>
<th>Mixed (%)</th>
<th>Softwood (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td></td>
<td>2.74 (±0.51)</td>
<td>10.5 (±2.8)</td>
<td>0.4 (±0.2)</td>
<td>42.1 (±7.4)</td>
<td>30.5 (±3.4)</td>
<td>27.3 (±7.0)</td>
</tr>
<tr>
<td>Female</td>
<td>Leaf-off</td>
<td>1.57 (±0.30)</td>
<td>8.3 (±1.9)</td>
<td>-</td>
<td>60.5 (±7.4)</td>
<td>31.5 (±9.7)</td>
<td>8.0 (±4.1)</td>
</tr>
<tr>
<td>Combined</td>
<td></td>
<td>9.9 (±2.1)</td>
<td>0.3 (±0.2)</td>
<td>-</td>
<td>47 (±6)</td>
<td>31 (±3)</td>
<td>22 (±6)</td>
</tr>
</tbody>
</table>

* 100% MCP
Table 2-5. Forest composition (%) within individual leaf-on seasonal home ranges for 18 marten (15 M, 3 F) from 1 November 2010-15 October 2012 in northern New Hampshire. Mean (±) home range (HR) size, and percent forest type within male, female and combined home ranges during for 2 leaf-on seasons.

<table>
<thead>
<tr>
<th>Marten</th>
<th>Season</th>
<th>HR Size</th>
<th>Regen (%)</th>
<th>Lowland Conifer/Shrub (%)</th>
<th>Hardwood (%)</th>
<th>Mixed (%)</th>
<th>Softwood (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F5</td>
<td>Leaf-on 1</td>
<td>1.65</td>
<td>7</td>
<td>0</td>
<td>55</td>
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<tr>
<td>F9</td>
<td>Leaf-on 1</td>
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<td>0</td>
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<td>Leaf-on 1</td>
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<td>0</td>
<td>62</td>
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<td>5</td>
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<tr>
<td>M3*</td>
<td>Leaf-on 1</td>
<td>5.31</td>
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<td>0</td>
<td>42</td>
<td>25</td>
<td>33</td>
</tr>
<tr>
<td>M5</td>
<td>Leaf-on 1</td>
<td>5.55</td>
<td>12</td>
<td>0</td>
<td>36</td>
<td>25</td>
<td>39</td>
</tr>
<tr>
<td>M6</td>
<td>Leaf-on 1</td>
<td>2.33</td>
<td>22</td>
<td>2</td>
<td>34</td>
<td>52</td>
<td>12</td>
</tr>
<tr>
<td>M7</td>
<td>Leaf-on 1</td>
<td>1.98</td>
<td>2</td>
<td>0</td>
<td>64</td>
<td>24</td>
<td>12</td>
</tr>
<tr>
<td>M8</td>
<td>Leaf-on 1</td>
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<td>46</td>
<td>1</td>
<td>87</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>M10</td>
<td>Leaf-on 1</td>
<td>2.22</td>
<td>5</td>
<td>0</td>
<td>45</td>
<td>32</td>
<td>23</td>
</tr>
<tr>
<td>M11</td>
<td>Leaf-on 1</td>
<td>2.19</td>
<td>20</td>
<td>0</td>
<td>81</td>
<td>17</td>
<td>2</td>
</tr>
<tr>
<td>F17</td>
<td>Leaf-on 2</td>
<td>2.04</td>
<td>15</td>
<td>4</td>
<td>54</td>
<td>29</td>
<td>14</td>
</tr>
<tr>
<td>M1</td>
<td>Leaf-on 2</td>
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<td>0</td>
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<td>49</td>
<td>26</td>
</tr>
<tr>
<td>M6</td>
<td>Leaf-on 2</td>
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<td>21</td>
<td>2</td>
<td>27</td>
<td>55</td>
<td>16</td>
</tr>
<tr>
<td>M10</td>
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<td>0</td>
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<td>29</td>
<td>42</td>
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<td>3</td>
<td>63</td>
<td>24</td>
<td>10</td>
</tr>
<tr>
<td>M15</td>
<td>Leaf-on 2</td>
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<td>0</td>
<td>75</td>
<td>24</td>
<td>1</td>
</tr>
<tr>
<td>M16</td>
<td>Leaf-on 2</td>
<td>2.53</td>
<td>10</td>
<td>2</td>
<td>58</td>
<td>29</td>
<td>11</td>
</tr>
<tr>
<td>M17*</td>
<td>Leaf-on 2</td>
<td>0.95</td>
<td>13</td>
<td>5</td>
<td>59</td>
<td>29</td>
<td>8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sex</th>
<th>Season</th>
<th>HR Size</th>
<th>Regen (%)</th>
<th>Lowland Conifer/Shrub (%)</th>
<th>Hardwood (%)</th>
<th>Mixed (%)</th>
<th>Softwood (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td></td>
<td>3.19 (±0.44)</td>
<td>14.7 (±3.0)</td>
<td>1.0 (±0.4)</td>
<td>52.5 (±5.2)</td>
<td>30.5 (±3.2)</td>
<td>16.1 (±3.5)</td>
</tr>
<tr>
<td>Female</td>
<td>Leaf-on</td>
<td>1.54 (±0.33)</td>
<td>12.7 (±2.8)</td>
<td>1.3 (±1.3)</td>
<td>68.0 (±13.5)</td>
<td>25.0 (±10.6)</td>
<td>6.0 (±4.2)</td>
</tr>
<tr>
<td>Combined</td>
<td></td>
<td>14.4 (±2.5)</td>
<td>1.1 (±0.4)</td>
<td>55.1 (±4.9)</td>
<td>29.6 (±3.1)</td>
<td>14.4 (±3.1)</td>
<td></td>
</tr>
</tbody>
</table>

* 100% MCP
Table 2-6. The total number of parameters (K), log likelihood statistic (logLik), \( \text{AIC}_c \) score, delta \( \text{AIC}_c \), and model weight for top competing seasonal landscape scale models (i.e., delta \( \text{AIC}_c \) scores <2), and the estimates, standard error (SE), z value and probability of the z value being >0 for the model-averaged coefficients. Marten minimized regenerating forests within their home range during both seasons and included more hardwood forest during leaf-on seasons.

### Leaf-off Season

<table>
<thead>
<tr>
<th>Model Selection based on ( \text{AIC}_c )</th>
<th>K</th>
<th>logLik</th>
<th>( \text{AIC}_c )</th>
<th>Delta</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full</td>
<td>6</td>
<td>-72.04</td>
<td>156.13</td>
<td>0</td>
<td>0.71</td>
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<tr>
<td>Regenerating Forest</td>
<td>3</td>
<td>-75.95</td>
<td>157.91</td>
<td>1.78</td>
<td>0.29</td>
</tr>
</tbody>
</table>

| Model-averaged coefficients:                | Estimate | SE   | z value | Pr(>|z|) |
|---------------------------------------------|----------|------|---------|---------|
| (Intercept)                                 | -56.477  | 46.558 | 1.213   | 0.225   |
| Regenerating Forest                         | -10.485  | 3.834 | 2.735   | 0.006   |
| Hardwood Forest                             | 76.484   | 37.364 | 2.047   | 0.041   |
| Mixed-wood Forest                           | 75.223   | 37.429 | 2.010   | 0.044   |
| Softwood Forest                             | 74.714   | 37.246 | 2.006   | 0.045   |

### Leaf-on Season

<table>
<thead>
<tr>
<th>Model Selection based on ( \text{AIC}_c )</th>
<th>K</th>
<th>logLik</th>
<th>( \text{AIC}_c )</th>
<th>Delta</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardwood + Regenerating</td>
<td>4</td>
<td>-83.14</td>
<td>174.33</td>
<td>0</td>
<td>0.55</td>
</tr>
<tr>
<td>Hardwood + Mixed + Softwood</td>
<td>5</td>
<td>-82.99</td>
<td>176.04</td>
<td>1.71</td>
<td>0.23</td>
</tr>
<tr>
<td>Hardwood + Regenerating + Softwood</td>
<td>5</td>
<td>-83.08</td>
<td>176.23</td>
<td>1.9</td>
<td>0.21</td>
</tr>
</tbody>
</table>

| Model-averaged coefficients                  | Estimate | SE   | z value | Pr(>|z|) |
|---------------------------------------------|----------|------|---------|---------|
| (Intercept)                                 | -4.353   | 1.349 | 3.226   | 0.001   |
| Hardwood Forest                             | 3.812    | 1.810 | 2.106   | 0.035   |
| Regenerating Forest                         | -9.894   | 2.928 | 3.379   | 0.001   |
| Mixed-wood Forest                           | 1.612    | 2.917 | 0.553   | 0.581   |
| Softwood Forest                             | -0.987   | 2.862 | 0.345   | 0.730   |
positioned their home ranges during leaf-off season to include significantly less regenerating forest \( (\beta = -10.49, P = 0.006) \) compared to randomly generated home ranges, and there was little difference between selection of mature forest types (Table 2-6). There were 3 top competing models for the landscape-scale leaf-on analysis, and the top model "Hardwood + Regenerating" had the fewest parameters (4) providing evidence that these 2 variables best explained home range composition (Table 2-6). During leaf-on seasons marten selected against regenerating forest \( (\beta = -9.89, P = 0.001) \) and included more hardwood forest \( (\beta = 3.81, P = 0.035) \) within their home ranges compared to randomly generated home ranges (Table 2-6). There was little evidence for selection of mixed-wood \( (\beta = 1.61, P = 0.581) \) and softwood \( (\beta = -0.99, P = 0.730; \) Table 2-6) forest.

**Stand Scale Habitat Use**

There were 409 leaf-off and 492 leaf-on locations available for 16 (11 M, 5 F) home ranges \( (n = 33) \) for the stand scale analysis; 12 marten contributed >1 season. The average stand composition at used locations during leaf-off seasons ranged from 13-74% hardwood, 10-72% mixed-wood, 2-75% softwood, 0-3% lowland conifer/shrub forest, and 0-20% regenerating forest (Table 2-7); stand composition during leaf-on seasons was 21-82% hardwood, 12-55% mixed-wood, 0-41% softwood, 0-5% lowland conifer/shrub and 2-33% regenerating forest (Table 2-8). Female marten had 26 and 27% less regenerating forest than males within used locations during leaf-off \( (\bar{X} = 6.4 \pm 2.7 \%) \) and leaf-on \( (\bar{X} = 9.2 \pm 3.7 \%) \) seasons, respectively, but sample size was too small to make comparisons (Tables 2-7 and 2-8).
Table 2-7. Average stand composition (%) within buffered leaf-off telemetry locations for 15 marten (11 M, 4 F) from 1 November 2010-15 October 2012 in northern New Hampshire. Mean (±) number of locations (n), and percent stand for male, female and combined buffered telemetry locations during for 2 leaf-off seasons.

<table>
<thead>
<tr>
<th>Marten</th>
<th>Season</th>
<th>n</th>
<th>Regen (%)</th>
<th>Conifer Lowland/Shrub (%)</th>
<th>Hardwood (%)</th>
<th>Mixed (%)</th>
<th>Softwood (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F4</td>
<td>Leaf-off 1</td>
<td>24</td>
<td>12</td>
<td>0</td>
<td>48</td>
<td>42</td>
<td>10</td>
</tr>
<tr>
<td>F5</td>
<td>Leaf-off 1</td>
<td>29</td>
<td>2</td>
<td>0</td>
<td>37</td>
<td>62</td>
<td>2</td>
</tr>
<tr>
<td>M1</td>
<td>Leaf-off 1</td>
<td>28</td>
<td>2</td>
<td>0</td>
<td>32</td>
<td>66</td>
<td>2</td>
</tr>
<tr>
<td>M3</td>
<td>Leaf-off 1</td>
<td>31</td>
<td>10</td>
<td>0</td>
<td>25</td>
<td>45</td>
<td>29</td>
</tr>
<tr>
<td>M5</td>
<td>Leaf-off 1</td>
<td>23</td>
<td>3</td>
<td>0</td>
<td>15</td>
<td>10</td>
<td>75</td>
</tr>
<tr>
<td>M7*</td>
<td>Leaf-off 1</td>
<td>18</td>
<td>12</td>
<td>2</td>
<td>34</td>
<td>50</td>
<td>14</td>
</tr>
<tr>
<td>F5</td>
<td>Leaf-off 2</td>
<td>31</td>
<td>2</td>
<td>0</td>
<td>29</td>
<td>44</td>
<td>27</td>
</tr>
<tr>
<td>F9</td>
<td>Leaf-off 2</td>
<td>20</td>
<td>10</td>
<td>0</td>
<td>74</td>
<td>24</td>
<td>2</td>
</tr>
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<td>M1</td>
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<td>2</td>
<td>0</td>
<td>27</td>
<td>45</td>
<td>29</td>
</tr>
<tr>
<td>M5</td>
<td>Leaf-off 2</td>
<td>27</td>
<td>1</td>
<td>0</td>
<td>25</td>
<td>23</td>
<td>52</td>
</tr>
<tr>
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<td>30</td>
<td>18</td>
<td>3</td>
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<td>72</td>
<td>8</td>
</tr>
<tr>
<td>M8*</td>
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<td>20</td>
<td>0</td>
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<td>11</td>
<td>33</td>
</tr>
<tr>
<td>M10</td>
<td>Leaf-off 2</td>
<td>35</td>
<td>0</td>
<td>0</td>
<td>13</td>
<td>33</td>
<td>54</td>
</tr>
<tr>
<td>M11</td>
<td>Leaf-off 2</td>
<td>35</td>
<td>15</td>
<td>0</td>
<td>60</td>
<td>32</td>
<td>8</td>
</tr>
<tr>
<td>M15*</td>
<td>Leaf-off 2</td>
<td>15</td>
<td>13</td>
<td>0</td>
<td>73</td>
<td>27</td>
<td>0</td>
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</table>

<table>
<thead>
<tr>
<th>Sex</th>
<th>Season</th>
<th>n</th>
<th>Regen (%)</th>
<th>Lowland Conifer/Shrub (%)</th>
<th>Hardwood (%)</th>
<th>Mixed (%)</th>
<th>Softwood (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td></td>
<td>27 (±2)</td>
<td>8.6 (±2.2)</td>
<td>0.5 (±0.3)</td>
<td>34.3 (±6.0)</td>
<td>37.7 (±6.1)</td>
<td>27.5 (±7.3)</td>
</tr>
<tr>
<td>Female</td>
<td>Leaf-off</td>
<td>26 (±2)</td>
<td>6.4 (±2.7)</td>
<td>-</td>
<td>47.1 (±9.8)</td>
<td>42.6 (±7.8)</td>
<td>10.4 (±6.0)</td>
</tr>
<tr>
<td>Combined</td>
<td></td>
<td>26 (±2)</td>
<td>8.0 (±1.7)</td>
<td>0.3 (±0.2)</td>
<td>37.7 (±5.2)</td>
<td>39.0 (±4.8)</td>
<td>22.9 (±5.9)</td>
</tr>
</tbody>
</table>

* 100% MCP
Table 2-8. Average stand composition (%) within buffered leaf-on telemetry locations for 15 marten (11 M, 4 F) from 1 November 2010-15 October 2012 in northern New Hampshire. Mean (±) number of locations (n), and percent stand for male, female and combined buffered telemetry locations during for 2 leaf-on seasons.

<table>
<thead>
<tr>
<th>Marten</th>
<th>Season</th>
<th>n</th>
<th>Regen (%)</th>
<th>Conifer Lowland/Shrub (%)</th>
<th>Hardwood (%)</th>
<th>Mixed (%)</th>
<th>Softwood (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F5</td>
<td>Leaf-on 1</td>
<td>33</td>
<td>15</td>
<td>0</td>
<td>64</td>
<td>32</td>
<td>4</td>
</tr>
<tr>
<td>F9</td>
<td>Leaf-on 1</td>
<td>27</td>
<td>2</td>
<td>0</td>
<td>82</td>
<td>15</td>
<td>2</td>
</tr>
<tr>
<td>M1</td>
<td>Leaf-on 1</td>
<td>34</td>
<td>7</td>
<td>1</td>
<td>43</td>
<td>51</td>
<td>5</td>
</tr>
<tr>
<td>M3*</td>
<td>Leaf-on 1</td>
<td>16</td>
<td>12</td>
<td>0</td>
<td>43</td>
<td>34</td>
<td>23</td>
</tr>
<tr>
<td>M5</td>
<td>Leaf-on 1</td>
<td>24</td>
<td>13</td>
<td>0</td>
<td>39</td>
<td>20</td>
<td>41</td>
</tr>
<tr>
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<td>13</td>
<td>3</td>
<td>35</td>
<td>53</td>
<td>9</td>
</tr>
<tr>
<td>M7</td>
<td>Leaf-on 1</td>
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<td>5</td>
<td>0</td>
<td>55</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>M8</td>
<td>Leaf-on 1</td>
<td>30</td>
<td>33</td>
<td>0</td>
<td>70</td>
<td>12</td>
<td>18</td>
</tr>
<tr>
<td>M10</td>
<td>Leaf-on 1</td>
<td>26</td>
<td>4</td>
<td>0</td>
<td>67</td>
<td>20</td>
<td>12</td>
</tr>
<tr>
<td>M11</td>
<td>Leaf-on 1</td>
<td>30</td>
<td>24</td>
<td>5</td>
<td>73</td>
<td>19</td>
<td>3</td>
</tr>
<tr>
<td>F17</td>
<td>Leaf-on 2</td>
<td>28</td>
<td>10</td>
<td>1</td>
<td>61</td>
<td>33</td>
<td>6</td>
</tr>
<tr>
<td>M1</td>
<td>Leaf-on 2</td>
<td>32</td>
<td>12</td>
<td>0</td>
<td>21</td>
<td>48</td>
<td>32</td>
</tr>
<tr>
<td>M6</td>
<td>Leaf-on 2</td>
<td>30</td>
<td>16</td>
<td>5</td>
<td>28</td>
<td>55</td>
<td>12</td>
</tr>
<tr>
<td>M10</td>
<td>Leaf-on 2</td>
<td>23</td>
<td>5</td>
<td>0</td>
<td>38</td>
<td>26</td>
<td>35</td>
</tr>
<tr>
<td>M11</td>
<td>Leaf-on 2</td>
<td>29</td>
<td>18</td>
<td>3</td>
<td>65</td>
<td>21</td>
<td>10</td>
</tr>
<tr>
<td>M15</td>
<td>Leaf-on 2</td>
<td>29</td>
<td>12</td>
<td>0</td>
<td>66</td>
<td>34</td>
<td>0</td>
</tr>
<tr>
<td>M16</td>
<td>Leaf-on 2</td>
<td>29</td>
<td>6</td>
<td>0</td>
<td>67</td>
<td>28</td>
<td>6</td>
</tr>
<tr>
<td>M17*</td>
<td>Leaf-on 2</td>
<td>20</td>
<td>10</td>
<td></td>
<td>61</td>
<td>34</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sex</th>
<th>Season</th>
<th>n</th>
<th>Regen (%)</th>
<th>Lowland Conifer/Shrub (%)</th>
<th>Hardwood (%)</th>
<th>Mixed (%)</th>
<th>Softwood (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>Leaf-on</td>
<td>27</td>
<td>12.6 (±2.0)</td>
<td>1.3 (±0.5)</td>
<td>51.5 (±4.4)</td>
<td>32.0 (±3.6)</td>
<td>15.2 (±3.3)</td>
</tr>
<tr>
<td>Female</td>
<td>Leaf-on</td>
<td>29</td>
<td>9.2 (±3.7)</td>
<td>0.2 (±0.2)</td>
<td>69.2 (±6.6)</td>
<td>26.8 (±5.7)</td>
<td>3.9 (±0.9)</td>
</tr>
<tr>
<td>Combined</td>
<td></td>
<td>28</td>
<td>12.0 (±1.8)</td>
<td>1.1 (±0.4)</td>
<td>54.4 (±4.1)</td>
<td>31.2 (±3.1)</td>
<td>13.3 (±2.9)</td>
</tr>
</tbody>
</table>

* 100% MCP
Table 2-9. The total number of parameters (K), log likelihood statistic (logLik), AICc score, delta AICc, and model weight for top competing seasonal stand scale models (i.e., delta AICc scores <2), and the estimates, standard error (SE), z value and probability of the z value being >0 for the model-averaged coefficients. Marten selected mixed-wood stands and avoided hardwood and regenerating stands during leaf-off seasons.

### Leaf-off season

<table>
<thead>
<tr>
<th>Model Selection based on AICc</th>
<th>K</th>
<th>logLik</th>
<th>AICc</th>
<th>Delta</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixed + Softwood</td>
<td>4</td>
<td>-1061.29</td>
<td>2130.6</td>
<td>0</td>
<td>0.19</td>
</tr>
<tr>
<td>Hardwood + Mixed</td>
<td>4</td>
<td>-1061.39</td>
<td>2130.8</td>
<td>0.2</td>
<td>0.17</td>
</tr>
<tr>
<td>Hardwood + Softwood</td>
<td>4</td>
<td>-1061.55</td>
<td>2131.1</td>
<td>0.51</td>
<td>0.15</td>
</tr>
<tr>
<td>Mixed + Regenerating + Softwood</td>
<td>5</td>
<td>-1060.75</td>
<td>2131.5</td>
<td>0.91</td>
<td>0.12</td>
</tr>
<tr>
<td>Hardwood + Mixed + Regenerating</td>
<td>5</td>
<td>-1060.8</td>
<td>2131.6</td>
<td>1.03</td>
<td>0.11</td>
</tr>
<tr>
<td>Hardwood + Regenerating + Softwood</td>
<td>5</td>
<td>-1060.92</td>
<td>2131.8</td>
<td>1.26</td>
<td>0.1</td>
</tr>
<tr>
<td>Hardwood</td>
<td>3</td>
<td>-1063.16</td>
<td>2132.3</td>
<td>1.72</td>
<td>0.08</td>
</tr>
<tr>
<td>Hardwood + Mixed + Softwood</td>
<td>5</td>
<td>-1061.26</td>
<td>2132.5</td>
<td>1.95</td>
<td>0.07</td>
</tr>
</tbody>
</table>

| Model-averaged coefficients | Estimate | SE     | z value | Pr(|z|) |
|-----------------------------|----------|--------|---------|-------|
| (Intercept)                 | -1.655   | 0.543  | 3.045   | 0.002 |
| Mixed-Wood Forest           | 0.604    | 0.591  | 1.022   | 0.307 |
| Softwood Forest             | 0.131    | 0.682  | 0.193   | 0.847 |
| Hardwood Forest             | -0.426   | 0.613  | 0.695   | 0.487 |
| Regenerating Forest         | -0.331   | 0.312  | 1.060   | 0.289 |

### Leaf-on season

<table>
<thead>
<tr>
<th>Model Selection based on AICc</th>
<th>K</th>
<th>logLik</th>
<th>AICc</th>
<th>Delta</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Null Model</td>
<td>2</td>
<td>-1322.27</td>
<td>2648.5</td>
<td>0</td>
<td>0.43</td>
</tr>
<tr>
<td>Hardwood</td>
<td>3</td>
<td>-1322.03</td>
<td>2650.0</td>
<td>1.53</td>
<td>0.2</td>
</tr>
<tr>
<td>Mixed</td>
<td>3</td>
<td>-1322.13</td>
<td>2650.2</td>
<td>1.72</td>
<td>0.18</td>
</tr>
<tr>
<td>Softwood</td>
<td>3</td>
<td>-1322.13</td>
<td>2650.2</td>
<td>1.73</td>
<td>0.18</td>
</tr>
</tbody>
</table>

| Model-averaged coefficients | Estimate | SE     | z value | Pr(|z|) |
|-----------------------------|----------|--------|---------|-------|
| (Intercept)                 | -1.706   | 0.150  | 11.36   | <2e-16|
| Hardwood Forest             | 0.096    | 0.138  | 0.693   | 0.488 |
| Mixed Forest                | -0.086   | 0.162  | 0.533   | 0.594 |
| Softwood Forest             | -0.101   | 0.192  | 0.524   | 0.600 |
Selection was not random during the leaf-off season (Table 2-9), yet during the leaf-on season the null hypothesis was the top competing model (Table 2-9). There were 8 top competing models for the stand scale leaf-off analysis; the “Hardwood” model had the fewest parameters (3) suggesting this variable was an important predictor (Table 2-9). During leaf-off seasons marten had less deciduous ($\beta = -0.426, P = 0.487$) and regenerating ($\beta = -0.331, P = 0.289$) stands within used locations and more mixed-wood ($\beta = 0.604, P = 0.307$) and softwood ($\beta = 0.131, P = 0.847$) stands compared to randomly generated locations (Table 2-9). There were 4 top competing models for the stand scale leaf-on analysis and the null model was the top competing model indicating that no pronounced stand scale selection occurred during leaf-on seasons (Table 2-9).

**Home Range Composition Analysis**

There were 2 top competing models that best explained the effect of habitat composition on home range size: the top model had fewer parameters (5), and included regenerating and softwood stands, and was averaged with the second model to include seasonal influence on home range size (Table 2-10). Specifically, home range size was larger during leaf-on seasons ($\beta = 0.507, P = 0.259$), and when there was a greater proportion of regenerating ($\beta = 0.104, P = 0.0001$) and softwood ($\beta = 0.054, P = 0.0003$) stands (Table 2-10).
Table 2-10. The total number of parameters (K), log likelihood statistic (logLik), AICc score, delta AICc, and model weight for top competing home range composition models (i.e., delta AICc scores <2), and the estimates, standard error (SE), z value and probability of the z value being >0 for the model-averaged coefficients. Results indicate that marten home range size was significantly larger when marten had a greater proportion of softwood and regenerating forest in their home range and also larger during leaf-on seasons.

<table>
<thead>
<tr>
<th>Component models:</th>
<th>K</th>
<th>logLik</th>
<th>AICc</th>
<th>Delta</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regenerating + Softwood</td>
<td>5</td>
<td>-60.18</td>
<td>132.58</td>
<td>0</td>
<td>0.68</td>
</tr>
<tr>
<td>Regenerating + Softwood + Season</td>
<td>6</td>
<td>-59.45</td>
<td>134.13</td>
<td>1.55</td>
<td>0.32</td>
</tr>
</tbody>
</table>

| Model-averaged coefficients:       | Estimate | SE  | z value | Pr(>|z|) |
|------------------------------------|----------|-----|---------|---------|
| (Intercept)                        | 0.3376   | 0.5875 | 0.575 | 0.5655 |
| Regenerating Forest                | 0.1037   | 0.0270 | 3.846 | 0.0001 |
| Softwood Forest                    | 0.0541   | 0.0149 | 3.631 | 0.0003 |
| Leaf-on Season                     | 0.5066   | 0.4486 | 1.129 | 0.2588 |
Discussion

The spatial ecology of marten in northern New Hampshire was similar to that described in other studies in the northeastern United States, and across its geographic range. Overall, males had larger home ranges and movements than females which is the trend throughout North America (Powell et al. 2003). Aggregate home range size of males was 92% smaller than those recorded in a forest reserve in New York (5.67 km\(^2\) ± 3.64 SD); females were 56% smaller (2.59 km\(^2\) ± 1.10 SD; Jensen 2012). Male home range size was 23% larger than those measured in a forest reserve in Maine during winter (1.95 km\(^2\) ± 0.92 SD), and summer ranges were 2% and 7% smaller than males (3.25 km\(^2\) ± 1.42 SD) and females (1.65 km\(^2\) ± 0.86 SD), respectively (Payer and Harrison 1999).

Male and female home range size in winter was 67% smaller than in an untrapped industrial forest in Maine (4.23 km\(^2\) ± 2.06 SD); females were 37% smaller (2.45 km\(^2\) ± 1.47 SD) and during summer, male and female range size was 53% and 87% smaller (male = 4.89 km\(^2\) ± 2.23 SD, female = 2.88 km\(^2\) ± 1.15 SD; Payer and Harrison 1999).

Male marten had smaller leaf-off home ranges and although sample size was low, female home range size was similar in both seasons. The same trend towards smaller home ranges during winter also occurred in trapped and untrapped industrial forests and an adjacent forest reserve in Maine; however, there was minimal seasonal difference in home range size in the forest reserve (Phillips et al. 1998, Payer 1999). Further, HRO that was variable between consecutive (overall \(\bar{X} = 66\)) and corresponding (overall \(\bar{X} = 57\)) seasons was similar to measures of seasonal fidelity in varied habitat in Maine (consecutive \(\bar{X} = 67.4\), Payer et al. 2004), but lower than conifer-dominated sites in Wyoming (consecutive \(\bar{X} = 74.8\), O’Doherty et al. 1997) and Newfoundland (annual \(\bar{X} =

76
suggesting that these home range shifts are common. Importantly, the consecutive HRO was considered high based on previous measurements using computer simulations (65%; O’Doherty et al. 1997).

Direct comparisons of fidelity measures can be made between summer and winter and between winters as sampling effort and error were reasonably similar (Table 2-3). Marten in New Hampshire exhibited high seasonal fidelity and presumably made subtle home range shifts to meet seasonal needs. Marten with home ranges comprised of >10% partially harvested stands had larger leaf-off home ranges than marten in uncut forests; they shifted home range position to include more uncut forest during winter (Fuller and Harrison 2005), and females had lower fidelity compared to those without partial harvests (Fuller and Harrison 2000). Marten living in harvested landscapes likely need to reorient their home range seasonally to adjust to loss of canopy cover and this was most pronounced for marten living in partially harvested forest (Fuller and Harrison 2005). However, home range expansion might be prohibitive if high population density increases territoriality among conspecifics (Fuller and Harrison 2005).

Spatial ecology differences in New Hampshire and Maine (Fuller and Harrison 2005) was probably related to spatial configuration and composition of mature and regenerating forest. Because marten position their home range to include older contiguous forest (>6 m tall; Katnik 1992, Chapin et al. 1998), the spatial arrangement of suitable and unsuitable (i.e., regenerating forest) habitat can influence the size and shape of home ranges. The New Hampshire study site had a greater proportion of mature forest (75%) compared to the partial harvest study area in Maine (35%; Fuller and Harrison 2000) and it was aggregated along high elevation ridgelines with timber harvests at lower
elevation. Presumably, the contiguous and unfragmented residual forest provided optimal winter habitat and supported a high density population (see Chapter 1).

The prediction that marten would select for mixed-wood and coniferous forests and against regenerating forest during winter was supported by both the home range and stand scale analyses. Marten positioned their home ranges to include all mature forest types with highest selection for mixed-wood stands during winter. Landscape scale selection was more pronounced than stand scale during both seasons. The top performing landscape models indicated that marten situated home ranges within a mosaic of mixed-wood, softwood, and hardwood forests and avoided regenerating forest during leaf-off seasons; during leaf-on seasons there was a higher proportion of hardwood forest with minimal use of regenerating forest. The tendency for higher selection at large spatial scales is consistent with research across marten range (Thompson et al. 2012), especially when landscapes are managed for timber production (Chapin et al. 1998, Hargis et al. 1999, Payer 1999, Potvin et al. 2000, Cheveau et al. 2013). Marten in New Hampshire selected strongly against regenerating forest at the landscape scale during both seasons, and past studies clearly identify selection against regenerating forest and that it is the least suitable (used) during winter (Thompson et al. 2012). The sampled landscape was comprised of 25% regenerating forest, which was close to the 30% threshold where occupancy sharply declines (Bissonette et al. 1997, Fuller 2006).

Marten also exhibited the greatest selection for deciduous and mixed-wood forest at the landscape scale during leaf-on seasons. Home range boundaries shifted to include more of these forest types and less regenerating and softwood forest. Leaf-on home ranges with a greater proportion of softwood and regenerating forest expanded to include
deciduous and mixed-wood forest types, whereas those with a greater proportion of mature deciduous and mixed-wood forest were smaller with greater seasonal overlap. Similarly, home range size and regenerating forest was positively correlated for marten in Maine (Payer 1999). Possible explanations for this trend are that higher small mammal abundance and diversity exists in deciduous and mixed-wood forests (Payer and Harrison 2004, Fuller et al. 2004), the lower canopy cover in harvested stands (Fuller and Harrison 2005), that wind farm construction caused disturbance and fragmentation, or reproductive behavior of males causes home range expansion. However, marten in Maine did not expand home range size during breeding season to increase access to females (Katnik et al. 1994). Smaller home ranges were associated with higher proportions of mature mixed forest in a conifer-dominated landscape in Quebec (Cheveau et al. 2013), and there was selection for mixed-wood forests in an industrial forest landscape in Maine (Katnik 1992).

Marten exhibited greater selection for mixed-wood and conifer stands and selected against regenerating and hardwood stands during leaf-off seasons, and no stand scale selection was detected during leaf-on seasons. Conversely, no seasonal selection for forest cover type was detected at the stand scale in a forest reserve in New York (Jensen 2012), or industrial and forest reserve sites in Maine (Chapin et al. 1997, Payer 1999). However, marten avoided recent clear-cuts year-round and used partially harvested stands less frequently during winter in Maine (Fuller and Harrison 2005). Regenerating cuts were avoided during winter in Ontario (Potvin et al. 2000) and in Quebec marten selected for mixed-wood stands during winter and avoided regenerating stands (Cheveau et al. 2013). Typically, stands with complex vertical and horizontal
structure (e.g., spruce budworm (*Choristoneura fumiferana*) regenerating stands), rather than forest type are important at the stand scale in cut or uncut landscapes (Payer and Harrison 2003, Payer and Harrison 2004), and mixed-wood stands in particular contain abundant structure (Payer and Harrison 2003). Because the forest type of regenerating stands was not available, it is unknown which types were avoided. However, hardwood species were harvested extensively within the study area and were the target of partial harvests, and these regenerating stands were probably under-represented because they were unrecognizable during the GIS digitization process (NHFG, unpublished data). It is likely that hardwood stands were avoided by marten during the winter because they were actually partial harvest stands and lacked the canopy cover required during winter (Payer and Harrison 2003, Fuller and Harrison 2005).

Density at our study site was moderate and high during both years and this could have influenced habitat selection (Thompson et al. 2012); indeed, the age structure and density of a population can influence selection (Paragi et al. 1996). While the exact age structure of the population is unknown, all marten included in the habitat selection analyses were >1 yr old and most were likely breeding individuals, inferring that habitat quality was high (Van Horne 1983). Further, the ratio of adult:juvenile captured during the 2-year study was 28:6 indicating the population was older.

Density could have reduced the fitness of younger adults (≥1 and ≤2 yr) by requiring them to use greater space and/or suboptimal habitats as this was observed for at least 2 marten during the study. One yearling male (M8) had longer leaf-off movements, larger home range size, and higher proportion of regenerating forest within its home range; it was in poor condition and died during its second winter. Another young
transient male (M6) had long daily movements and was often located in lowland conifer/shrub and regenerating forest up to 10 km from the study area; it was not included in habitat use analyses during this period as it had too few locations and was considered transient. However, it eventually established a home range the following season and was included in subsequent habitat selection analyses.

Female marten had less regenerating habitat within their home ranges and at telemetry locations, and home range size and movements were less variable compared to males. Likewise, females in an industrial forest in Maine had small home ranges and had less regenerating forest within their home range (Chapin et al. 1998). It is likely that females are more sensitive to habitat fragmentation and require high quality habitat to raise young (Katnik et al. 1994). Because contiguous forest is generally found at higher elevation in New Hampshire, it probably represents the highest quality habitat for survival and productivity.

Overall, the spatial ecology and habitat selection in New Hampshire was similar to that in other areas of northeastern North America. Home range size was slightly smaller than average for both sexes and marten exhibited greater selection at the landscape scale, selecting a mixture of mature forest and avoiding regenerating forest year-round, although regenerating forest was not avoided at the stand scale during leaf-on seasons. The preference for mixed-wood is a recurring theme as these forest types presumably provide critical annual resources (i.e., abundant prey, security, and structure for resting and denning; Thompson et al. 2012). Although, marten establish home ranges in forest composed primarily of softwood or deciduous forests, it is interesting to note that mixed-wood forest was an important predictor for occurrence at the ecoregional scale.
and that occupancy drops when deciduous forest comprises >69% of the landscape (Jensen 2012). Overall, the study area had deep snow which is the primary requirement for occupancy (Krohn et al. 1995, Kelly 2005, Carroll 2007, Jensen 2012), and it is likely that all the sampled landscape was suitable for marten. Further, reproduction was documented, and the population was comprised mostly of adults; both evidence that these landscapes are productive for marten in New Hampshire (see Chapter 1). However, because 25% of the landscape is comprised of early successional forest, increasing this habitat type and/or fragmentation on the landscape would likely reduce carrying capacity (Thompson and Harestad 1994, Payer and Harrison 1999). Further, partially harvested hardwood forest was common and underrepresented, and this habitat type is used less during winter (Payer and Harrison 2005). Forest management strategies should consider the age, size, and arrangement of suitable habitat on the landscape (Chapin et al. 1998) to ensure sustainable marten populations (Payer and Harrison 2003, Thompson et al. 2012).

Boreal and high elevation forest is predicted to decline regionally due to climate change and be limited to northwestern Maine and northern New Hampshire; deciduous forests are predicted to expand northward (Tang and Beckage 2010). While deciduous forests are important for marten (Payer et al. 2003, Poole et al. 2004, Dumyahn et al. 2007), occupancy increases with a higher percentage of mixed-wood and conifer forest at the ecoregional scale (Jensen 2012) and stands with a conifer component were important during winter. The aforementioned region is considered vital for providing connectivity from source populations in Maine to New Hampshire and Vermont (Jensen 2012), and could play an important role in maintaining local source populations if the recent trend of reduced snowfall persists (Carroll 2007). While natural disturbance within these habitats
is common (Sprugel 1976), greater wind speed creates more wind throw at high contrast edges compared to the interior forest (Raynor 1971). Wind power development creates high contrast edges along ridgelines which contributes to direct habitat loss and provides increased access for predators and competitors (see Chapter 4). Because this habitat is rare and important for marten long-term, maintaining the contiguous nature of this habitat is recommended.

This study is important as it was the first to document spatial ecology and habitat selection of marten at high elevations in New Hampshire. High elevation forests are old, contiguous, structurally complex, and contain deep snow (WAP 2005). Further, the terrain is rugged with extreme elevational gradients that were positively associated with occurrence in New York where terrain ruggedness was correlated with complex structure (i.e., boulders, fallen trees) that is important in marten ecology (Jensen 2012). The New Hampshire study site also contained steep slopes with abundant rocks and boulders that marten used frequently for resting, foraging, and denning throughout the year. It is possible that the combination of deep snow, rugged habitat, and older forest provides a unique local advantage for marten; indeed, the density and home range size of marten in this study were similar to a lower elevation, high latitude forest reserve in Maine which was considered prime habitat (Payer 1999).

Further studies of marten spatial ecology and habitat selection at higher elevation are needed as construction activities and habitat loss associated with wind power development affected temporal use of this habitat (see Chapter 3). Although, landscape selection was more pronounced, mixed-wood and coniferous stands were important at the stand scale during winter and regenerating and hardwood stands were avoided. Further,
dataloggers recorded obvious shifts to higher elevation and greater nocturnal use during winter which suggests that ground telemetry underestimates resource selection during leaf-off seasons (see Chapter 3). Incorporating nocturnal locations via GPS technology will be useful for resource selection studies to better understand stand scale selection.

Mature mixed-wood and coniferous stands at high elevation contain deeper snow (see Chapter 4) providing marten a competitive advantage over competing carnivores (Krohn et al. 2004), and mature stands contain abundant structure, taller trees, and higher canopy cover (Payer and Harrison 2003) important for predator avoidance (Hodgman et al. 1997), thermoregulation (Buskirk et al. 1989), and prey access (Sherburne and Bissonette 1994) during winter. Habitat loss along high elevation ridgelines would be additive to the effects of forest fragmentation occurring elsewhere on the landscape and the footprints associated with wind farm development may reduce long-term value at the local stand scale (Harrison 2011).
CHAPTER 3

IMPACT OF WIND FARM DEVELOPMENT ON USE OF HIGH-ELEVATION HABITAT BY AMERICAN MARTEN

Introduction

American marten currently are at their distributional edge in northern New England (Krohn et al. 2004); that has shifted temporarily due to climatic changes (Graham and Graham 1994). However, anthropogenic disturbances during the past 2 centuries have caused precipitous decline throughout the United States due to extensive logging, forest conversion to agriculture, and unregulated furbearer trapping (Silver 1957, Gibilsco 1994). Current and future threats to marten populations include logging, wind development, and climate change, with wind farm development as the most immediate threat to high elevation habitat (WAP 2005). Much of the current and proposed wind farm development in the northeast occurs along ridgelines where disturbance could destabilize fragile, high elevation forest communities that are characterized by long winters, short growing seasons, shallow and acidic soils, and frequent natural disturbances (Sprugel 1976). Impacts of wind farm development could be substantial within high elevation habitat as the rate of forest succession is slower compared to lower elevation habitats, and the associated fragmentation might reduce occupancy for forest-
sensitive species such as marten (Chapin et al. 1998, Hargis et al. 1999, Fuller 2006). Additionally, climate change models predict high elevation habitat to either disappear (Iverson and Prasad 2001) or become reduced regionally in the long-term (Tang and Beckage 2010).

Forest patch size, arrangement, and proximity to large contiguous forests influence local populations of marten (Chapin et al. 1998, Hargis et al. 1999). Marten are sensitive to landscape fragmentation, with occupancy rate dropping sharply in landscapes comprised of >30% non-forested habitat (Thompson and Harestad 1994, Hargis et al. 1999, Fuller 2006). They typically occupy forests with complex structure, trees >6 m in height, and >30% canopy (Katnik 1992, Thompson and Harestad 1994, Payer and Harrison 2003) that provide refuge from predators (Buskirk and Rugerrio 1994, Hodgman et al. 1997), thermoregulatory advantage (Buskirk et al. 1989), prey access (Sherburne and Bissonette 1994), and structure for denning and resting (Ruggerio et al. 1998). Seasonal use patterns indicate that marten require forests with highest canopy cover during winter (Steventon and Major 1982, Buskirk and Powell 1994, Hodgman et al. 1997, Fuller and Harrison 2005), with clear-cut and partially harvested stands with reduced basal area typically avoided except during summer months when canopy cover increases (Soutiere 1979, Steventon and Major 1982, Fuller and Harrison 2005). In northern New Hampshire contiguous forest is more common at higher elevations (WAP 2005), and habitat use models predict that marten prefer high elevation mixed and coniferous stands with deep snow (Kelly 2005, Carroll 2007). These forests contain the majority of mature forest in the state (WAP 2005) and older forests typically contain complex horizontal and vertical structure (Buskirk and Powell 1994, Payer and Harrison 2003).
2003). Further, logging restrictions and reduced exposure to fisher trapping at high elevation prevent fragmentation of suitable habitat and reduce incidental captures of marten in high elevation habitat (WAP 2005).

To date, there are no studies that document the impact of wind farm development on marten use of high elevation habitat despite an increasing number of wind farms planned in the northeast, and marten are listed as threatened in New Hampshire, endangered in Vermont, and projected to decline long-term in New York and Maine (Carroll 2007). Of concern is that wind farm construction and operation includes permanent roads (20-50 m wide) and turbine pads (80-100 m wide) that would fragment and reduce high elevation habitat and increase edge favored by many generalist species. Further, high elevation roads would presumably expose the forest to increased wind throw along road edges.

The objectives of this research were to document marten use of high elevation habitat and to assess the impacts of wind farm development on marten habitat use in these forests. It was predicted that marten use of high elevation habitat would decline during and after wind farm construction due to the associated disturbance, and fragmentation and habitat loss of high elevation habitat. Further, that there would be seasonal use of high elevation habitat, with greatest use during winter.

Methods

Remote Monitoring

The use of high elevation habitat on Kelsey and Owlhead Mountains by radio-marked marten was continuously monitored by ATS 4500S receiver/dataloggers that
detected and stored radio signals from 3 towers (north, middle, south; Fig. 3-1) within a prescribed area of ~8 km². Datalogger data included the Julian day, time (to the nearest min), and radio signal strength (40-154 dBm; higher values indicate stronger signals) for each marten detection. The study was divided temporally into construction and seasonal periods to test the hypotheses that wind farm construction and/or season affected marten presence and movement (Fig. 3-2). Monitoring of Pre-Construction began on 5 December 2010, construction on 12 February 2011, towers became operational on 12 November 2011, and monitoring ended on 23 December 2012. Five separate construction periods were defined initially, and the following year alike Operational Periods were used for temporal comparison (Table 1, Fig. 3-2). The seasonal periods were defined by local conditions with respect to leaf emergence and senescence (i.e., leaf-on = 16 May-15 October and leaf-off = 16 October-15 May) (Table 1, Fig. 3-2). As seasonal periods were longer, the wind farm construction and operational periods both nested within and overlapped them (Fig. 3-2).

Analysis of construction and seasonal periods in 2010-2012 included 11 marten (9M:2F) monitored for ≥3 construction periods for ≥30 days per period, and ≥2 seasonal periods for ≥35 days per period (Table 1). The number of marten fluctuated per monitoring period (4-9) and the range of detection frequency per period was 0-37,848 (Table 3-1). A power analysis was performed to determine the minimal number of days required per marten each period; all marten exceeded the minimum. Marten were included as a random effect in all models to minimize the magnitude of contribution and fluctuating sample size. All analyses were restricted to marten with home ranges containing high elevation habitat based on standard evaluation of home range from VHF.
Fig. 3-1. Location of 3 remote telemetry dataloggers (south, middle, and north) on Kelsey Mountain used to monitor ~8 km² of high elevation habitat (>823 m).
Fig. 3-2. Monitoring calendar for years (2010-2012), leaf seasons, and construction periods. Operational periods correspond to the construction periods of the previous year as do leaf seasons, allowing for relative comparisons between wind farm development phases and seasons. The dates of the construction periods are delineated by dashed lines and the dates of the seasonal periods are solid. The “Pre-Construction” period and “Leaf-off 1” season were the
Table 3-1. Summary of construction and seasonal periods, length (days), range (total) of raw detection data, and sample size of marten monitored each period.

<table>
<thead>
<tr>
<th>Construction Periods</th>
<th>Length (days)</th>
<th>Range (total)</th>
<th># of marten</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Construction (5 December 2010-11 February 2011)*</td>
<td>69</td>
<td>67-2098 (3876)</td>
<td>5</td>
</tr>
<tr>
<td>Road Clearing (12 February-31 March 2011)</td>
<td>48</td>
<td>99-5178 (7791)</td>
<td>5</td>
</tr>
<tr>
<td>Construction Lull (1 April-19 May 2011)</td>
<td>49</td>
<td>138-2450 (5491)</td>
<td>5</td>
</tr>
<tr>
<td>Road Construction (20 May-31 August 2011)</td>
<td>104</td>
<td>0-661 (1936)</td>
<td>9</td>
</tr>
<tr>
<td>Tower Construction (1 September-11 November 2011)</td>
<td>72</td>
<td>1-4362 (9540)</td>
<td>7</td>
</tr>
<tr>
<td>Operational 1 (12 November 2011-11 February 2012)</td>
<td>92</td>
<td>262-21166 (48714)</td>
<td>7</td>
</tr>
<tr>
<td>Operational 2 (12 February-31 March 2012)</td>
<td>48</td>
<td>303-5160 (13943)</td>
<td>6</td>
</tr>
<tr>
<td>Operational 3 (1 April-19 May 2012), 9</td>
<td>49</td>
<td>14-10018 (18153)</td>
<td>5</td>
</tr>
<tr>
<td>Operational 4 (20 May-31 August 2012)</td>
<td>104</td>
<td>5-4398 (7504)</td>
<td>5</td>
</tr>
<tr>
<td>Operational 5 (1 September-11 November 2012)</td>
<td>72</td>
<td>5-1127 (1427)</td>
<td>4</td>
</tr>
<tr>
<td>Operational 6 (12 November 2012-23 December 2012)**</td>
<td>42</td>
<td>38-882 (1309)</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Seasonal Periods</th>
<th>Length (days)</th>
<th>Range (total)</th>
<th># of marten</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaf-off 1 (5 December 2010-15 May 2011)*</td>
<td>162</td>
<td>605-9674 (16963)</td>
<td>5</td>
</tr>
<tr>
<td>Leaf-on 1 (16 May 2011-15 October 2011)</td>
<td>153</td>
<td>0-2999 (6068)</td>
<td>9</td>
</tr>
<tr>
<td>Leaf-off 2 (16 October 2011-15 May 2012)</td>
<td>213</td>
<td>263-37848 (85558)</td>
<td>8</td>
</tr>
<tr>
<td>Leaf-on 2 (16 May 2012-15 October 2012)</td>
<td>153</td>
<td>6-4701 (9143)</td>
<td>6</td>
</tr>
<tr>
<td>Leaf-off 3 (16 October 2012-23 December 2012)**</td>
<td>69</td>
<td>42-1361 (1952)</td>
<td>4</td>
</tr>
</tbody>
</table>

* Dataloggers began monitoring on 5 December 2010.
** Dataloggers ended monitoring on 23 December 2012.
telemetry (minimum of 24 per leaf-off [16 October-15 May] and 24 per leaf-on season [16 May-15 October]) and live-trapping followed protocol described in Chapter 1.

**Datalogger Tests**

Reception tests for radio-collars were conducted throughout the study area to determine the efficacy and range of the dataloggers and for data interpretation. Tests were conducted as followed: 3 radio-collars were attached to a waist belt and worn while conducting fieldwork. Movement paths were recorded via the track log function on a GPS, and the time of the GPS was synchronized to that of the dataloggers. The track logs were then uploaded into GIS software and cross-referenced with datalogger data to create a spatio-temporal database consisting of detections and non-detections; detection data included the tower, collar frequency, and the signal strength of each collar. The slope, aspect, elevation, distance from datalogger towers, and viewshed (a line-of-site calculation to quantify view) were calculated for each data point in ArcGIS 10 (ESRI 2011); the best fitting logistic and linear regression models were performed with JMP Pro statistical software (JMP 2012) to predict presence/absence and signal strength (proximity) of verified detections. Eleven models were evaluated for both analyses incorporating various combinations of the listed variables. Detection probability and proximity maps were generated with the raster calculator tool in ArcGIS 10 (ESRI 2011) using the best fitting logistic and linear regression models from these data.

Additionally, telemetry locations and camera trap captures ([n = 303, 824-1037 m elevation] [n = 495, 550-822 m elevation]) were cross-referenced with datalogger data to determine monitoring accuracy and provide a detection probability map based on location
data for comparison with test data. Verified detections (i.e., detection in high elevation habitat), false negatives (i.e., no detection when in high elevation habitat), and false positives (i.e., detection within 15 min when not in high elevation habitat) were calculated to evaluate the accuracy of presence/absence data. Detection accuracy relative to camera and VHF telemetry locations and datalogger detections were assessed at 5 temporal scales (detections the same day, ±2 hr, ±1 hr, ±30 min, and ±15 min); marten would typically move within 1 day, ±15 min incorporated telemetry error and movement, and scales between were included to detect trends. Accuracy was measured as the percentage of verified detections for each scale compared to the total. Logistic regression was used to measure the relationships among detection accuracy, the elevation of marten locations, and the number of datalogger detections for the day, and false positives were expressed as the percentage of locations <823 m detected by dataloggers ±15 min. Detection probability maps were created from the best fitting logistic model using the same methods and variables employed for datalogger testing. Further, activity data was available for location data (n = 45 moving, n = 55 stationary) and was used to measure its effect on detection probability.

Data Imputation

Remote monitoring was sporadic during the Pre-construction period and the beginning of the Leaf-off 1 season when the datalogger systems were calibrated and the 3 tower locations were evaluated for optimal coverage. Consequently, 3 towers monitored for 9 and 53% of these periods, respectively; the periods/seasons following were characterized by nearly continuous monitoring by all 3 towers (Appendices B and C). Monitoring during the final weeks of data collection (Operational 6/Leaf-off 3) was also
sporadic due to battery failure at the north tower; however, this tower only contributed 11.9% of detections during the previous season (Leaf-on 2) when it was fully operational (Appendix E). At the beginning of Pre-construction (Day 339), the north and south tower (N/S) were operational and the detection rate was $45 \pm 12$ detections/day; detection rate dropped to $11 \pm 2$ detections/day when only the south tower (S) was operational; detection rate increased again to $42 \pm 15$ detections/day when the south and middle towers (S/M) operational; and the detection rate increased to $391 \pm 37$ detections/day when all 3 towers (S/M/N) were operating the final 6 days of Pre-construction (Fig. 3-3).

Because the south tower was fully operational during Pre-construction, it served as a standard for predictive models when 2 towers were operational (i.e., N/S; S/M). Specifically, logistic and quasi-Poisson regression were used to predict marten presence/absence and detections/day to account for monitoring gaps when the north and middle towers were not operational during Pre-construction. A moving average of 3 days was used to generate predicted values and to assess model accuracy, and predicted values were tested against observed values; logistic and Poisson regression analyses were performed with and without the imputed data to evaluate potential effects on model selection and results.

High Elevation Habitat Use

The proportion of days marten were detected each period was averaged and expressed as a percent, and detection rates were averaged for each period. Nocturnal use was measured for each season (leaf-off = 1700-0700 h, leaf-on = 1900-0500 h) and expressed as a percent (night detections ÷ seasonal total) to compare with habitat use data
Fig. 3-3. Mean (±SE error bars) detections/day for 3 towers during the Pre-Construction monitoring period.
N/S = north/south, S = South, S/M = South/Middle, and S/M/N = South/Middle/North. Julian day 339 (5 December 2010) is the beginning of the Pre-construction period and Julian day 42 (407) (11 February 2011) is the end.
that was all diurnal. The daily time (min) martens were detected in high elevation habitat was calculated to determine if count data (detections/day) was correlated with time (min/day). For each marten, time was calculated by summing detections that were spaced ≤5 minutes apart; this cluster parameter was chosen as it provided the most conservative measure of time. A correlation analysis of detections/day vs. time/day was performed to determine if count data could be used for Poisson regression analysis.

Generalized linear mixed models (GLMM) are useful to account for and measure the variability associated with observational data (e.g., unbalanced designs and contrasting effects of individuals) and allow for multiple, competing hypotheses (Burnham and Anderson 2002, Bolker et al. 2008). They were performed in R (R Development Core Team 2013) using the lme4 package (Bates et al. 2012) to determine if wind farm construction/operation and/or seasons impacted use of high elevation habitat. The best fitting models were determined by using the lowest second order Akaike Information Criterion (AICc) scores with the AICcmodavg package in R (Mazerolle 2012). When top competing models were close (i.e., shared AICc weights (AICcWt)) and Delta_AICc scores were <2), model parameters were averaged using the MuMIn package (Barton 2013) in R. Model averaging can lead to more precise parameter estimates (Burnham and Anderson 2002, Bolker et al. 2008). Significance values for the parameter estimates of the best fitting models were calculated using the Wald z-statistic.

Competing models ("Local Season", "Traditional Season", "Construction 1", "Construction 2", "Season", "Day", "Local Season + Construction 2") were tested to determine a best fit to explain the frequency (presence/absence) and time (detections/day)
marten used high elevation habitat; individual marten ("marten") were included as a random effect in all models. Model parameters were compared to the "Pre-Construction" period and "Leaf-off 1" season. An additional analysis was conducted to measure the proximity of marten to the ridgeline. Proximity was measured using the signal strength parameter recorded during a detection; 4 competing models were tested ("Local Season", "Season", "Construction Period", "Local Season + Construction"); "marten" and "tower" were included as random effects in these models.

**Results**

**Datalogger Tests**

Radio reception tests were conducted over a 9-day period in summer 2011 resulting in 13,627 total locations (2,298 detections; 11,329 non-detections) (Fig. 3-4; left). The best fitting model to map detection probability ("Full Interact 1") included distance from datalogger towers (m), elevation (m), slope, aspect, viewshed, and 3 interaction terms (Table 3-2). Detection probability was most influenced by the following predictors: test collars were more likely to be detected at higher elevations ($P < 0.0001$), closer to datalogger towers ($P < 0.0001$), or with unobstructed views to the towers ($P < 0.0001$) and slope, aspect, and their interaction had less influence, yet provided insight into microsite variation that either increased or decreased detection probability (Table 3-2, Fig. 3-4). The best fitting model to predict the proximity (signal strength) of radio detections in high elevation habitat was the same as the detection probability model and similar dynamics persisted; signal strength increased at higher
elevations, closer to datalogger towers, or with unobstructed views to the tower, and
slope, aspect, and interaction effects also influenced signal strength (Table 3-2, Fig. 3-5).

Marten located >823 m elevation (i.e., by camera trap/VHF telemetry) were
detected by dataloggers 80% of the time the same day, 56% of the time within ±2 hrs,
47% of the time within ±1 hr, and 34% of the time within ±15 min (Table 3-3). For all
temporal scales, detection probability and accuracy improved when marten were at higher
elevation ($P <0.0001$) and/or when detection rates were higher ($P <0.0001$); marten not
detected in high elevation habitat were at lower elevations ($\bar{x} = 865 ±5$ m, Table 3-3).
Marten located <823 m elevation were detected 36% of the time that day, 12% within ±2
hrs, 8% within ±1 hr, and 6% within ±30 min; false positives (detections within ±15
min) were uncommon (4%) and often occurred when marten locations were ~823 m ($n =
19, \bar{x} = 734 ±15$ m; Table 3-3). As with the datalogger tests, detection probability was
higher along the Kelsey Mountain ridgeline, close to the datalogger towers, and where
unobstructed views were between topographical features and the towers; local variations
were explained by slope, aspect, and interactions between these variables (Fig. 3-4).

Both methods of datalogger testing provide inference into detection probability.
Marten located in high elevation habitat were not detected the same day on 59 occasions
(20%), indicating that poor reception zones existed within high elevation habitat; these
zones were located at lower elevation (865 ±5 m) or in areas with rugged topography
(Table 3-3, Fig. 3-4; right). The detection probability during collar tests never exceeded
0.51 compared to the marten location data (0.96) because of the data collection method
and the limitations of the dataloggers. Collars were always moving during testing and the
Fig. 3-4. Detection probability maps derived from best fitting logistic formula from test data (left) and marten locations (right). Verified detections are green and non-detections are red. Detection probability is scaled from 0-0.51 based on predicted detection values for test data (left) and 0-0.96 for marten locations (right); detection was less likely when collars were moving and higher when stationary. Detection probability increased at higher elevations, proximity to datalogger towers and with unobstructed views to the towers. Slope, aspect, and interactions between tower distance and elevation, tower distance and viewshed, and slope and aspect all explained local variations in detection probability.
Table 3-2. Parameter estimates, standard errors (SE), L-R ChiSquare ($\chi^2$), and test statistic (Prob>$\chi^2$) for the best fitting detection probability and proximity models ("Full Interact") from datalogger testing. Elevation, distance from tower (towerdist), unobstructed views of towers (view), and interaction between these variables influenced detection probability and proximity. Aspect and slope and interactions between these variables explained local variations of probability and proximity.

<table>
<thead>
<tr>
<th>Parameter (detection probability)</th>
<th>Estimate</th>
<th>Std. Error</th>
<th>L-R $\chi^2$</th>
<th>Prob&gt;$\chi^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-10.1950</td>
<td>0.8746</td>
<td>171.96</td>
<td>0.0001***</td>
</tr>
<tr>
<td>slope</td>
<td>0.0044</td>
<td>0.0030</td>
<td>2.22</td>
<td>0.1362</td>
</tr>
<tr>
<td>elevation</td>
<td>0.0030</td>
<td>0.0003</td>
<td>150.23</td>
<td>0.0001***</td>
</tr>
<tr>
<td>east</td>
<td>-0.2677</td>
<td>0.0571</td>
<td>23.30</td>
<td>0.0001***</td>
</tr>
<tr>
<td>north</td>
<td>0.0272</td>
<td>0.0476</td>
<td>0.33</td>
<td>0.5682</td>
</tr>
<tr>
<td>south</td>
<td>-0.0046</td>
<td>0.0435</td>
<td>0.01</td>
<td>0.9164</td>
</tr>
<tr>
<td>distance from tower (towerdist)</td>
<td>-0.0025</td>
<td>0.0001</td>
<td>943.17</td>
<td>0.0001***</td>
</tr>
<tr>
<td>(towerdist-896.201)*(elevation-3150.66)</td>
<td>0.0000</td>
<td>0.0000</td>
<td>97.61</td>
<td>0.0001***</td>
</tr>
<tr>
<td>east*(slope-29.1703)</td>
<td>-0.0209</td>
<td>0.0056</td>
<td>14.13</td>
<td>0.0002***</td>
</tr>
<tr>
<td>north*(slope-29.1703)</td>
<td>0.0098</td>
<td>0.0045</td>
<td>4.63</td>
<td>0.0314*</td>
</tr>
<tr>
<td>south*(slope-29.1703)</td>
<td>-0.0003</td>
<td>0.0042</td>
<td>0.00</td>
<td>0.9485</td>
</tr>
<tr>
<td>view</td>
<td>0.5341</td>
<td>0.0505</td>
<td>122.82</td>
<td>0.0001***</td>
</tr>
<tr>
<td>(view-1.03999)*(towerdist -896.201)</td>
<td>0.0004</td>
<td>0.0001</td>
<td>22.85</td>
<td>0.0001***</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter (proximity model)</th>
<th>Estimate</th>
<th>Std. Error</th>
<th>L-R $\chi^2$</th>
<th>Prob&gt;$\chi^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>16.2388</td>
<td>9.9849</td>
<td>2.64</td>
<td>0.104</td>
</tr>
<tr>
<td>slope</td>
<td>-0.0909</td>
<td>0.0424</td>
<td>4.59</td>
<td>0.0322</td>
</tr>
<tr>
<td>elevation</td>
<td>0.0220</td>
<td>0.0030</td>
<td>52.33</td>
<td>0.0001***</td>
</tr>
<tr>
<td>west</td>
<td>0.5657</td>
<td>0.5284</td>
<td>1.15</td>
<td>0.2844</td>
</tr>
<tr>
<td>east</td>
<td>0.8826</td>
<td>0.7513</td>
<td>1.38</td>
<td>0.2402</td>
</tr>
<tr>
<td>north</td>
<td>-1.7948</td>
<td>0.6499</td>
<td>7.62</td>
<td>0.0058**</td>
</tr>
<tr>
<td>distance from tower (towerdist)</td>
<td>-0.0259</td>
<td>0.0012</td>
<td>452.70</td>
<td>0.0001***</td>
</tr>
<tr>
<td>(towerdist-524.337)*(slope-27.9874)</td>
<td>-0.0009</td>
<td>0.0001</td>
<td>57.57</td>
<td>0.0001***</td>
</tr>
<tr>
<td>west*(towerdist-524.337)</td>
<td>0.0177</td>
<td>0.0015</td>
<td>141.27</td>
<td>0.0001***</td>
</tr>
<tr>
<td>east*(towerdist-524.337)</td>
<td>-0.0006</td>
<td>0.0018</td>
<td>0.13</td>
<td>0.7145</td>
</tr>
<tr>
<td>north*(towerdist-524.337)</td>
<td>-0.0204</td>
<td>0.0019</td>
<td>111.58</td>
<td>0.0001***</td>
</tr>
<tr>
<td>west*(slope-27.9874)</td>
<td>0.0419</td>
<td>0.0534</td>
<td>0.62</td>
<td>0.4329</td>
</tr>
<tr>
<td>east*(slope-27.9874)</td>
<td>-0.6591</td>
<td>0.0830</td>
<td>62.25</td>
<td>0.0001***</td>
</tr>
<tr>
<td>north*(slope-27.9874)</td>
<td>0.4666</td>
<td>0.0647</td>
<td>51.39</td>
<td>0.0001***</td>
</tr>
<tr>
<td>view</td>
<td>4.6942</td>
<td>0.4996</td>
<td>86.64</td>
<td>0.0001***</td>
</tr>
<tr>
<td>(view-1.36815)*(towerdist-524.337)</td>
<td>-0.0104</td>
<td>0.0013</td>
<td>64.98</td>
<td>0.0001***</td>
</tr>
</tbody>
</table>

* $P < 0.05$
** $P < 0.01$
***$P < 0.001$
Fig. 3-5. Proximity map based on best fitting regression formula from test data. Detection locations are in green. Range in predicted signal strength is 40-120; signal strength increased in response to higher elevations, proximity to datalogger towers, and unobstructed view (viewshed) to the towers. Slope, aspect, and interactions between tower distance and slope, tower distance and aspect, tower distance and viewshed, and slope and aspect all explained local variations in signal strength.
Table 3-3. Results of accuracy and detection probability tests using telemetry and camera trap locations of marten located above and below 823 m elevation. Accuracy was expressed as the # of detections (%) at 5 different scales. The mean (±SE) elevation (m), and mean (±SE) detection rate were significant predictors ($P < 0.0001$) of detection probability above 823 m for all temporal scales.

<table>
<thead>
<tr>
<th>Scale</th>
<th>Above 823 m (n = 299)</th>
<th>Below 823 m (n = 494)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Detections</td>
<td>$\bar{x}$ (± m) elev</td>
</tr>
<tr>
<td>day</td>
<td>240 (80%)</td>
<td>923 (± 4 m)</td>
</tr>
<tr>
<td>±2 hr</td>
<td>168 (56%)</td>
<td>935 (± 4 m)</td>
</tr>
<tr>
<td>±1 hr</td>
<td>140 (47%)</td>
<td>941 (± 4 m)</td>
</tr>
<tr>
<td>±30 min</td>
<td>118 (39%)</td>
<td>945 (± 5 m)</td>
</tr>
<tr>
<td>±15 min</td>
<td>103 (34%)</td>
<td>950 (± 5 m)</td>
</tr>
</tbody>
</table>

dataloggers typically take 2-3 min to scan through all programmed frequencies depending on the # of signals detected. Consequently, test collars were not always detected even when collars were within the reception range of dataloggers. While activity was not available for all location data, marten were detected within 15 min by dataloggers on 19 occasions (79%) when marten were known to be stationary (camera trap visits); marten averaged 15 (1-90) min per camera trap visit (see Chapter 1), and these visits were characterized by high detection rates ($\bar{X} = 201 \pm 20$ detections).

Although presence/absence in high elevation habitat was not always confirmed, dataloggers were reasonably accurate (80%) at confirming marten presence during the same day and false positives were rare (4%); therefore, logistic regression was used to measure presence/absence for seasonal and construction hypotheses. Also, as radio signal strength was positively associated with elevation and distance to datalogger towers, it provided a measure to estimate proximity to high elevation habitat.

**Data Imputation**

The detection data for towers with missing data was imputed to assess impact on model selection. A comparison of AICc tables for logistic (detection probability) and Poisson (detection rate) models with and without imputed data revealed little difference in ordering; the “Local Season + Construction 2” was clearly the top model (i.e., Delta AICc scores were not <2 and competing models did not share AICc weights) (Tables 3-4, 3-5). The predicted presence/absence and detections/day data for the north tower was compared to the observed data to assess the accuracy of model predictions. The predicted presence/absence model had a high classification rate (0.91), and the predicted
detections/day was positively correlated ($r = 0.81$) with the observed detections/day; imputed data from the north tower during the “Pre-Construction” period and “Leaf-off 1” season were used as the final model to evaluate hypotheses (Tables 3-4, 3-5; “North Imputed Data”). It is likely that the predicted estimates of presence/absence and detections/day were conservative because the middle tower provided the greatest contribution to the data pool (Appendices D and E) and detection rates were 10 x higher when all 3 towers were operating at the end of “Pre-Construction” (Fig. 3-3).  

**High Elevation Habitat Use**

There were 119,834 high elevation habitat detections from 5 December 2010-23 December 2012 (749 days); all 3 towers detected all marten during monitoring. The majority of detections occurred during the leaf-off seasons ($n = 104,473$; 87%). The lowest average % of days marten were detected occurred during “Leaf-on 1” (33 ±10%); this season also had the lowest average detection rate (6 ±2 detections/day, Appendix F). The highest average % of days marten were detected was in “Leaf-off 2” (74 ± 10%) and this season also had the highest detection rate (59 ± 20 detections/day, Appendix F). For the construction periods, the highest use values occurred during the first 3 operational periods when marten were detected 80-84% of the days and detection rates averaged between 55-90 detections/day (Appendix G). The lowest use values were recorded during “Road Construction” when marten were detected on average 29% (0-74) of the days, and the mean detection rate was 3 (0-8) detections/day (Appendix G). Nocturnal use was similar during leaf-off seasons ($n = 54,464, 52$%), whereas in leaf-on seasons nocturnal use was less ($n = 4834, 31$%). The detection rate (detections/day) was highly
correlated for 5-min time clusters \((r = 0.992)\), indicating that this measurement was a reliable index for time spent in high elevation habitat per day; count data was used for Poisson regression analysis.

**Model Selection**

The “Local Season + Construction 2” model had the lowest \(AIC_c\) scores for logistic and Poisson analyses; both seasonal and construction related periods influenced the presence/absence and the detection rate of marten in high elevation habitat (Tables 3-4, 3-5). The “Local Season + Construction” model had the lowest \(AIC_c\) scores for the proximity analysis indicating that proximity to the high elevation habitat ridgeline was affected by seasons, and construction periods (Table 3-6).

**Seasonal Use Model**

All model parameters were compared to the “Leaf-off 1” season. Marten were less likely to be detected during “Leaf-on 1” \((P = 0.026)\) and detection rates declined 78\% during this period \((P < 0.0001, \text{Tables 3-7, 3-8, Fig. 3-6})\). Marten presence and detection rates were similar in other seasons with a trend towards higher detection and rates occurring in leaf-off seasons compared to leaf-on (Fig. 3-6). Marten proximity measures were lower in all seasons following “Leaf-off 1” with the lowest measure occurring during “Leaf-on 2” when proximity declined 3.7 dBm (Table 3-6, Fig. 3-7). A relative comparison can be made among seasonal periods occurring in the previous year (i.e., “Leaf-on 2” can be compared to “Leaf-on 1”; Fig. 3-2). Detection probability and rates during “Leaf-on 1” were significantly less than the control parameter (“Leaf-off 1”),
Table 3-4. AICc table comparison for detection probability models with and without imputed data from the “Pre-Construction” period and “Leaf-off 1” season. Results indicate the “Local Season + Construction 2” model to best explain marten detection probability in high elevation habitat, regardless of data imputation.

**Raw Data**

<table>
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<tr>
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<th>Delta_AICc</th>
<th>AICcWt</th>
<th>Cum.Wt</th>
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**North Imputed Data**

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* The “Local Season” model surpassed the “Construction 2” model when all data imputed.
Table 3-5. AICc table comparison for detection rate models with and without imputed data from the “Pre-Construction” period and “Leaf-off 1” season. Results indicate the “Local Season + Construction 2” model to best explain marten detection rate in high elevation habitat, and model order did not shift with regards data imputation.

### Unimputed Data

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Table 3-6. AICc table comparison for 4 models of proximity to high elevation habitat ridgeline on Kelsey Mountain in northern New Hampshire. Parameter estimates for the top 2 models were averaged as both Delta_AICc scores <2. Parameter estimates, standard errors, z values, and test statistic (Pr(>\mid z\mid)) for the “Local Season + Construction” proximity model. Proximity measures were lower in all seasons following Leaf-off 1 and Pre-Construction and significantly lower in during Road Clearing, Construction Lull, and during Tower Construction.

<table>
<thead>
<tr>
<th>Model Candidate</th>
<th>K</th>
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<th>Delta_AICc</th>
<th>AICcWt</th>
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<th>SE</th>
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* P <0.05  
** P <0.01  
***P <0.001
yet during the following leaf-on season ("Leaf-on 2") detection probability and rates were similar to the control parameter (Fig. 3-6).

Construction Periods

All model parameters were compared to the "Pre-Construction" period. Marten were more likely to be detected during "Road Clearing" ($P = 0.045$), "Operational 1" ($P = 0.003$), "Operational 3 ($P = 0.02$), and "Operational 6" ($P = 0.03$) periods compared to "Pre-Construction" (Table 3-7, Fig. 3-6). The only decrease in the detection rate occurred during "Road Construction" (21%; $P = 0.59$); in all other periods detection rates were higher (Table 3-8, Fig. 3-6). Detection rates were the highest during the first 3 operational periods ($P < 0.0001$); specifically, there was a twelve-fold increase during "Operational 1", seven-fold increase during "Operational 2", and an eight-fold increase in "Operational 3" compared to "Pre-Construction" (Table 3-8). Similar to the seasonal periods, proximity was lower in all periods following "Pre-construction. In the 2 periods immediately following "Pre-construction", proximity declined 6 dBm ("Road Clearing"; $P <0.0001$) and 8 dBm ("Construction Lull"; $P <0.0001$), and in the following year decreased 5 dBm during the first 2 operational periods ($P <0.05$, Table 3-6, Fig. 3-7). Proximity was also 8 dBm lower during "Tower Construction" compared to "Pre-construction" ($P <0.01$, Table 3-6, Fig. 3-7). Because the "Operational" periods correspond to the construction phases of the previous year, relative comparisons can be made to "Pre-Construction" (Fig. 3-2). Detection probability and rate was similar to Pre-Construction during "Road Construction", yet significantly higher in the period the following year ("Operational 3"; Fig. 3-6).
Fig. 3-6. Beta coefficients (parameter estimates), standard errors (thick lines), and 2 standard deviations (thin lines) for the "Local Season + Construction 2" detection probability and rate models. Model parameters are compared to the "Leaf-off 1" season and "Pre-Construction" period (dotted line). Detection probability estimates are in black and detection rate estimates are in blue. Detection was less likely and rates were lower during leaf-on seasons. Detection was more likely and rates were higher during periods 4 periods following road construction.
Fig. 3-7. Beta Coefficients (parameter estimates), standard errors (thick lines), and 2 standard deviations (thin lines) for the "Local Season + Construction" proximity model. Model parameters are compared to the "Leaf-off 1" season and "Pre-Construction" period (dotted line). Average proximity measures were lower in all seasonal and construction periods.
Table 3-7. Parameter estimates, standard errors, z values, and test statistic (Pr(>|z|)) for the “Local Season + Construction 2” detection probability model with imputed data from the north tower. Detection probability was lower (P = 0.027) during the Leaf-on 1 season and higher during construction periods immediately following Pre-Construction, and during Operational periods 1, 3, and 6 (P <0.05).

| Parameter          | Estimate | Std. Error | z value | Pr(>|z|)) | Exp. Estimate |
|--------------------|----------|------------|---------|-----------|---------------|
| (Intercept)        | -1.0084  | 0.7565     | -1.333  | 0.182     |               |
| Leaf-on 1          | -1.5263  | 0.6898     | -2.213  | 0.027*    | 0.2           |
| Leaf-off 2         | 0.7092   | 0.7633     | 0.929   | 0.353     | 2.0           |
| Leaf-on 2          | -1.0697  | 1.4882     | -0.719  | 0.472     | 0.3           |
| Leaf-off 3         | -1.0406  | 1.5259     | -0.682  | 0.495     | 0.4           |
| Road Clearing      | 0.9935   | 0.4960     | 2.003   | 0.045*    | 2.7           |
| Construction Lull  | 0.6817   | 0.5053     | 1.349   | 0.177     | 2.0           |
| Road Construction  | 0.4719   | 0.7902     | 0.597   | 0.550     | 1.6           |
| Tower Construction | 1.0828   | 0.8194     | 1.321   | 0.186     | 3.0           |
| Operational 1      | 2.6309   | 0.8883     | 2.962   | 0.003**   | 13.9          |
| Operational 2      | 1.3719   | 0.8973     | 1.529   | 0.126     | 3.9           |
| Operational 3      | 2.309    | 1.0132     | 2.279   | 0.023*    | 10.1          |
| Operational 4      | 2.9681   | 1.5707     | 1.89    | 0.059     | 19.5          |
| Operational 5      | 2.7963   | 1.5844     | 1.765   | 0.078     | 16.4          |
| Operational 6      | 3.4935   | 1.6153     | 2.163   | 0.031*    | 32.9          |
Table 3-8. Parameter estimates, standard errors, z values, and test statistic (Pr(>|z|)) for the "Local Season + Construction 2" detection rate model. Detection rates were significantly lower during Leaf-on 1 and highest during the first 3 Operational periods.

| Parameter               | Estimate | Std. Error | z value | Pr(>|z|)) | Exp. Estimate |
|-------------------------|----------|------------|---------|-----------|---------------|
| (Intercept)             | 0.975    | 0.747      | 1.31    | 0.192     |               |
| Leaf-on 1               | -1.511   | 0.413      | -3.66   | 0.0003*** | 0.22          |
| Leaf-off 2              | 0.153    | 0.453      | 0.34    | 0.735     | 1.17          |
| Leaf-on 2               | -0.721   | 0.550      | -1.31   | 0.190     | 0.49          |
| Leaf-off 3              | -0.092   | 0.593      | -0.16   | 0.877     | 0.91          |
| Road Clearing           | 0.648    | 0.455      | 1.43    | 0.154     | 1.91          |
| Construction Lull       | 0.540    | 0.455      | 1.19    | 0.235     | 1.72          |
| Road Construction       | -0.238   | 0.451      | -0.53   | 0.598     | 0.79          |
| Tower Construction      | 1.040    | 0.486      | 2.14    | 0.032*    | 2.83          |
| Operational 1           | 2.452    | 0.486      | 5.05    | 0.000***  | 11.61         |
| Operational 2           | 2.005    | 0.494      | 4.06    | 0.000***  | 7.43          |
| Operational 3           | 2.109    | 0.549      | 3.84    | 0.000***  | 8.24          |
| Operational 4           | 1.175    | 0.565      | 2.08    | 0.037*    | 3.24          |
| Operational 5           | 0.541    | 0.606      | 0.89    | 0.372     | 1.72          |
| Operational 6           | 1.200    | 0.610      | 1.97    | 0.049*    | 3.32          |

* $P < 0.05$
** $P < 0.01$
***$P < 0.001$
Discussion

All analyses of monitoring data indicate that both season and construction likely influenced marten use of high elevation habitat. Though subtle differences exist between the analyses, trends indicate that marten were detected less often, and when detection occurred, rates were lower during leaf-on seasons, with the least use occurring during “Leaf-on 1”. These findings support the seasonal hypothesis that habitat use is influenced by annual emergence and senescence of canopy cover and marten require higher canopy cover in winter. Detection probability and rate did vary among the construction periods, yet absolute use did not decline from wind farm development. However, the construction periods (“Road Clearing” – “Tower Construction”), nested within the latter half of the “Leaf-off 1” and “Leaf-on 1” seasons, corresponded with the highest sample size (n = 5-9) of marten under monitoring (Table 3-1, Fig. 3-2) and were characterized by obvious construction activity (e.g., heavy machinery and blasting). Proximity was lowest during these periods, and the lowest average detection rate occurred during the “Road Construction” period.

Marten were more likely to be detected and had higher detection rates in high elevation habitat during the first 3 operational periods following construction indicating that use did not decline post-construction; these periods were nested within the “Leaf-off 2” season (Fig. 3-2). The proximity analysis revealed that marten were detected further from the ridgeline during all periods and seasons following the “Pre-Construction” period and “Leaf-off 1” season, with significant declines (6-8 dBms lower) during the construction phase periods (Table 3-6); these findings are in accordance with the construction hypothesis. Although proximity did not return to that of the “Pre-
Construction" period, it increased gradually after construction ended, suggesting that marten adjusted to site conditions (Table 3-6, Fig. 3-7). It is reasonable to assume that disturbance and open habitat (roads and wind turbine pads) shift proximal use of the ridgeline, cause behavioral disturbance, and lower habitat quality.

The seasonal periods have the potential to mask the effects of construction because of the predicted and observed pattern of less use of high elevation habitat during leaf-on seasons. For example, road construction occurred during “Leaf-on 1” (Fig. 3-2) and less use was predicted during construction periods. Although a seasonal trend was evident, relative comparisons between corresponding seasons reveal that detection probability and rates were exceptionally low during “Leaf-on 1” compared to “Leaf-on 2” (Fig. 3-6). It is possible that extreme (i.e., significant) variation in seasonal habitat use results from pulsed resources and/or density dynamics (Steventon and Major 1982, Fryxell et al. 1999, Jensen et al. 2012). Marten may intensively utilize pulsed resources when they become available (e.g., mountain ash [Sorbus americana] berries; Lachowski 1997) and mountain ash production was considered abnormally high in 2011 throughout the Northeast (personal observation, and pers. comm., P. Jensen [New York State Department of Environmental Conservation, Division of Fish, Wildlife, and Marine Resources] and R. Cross [Maine Department of Inland Fisheries of Wildlife]). Conversely, high population density may also influence habitat use and vary seasonally, especially if suboptimal conditions persist in the surrounding landscape (Van Horne 1983).

Marten require forests with >30% canopy cover during winter (Thompson and Harestad 1994; although see Potvin et al. 2000, Gosse et al. 2005) to avoid predators
(Buskirk and Ruggerio 1994, Hodgman et al. 1997), and canopy cover is greater in uncut forests (Thompson 1994). In Maine, marten with leaf-on home ranges composed of >10% partially harvested stands shifted their home range position to include more mature forest during leaf-off seasons; this was attributed to reduced canopy cover, basal area, and prey species in partial-harvest and regenerating clear-cut stands (Fuller and Harrison 2005). Canopy cover in these partially harvested stands shifted from 67% during the leaf-on to 26% in the leaf-off season, basal area was below previously reported thresholds, and hare densities were low and small mammals were less accessible during winter (Fuller and Harrison 2005). This study site was similar as it contained a mosaic of mature forest, regenerating clear-cuts, and partially harvested stands. Further, the trend of greater use of mature forest during leaf-off seasons is similar and may possibly reflect insufficient canopy cover of the hardwood stands at lower elevation. Although, no selection against mature hardwood stands occurred in Maine (Chapin et al. 1997) or New York (Jensen 2012), most hardwood stands were partially harvested and possibly below the minimum basal area thresholds (≥18 m²/ha) required during leaf-off seasons (Payer and Harrison 2003).

The wide roads and turbine sites associated with wind farms have the potential to reduce use of high elevation habitat and provide increased access to predators and competitors (see Chapter 4). Proximity measures indicate marten were further from high elevation habitat ridgelines during the construction periods, as compared with the later operational periods. Although marten use logging (Robataille and Aubry 2000) and recreational (Zielinski et al. 2008) roads, greater detection rates occur in the interior forest (Robataille and Aubry 2000), and females stayed 50 m from logging road edges at
a study site in Maine (Katnik 1992). Although, positive responses and high threshold towards fragmentation has been documented, these were in meadows (Spencer et al. 1983) and regenerating forests (Katnik 1992), unlike the permanent openings associated with wind farm infrastructure. Further, habitat loss along high elevation habitat ridgelines might be additive to fragmentation occurring elsewhere on the landscape, thereby reducing overall habitat value. It is clear that marten avoid non-forested habitats (Thompson et al. 2012), and the footprints associated with wind farm development may reduce long-term value at the stand scale (Harrison 2011). Although seasonal changes in canopy cover, forage resources, and snow depth explain use of high elevation habitat, there was less use of high elevation habitat during wind farm construction, and ridgeline use declined significantly during construction periods. Future research should include a longer pre-disturbance monitoring period to better evaluate baseline seasonal use patterns and include turbine activity data as the noise associated with operating turbines might influence use. Because this data was not available the potential impact of wind farm development was not fully described.

Remote dataloggers provided a measure of differential habitat use at several temporal scales (e.g., season, construction period, diel activity) and proximity related measurements provided a spatial component to assess the effects of wind farm construction. Although, traditional VHF ground telemetry is useful because it provides more exact locations, fieldwork can be difficult and costly in remote areas, and is often limited to diurnal periods. It is unlikely that traditional VHF telemetry data alone would have detected the fine-scale habitat use patterns procured from the datalogger data due to the absence of nocturnal locations; therefore, leaf-off (winter) stand scale selection was
likely underestimated. In combination, both methods provided an intensive data collection methodology unique to marten habitat use studies, and documented that marten used high elevation habitat seasonally and that wind farm construction influenced temporal use of this preferred habitat.
CHAPTER 4

POTENTIAL INFLUENCE OF WIND FARMS ON MOBILITY AND PRESENCE OF CARNIVORES AT HIGH ELEVATION

Introduction

Northern New England is the distributional edge for species such as marten (Martes americana) and lynx (Lynx canadensis) that are adapted for deep snow (Hoving et al. 2005, Carrol 2007) that typically partitions their seasonal habitat (Krohn et al. 1995, Buskirk et al. 2000, Krohn et al. 2004). Southward range expansion is inhibited by the interacting effects of a shallow snowpack and competition with sympatric predators (Krohn et al. 1995). Deep mid-winter snow favors species with a lower foot-load ratio (foot area ÷ body weight) that provides greater flotation in deep, powdery snow (Murray and Boutin 1991, Buskirk et al. 2000, Krohn et al. 2004). Lynx have a lower foot-load ratio compared to coyotes and bobcats (Murray and Boutin 1991, Buskirk et al. 2000), and marten have a lower foot-load ratio than fisher (Raine 1983, Krohn et al. 2004). Evidence suggests that fisher and coyote movements are negatively impacted by deep snow and require a shallow and compacted snowpack to survive winter conditions (Raine 1983, Murray and Boutin 1991, Crête and Larivière 2003).

Krohn et al. (1995) investigated the relationship between snow depth and furbearer records for marten and fisher in Maine and found that marten and fisher ranges overlapped at depths of 48 cm of snow per month. More marten were associated with
deeper snow (>48 cm per month) in northern Maine, whereas fisher represented the majority of furbearer records in southern Maine. They suggested that snow depth limits the range expansion of both species and provides marten a competitive edge in areas with greater snow depth. Krohn et al. (1997) found the same pattern in California, except that range overlap was more discrete compared to Maine; they suggested snowfall gradients were more pronounced in California because of greater elevational extremes.

Krohn et al. (2004) further examined snowfall over 2 decades (1970-1990) in the northeastern United States and southeastern Canada and predicted that reduced snowfall allowed northward expansion of fisher. If the trend continued, they predicted that marten would be outcompeted in much of its southern range. Also, spatially explicit population models for marten and lynx in the northeastern United States predict significant declines if climate change trends continue (Carroll 2007). Marten and fisher distribution in New Hampshire are correlated with annual snow depth based on sightings, live-trapping, and harvest data; marten are associated with the greatest snow depths in the north and central mountainous regions (Kelly 2005).

Recent research suggests that year-round road/snowmobile access can introduce competitors and predators into winter habitats otherwise inaccessible (Buskirk et al. 2000, Bunnell et al. 2006); e.g., backcountry snowmobile trails allowed coyotes to access lynx habitat in Colorado and Wyoming (Bunnell et al. 2006, Dowd 2010). In Montana, Kolbe et al. (2007) did not find a correlation between coyote movements and snowmobile trails, and because snowshoe hare (Lepus americanus) were not primary prey of coyotes, they suggested that lynx and coyotes were not competing for resources. However, greater snow depths create habitat partitioning and enhance the importance of physical
adaptations; it follows that compacted trails have the potential to erode abiotic barriers (Dowd 2010).

Establishment of wind power parks along high elevation ridgelines is increasingly proposed in the northeast. Maintenance of high elevation wind turbines requires that access roads remain open year-round and long-term, unlike most logging roads. These roads represent a potential travel corridor for terrestrial predators, as they are gradually sloped and compacted from regular grooming. These access roads could erode spatial boundaries created by snow depth, thereby allowing fisher, coyotes, red fox (*Vulpes fulva*), and bobcat (*Lynx rufus*) to invade critical winter habitat for marten. Competition from fisher – an intraguild predator of marten – could have the greatest impact on marten fitness and survival (Hodgman et al. 1997).

This study was designed to assess whether compacted snow on high elevation roads, snowmobile trails, and snowshoe trails allowed sympatric carnivores of marten (fisher, coyote, red fox, and bobcat) to access high elevation habitat. It was predicted that 1) compared to other survey route types, high elevation roads would allow competing carnivores to access high elevation habitat, 2) competing carnivores would use roads and snowmobile trails more often than marten, 3) use of snowshoe trails by competing carnivores would be infrequent except for travelling down the mountain, and 4) an increasing snowpack would cause competing carnivores to use the compacted survey routes. Additionally, local factors (e.g., forest type, elevation, canopy closure) were examined to determine their contribution to the snowpack and to provide ancillary information for the survey data.
Methods

Snow Track Surveys

Snow tracks and/or trails of marten, fisher, coyote, red fox, and bobcat were counted during winter 2011-2012 to compare their relative use of 3 high elevation survey route types (roads, snowmobile, and snowshoe trails). Two routes for each route type (2.5-6.3 km) were surveyed to count tracks and measure snow depth and penetrability (Fig. 4-1). Survey lengths of at least 3 km are suggested to increase likelihood of detecting mesocarnivores (Thompson et al. 1989); one snowmobile route was shorter (2.5 km) due to limited availability. Survey routes were chosen based on availability (i.e., existing trails) and similarity (e.g., similar slope); further, snow tracks of survey carnivores were detected on all routes before the first survey (personal observation). Road routes were located on Kelsey and Dixville Mountains totaled 10.3 km (4-6.3 km each), ranged between 636-1045 m in elevation, and included 12 snow stations (Fig. 4-1; KORD and DIX). Snowmobile routes were located on the west and east side of Kelsey and Owlhead Mountains, totaled 5.5 km (2.5-3 km each), ranged between 624-901 m in elevation, and included 8 snow stations (Fig. 4-1; YT and OHT). Snowshoe routes were located on the west and east side of Kelsey Mountain, totaled 8 km (3.8-4.1 km each), ranged between 619-1056 m in elevation, and included 10 snow stations (Fig. 4-1; PCT and 12MT).
Fig. 4-1. Snow stations and survey routes along roads (red), snowmobile trails (dotted blue), and snowshoe hiking trails (green) within Kelsey Mountain study area used for counting tracks and measuring snowpack during winter 2011-2012.
Snowpack Analysis

Surveys were conducted over a 4-month period from December 2011-March 2012 (n = 6), 24-72 h after a snow event (Golden 1988, Zielinski and Kucera 1995); this time period allows for tracks to accumulate, yet minimized misidentifications. Snow stations were established at the beginning, end, and at 1 km intervals on the survey route. At each snow station, snow depth and penetrability were measured 10-20 m (off trail) perpendicular from the edge and on the survey route. Snow depth was measured with an avalanche probe pole (X of 5 samples) and penetrability was measured by dropping a 100 g brass weight from 1 m above the snow surface, and recording the depth of the indentation (Kolbe et al. 2007). There were a total of 30 snow stations (12 road, 8 snowmobile, and 10 snowshoe). GIS was used to calculate the slope, aspect, and elevation at all snow stations; additionally, stand data provided by American Forest Management (AFM) and Wagner Forest Management (WFM) was used to assign forest type and crown closure values.

Statistical Analysis (Snowpack)

To quantify snow compaction along survey routes, one-way analysis of variance (ANOVA) was used to compare off and on-trail depth and penetrability measurements for each survey. Generalized linear mixed regression models (GLMM) were performed in R (R Development Core Team 2013) using the lme4 package (Bates et al. 2012) to explain the off-trail snowpack measurements for the entire winter. Model parameters included the survey route type, elevation, slope, forest type, and canopy closure for each snow station; the survey dates, transect, and snow station were included as random effects in all models (Table 4-1). Twenty-one competing models were chosen to explain
the snowpack measurements. The best fitting models were determined by using the lowest second order criterion Akaike Information Criterion (AICc) scores with the AICcmodavg package (Mazerolle 2012) in R. When top competing models were close (i.e., shared AICc weights (AICcWt)) and had Delta_AICc scores <2), top models were averaged using the MuMIn package (Barton 2013) in R. Model averaging can lead to more precise parameter estimates (Burnham and Anderson 2002, Bolker et al. 2008).

**Carnivore Detections**

Snow tracks were identified based on size, morphology, and trail characteristics (Elbroch 2003). Track intersections were recorded with a GPS and considered independent if detected >100 m from a previously recorded track. If the animal was traveling the survey route, trail length was recorded by marking a GPS waypoint for the first and last observed tracks. Trail length between the 2 waypoints was calculated in GIS using the tools “Create Routes” and “Locate Features Along Routes” (ESRI 2011). Direction of travel (i.e., up, down, or across the survey route) was recorded for each observation.

**Statistical Analysis (Carnivore Surveys)**

A Chi-squared test of independence was used to detect differences of use between species and route types, and direction of travel along survey routes. Kruskal-Wallis tests were used to evaluate species-specific use of survey routes, and Dunn Comparison of Rank Sum tests compared differences between levels; as survey route lengths varied, the sampling distance was incorporated as a frequency variable into all count analyses. To detect trends in survey route relative to an increasing snowpack, correlation was used to compare species encountered and distance travelled vs. the off-trail snow depth/penetrability measurements. An ANOVA was used to determine if the mean
elevation of species tracks varied to evaluate spatial partitioning among survey species. JMP Pro software (JMP 2012) was used to analyze count, distance, and direction data, and R software was used to conduct ANOVA (R Development Core Team 2011).

Results

Snow Track Surveys

Six surveys were conducted 24-39 h after a snow event; 58, 33, and 48 km were surveyed in total for roads, snowmobile trails, and snowshoe trails, respectively. Roads were usually surveyed first, as wind and sun exposure during the afternoon often reduced detectability; this rarely occurred on snowmobile and hiking routes as they were less exposed. No measurements occurred on one road route (DIX) during the first survey (12 December 2011) as it had not been established. The deepest and least supportive snowpack was recorded on the 3 March survey; the first (12 December) and last (31 March) surveys were characterized by a shallow and supportive snowpack (Table 4-2, Fig. 4-2). Overall, snowmobile routes had the deepest and least supportive snowpack compared to roads and snowshoe trails (Table 4-2).

Snowpack Analysis

On-trail snow measurements were not performed during the first survey as little snow persisted and routes were not compacted; it was assumed that on- and off-trail snow conditions were similar (off-trail snow depth: $\bar{X} = 13.7 \pm 0.3$ cm; off-trail snow penetrability: $\bar{X} = 12.7 \pm 0.8$ cm). In the next 4 surveys off-trail snow depth and penetrability were greater ($P < 0.001$) than on-trail measurements for most survey routes; the exception was when penetrability was similar along snowshoe trails on 4 March (Table 4-2, Fig. 4-3). Overall, snowshoe trails were less compacted and snowpack was
Table 4-1. Variables used in a generalized linear mixed effects model to explain snowpack data from 6 carnivore track surveys conducted from 12 December 2011-31 March 2012 on Kelsey and Dixville Mountains in Coos County, New Hampshire.

<table>
<thead>
<tr>
<th>Explanatory Variable</th>
<th>Effect</th>
<th>Parameters</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survey</td>
<td>Random</td>
<td>Survey Dates (6 total)</td>
<td>Categorical</td>
</tr>
<tr>
<td>Transect</td>
<td>Random</td>
<td>12MT, PCT, YT, OHT, DIX, and KORD</td>
<td>Categorical</td>
</tr>
<tr>
<td>Snow station</td>
<td>Random</td>
<td>Individual snow stations</td>
<td>Categorical</td>
</tr>
<tr>
<td>Survey route type</td>
<td>Fixed</td>
<td>Road, Snowmobile, Snowshoe</td>
<td>Categorical</td>
</tr>
<tr>
<td>Aspect</td>
<td>Fixed</td>
<td>Cardinal directions (N, E, S, W)</td>
<td>Categorical</td>
</tr>
<tr>
<td>Slope</td>
<td>Fixed</td>
<td>Shallow, Moderate, Steep</td>
<td>Categorical</td>
</tr>
<tr>
<td>Forest Type</td>
<td>Fixed</td>
<td>Softwood, Hardwood, Mixed</td>
<td>Categorical</td>
</tr>
<tr>
<td>Canopy Closure</td>
<td>Fixed</td>
<td>A = 61-100%; B = 40-60%; and C = 0-39%</td>
<td>Categorical</td>
</tr>
<tr>
<td>Elevation</td>
<td>Fixed</td>
<td>2031-3430 ft.</td>
<td>Numerical</td>
</tr>
</tbody>
</table>
Table 4-2. Mean (±SE) off- and on-trail snowpack measurements for 6 surveys along 3 survey route types from 12 December 2011-31 March 2012.

<table>
<thead>
<tr>
<th>Survey route</th>
<th>Off-trail depth</th>
<th>Off-trail penetrability</th>
<th>On-trail depth</th>
<th>On-trail penetrability</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Snowshoe</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12-Dec-11</td>
<td>13.7 (± 0.69)</td>
<td>12.6 (± 0.43)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>9-Jan-12</td>
<td>28.3 (± 1.49)</td>
<td>20.0 (± 1.32)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>19-Feb-12</td>
<td>61.0 (± 2.11)</td>
<td>13.0 (± 0.93)</td>
<td>5.9 (± 0.34)</td>
<td>5.5 (± 0.37)</td>
</tr>
<tr>
<td>4-Mar-12</td>
<td>94.1 (± 2.61)</td>
<td>35.4 (± 1.53)</td>
<td>38.7 (± 1.71)</td>
<td>33.4 (± 1.71)</td>
</tr>
<tr>
<td>10-Mar-12</td>
<td>77.2 (± 2.85)</td>
<td>12.6 (± 0.74)</td>
<td>9.2 (± 0.36)</td>
<td>10.1 (± 0.52)</td>
</tr>
<tr>
<td>31-Mar-12</td>
<td>17.1 (± 1.98)</td>
<td>8.8 (± 0.53)</td>
<td>8.1 (± 0.56)</td>
<td>7.8 (± 0.55)</td>
</tr>
<tr>
<td></td>
<td><strong>48.6 (± 1.97)</strong></td>
<td><strong>8.8 (± 0.65)</strong></td>
<td><strong>15.5 (± 1.06)</strong></td>
<td><strong>14.2 (± 0.93)</strong></td>
</tr>
<tr>
<td><strong>Snowmobile</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12-Dec-11</td>
<td>13.8 (± 0.66)</td>
<td>13.2 (± 0.49)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>9-Jan-12</td>
<td>35.4 (± 1.47)</td>
<td>22.1 (± 1.44)</td>
<td>8.0 (± 0.50)</td>
<td>10.5 (± 0.63)</td>
</tr>
<tr>
<td>19-Feb-12</td>
<td>63.5 (± 1.94)</td>
<td>13.9 (± 0.88)</td>
<td>4.4 (± 0.52)</td>
<td>4.7 (± 0.34)</td>
</tr>
<tr>
<td>4-Mar-12</td>
<td>101.0 (± 2.43)</td>
<td>39.2 (± 1.06)</td>
<td>6.4 (± 0.49)</td>
<td>6.9 (± 0.60)</td>
</tr>
<tr>
<td>10-Mar-12</td>
<td>82.5 (± 2.81)</td>
<td>13.4 (± 0.80)</td>
<td>7.8 (± 0.47)</td>
<td>7.5 (± 0.58)</td>
</tr>
<tr>
<td>31-Mar-12</td>
<td>20.6 (± 3.67)</td>
<td>7.2 (± 0.62)</td>
<td>8.7 (± 0.52)</td>
<td>6.6 (± 0.43)</td>
</tr>
<tr>
<td></td>
<td><strong>52.8 (± 2.30)</strong></td>
<td><strong>18.2 (± 0.78)</strong></td>
<td><strong>7.1 (± 0.24)</strong></td>
<td><strong>7.3 (± 0.27)</strong></td>
</tr>
<tr>
<td><strong>Road</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12-Dec-11</td>
<td>13.4 (± 0.59)</td>
<td>12.3 (± 0.55)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>9-Jan-12</td>
<td>26.1 (± 1.43)</td>
<td>20.0 (± 0.95)</td>
<td>6.5 (± 1.02)</td>
<td>6.4 (± 0.63)</td>
</tr>
<tr>
<td>19-Feb-12</td>
<td>54.2 (± 2.38)</td>
<td>14.5 (± 0.89)</td>
<td>3.8 (± 0.30)</td>
<td>3.8 (± 0.25)</td>
</tr>
<tr>
<td>4-Mar-12</td>
<td>98.9 (± 2.68)</td>
<td>34.9 (± 1.30)</td>
<td>8.6 (± 0.28)</td>
<td>8.3 (± 0.30)</td>
</tr>
<tr>
<td>10-Mar-12</td>
<td>76.2 (± 2.7)</td>
<td>11.6 (± 0.58)</td>
<td>5.9 (± 0.54)</td>
<td>4.6 (± 0.39)</td>
</tr>
<tr>
<td>31-Mar-12</td>
<td>17.9 (± 1.53)</td>
<td>10.3 (± 0.32)</td>
<td>6.1 (± 0.45)</td>
<td>5.2 (± 0.44)</td>
</tr>
<tr>
<td></td>
<td><strong>47.8 (± 1.93)</strong></td>
<td><strong>17.3 (± 0.59)</strong></td>
<td><strong>6.2 (± 0.27)</strong></td>
<td><strong>5.6 (± 0.21)</strong></td>
</tr>
</tbody>
</table>
Fig. 4-2. Mean (±SE bars) off-trail depth (OffSD) and penetrability (OffSP) measurements for 6 surveys on Kelsey and Dixville Mountains during winter 2011-2012.
Fig. 4-3. Mean (±SE bars) off-trail snow depth (OffSD) and penetrability (OffSP) by survey date for road, snowmobile and snowshoe survey routes on Kelsey and Dixville Mountains during winter 2011-2012. Differences in snow depth were significant during the 9 January 2012 survey (P <0.0001), 19 February 2012 survey (P <0.012) and for snow penetrability during the 31 March survey.
more variable (Table 4-2, Fig. 4-3). The last survey (31 March) was characterized by a diminishing snowpack that consisted of shallow and supportive snow; on- and off-trail snow depths were different ($P < 0.0001$), yet on and off-trail snow penetration measurements were not (Table 4-2, Fig. 4-3).

**Snowpack Model Results**

Twenty-one competing models were tested to explain the off-trail snowpack data for the entire winter; there were 4 and 2 top competing models for the snow depth and penetrability analyses, respectively (Tables 4-3, 4-4). The parameters of the top models ("Forest Type", "Elevation", and "Survey Route Type") were averaged to explain the snowpack during surveys (Tables 4-3, 4-4). Model parameters were compared against softwood stands and snowshoe trails that were considered to represent baseline conditions present in high elevation forests. The deepest and least supportive snowpack was found at higher elevations, in mixed-wood stands, and along snowmobile trails, whereas hardwood stands had the shallowest and most supportive snowpack (Tables 4-3, 4-4). Further, the high elevation roads had a similar snowpack to the control parameters (Tables 4-3, 4-4).

**Carnivore Detections**

A total of 482 track encounters occurred including red fox, marten, coyote, and fisher; no bobcat tracks were detected. Red fox were detected most often (n = 258; 54%), and marten (n = 122; 25%), coyote (n = 97; 20%), and red fox combined represented 99% of encounters; fisher were rare (n = 5; 1%) and excluded from comparative analyses (Table 4-5). Use of survey routes differed among species ($\chi^2 < 0.0001$). Red fox and
Table 4-3. Model candidate, number of parameters (K), AICc, Delta AICc, AICc weight, cumulative weight (Cum. Wt), and log likelihood (LL) for 21 snow depth models, and parameter estimates, standard error (SE), z-value, and z-statistic for top models (Delta AICc scores <2). Model selection indicates that forest type, elevation, and survey route type were the best predictors of snow depth. A deep snowpack was found at higher elevation and mixed wood stands whereas hardwood stands contained shallow snow.

<table>
<thead>
<tr>
<th>Model Candidate</th>
<th>K</th>
<th>AICc</th>
<th>Delta AICc</th>
<th>AICcWt</th>
<th>Cum.Wt</th>
<th>LL</th>
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</tr>
<tr>
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<td>13.19</td>
<td>0</td>
<td>1</td>
<td>-678.56</td>
</tr>
</tbody>
</table>

Model-averaged coefficients:  

|                          | Estimate | SE   | z-value | Pr(>|z|) |
|--------------------------|----------|------|---------|---------|
| (Intercept)              | 47.816   | 15.818 | 3.023   | 0.003   |
| elevation                | 0.009    | 0.005 | 1.879   | 0.060   |
| Hardwood                 | -17.787  | 5.771 | 3.082   | 0.002** |
| Mixed                    | 2.908    | 4.109 | 0.708   | 0.479   |
| Road                     | -1.512   | 6.908 | 0.219   | 0.827   |
| Snowmobile               | 10.416   | 7.257 | 1.435   | 0.151   |

* P <0.05  
** P <0.01
Table 4-4. Model candidate, number of parameters (K), AICc, Delta AICc, AICc weight, cumulative weight (Cum. Wt), and log likelihood (LL) for 21 snow penetrability models, and parameter estimates, standard error (SE), z-value, and z-statistic for top models (Delta AICc scores <2). Model selection indicates that forest type, elevation, and survey route type were the best predictors of snow penetrability. An unsupportive snow was found at higher elevation and mixed wood stands whereas hardwood stands contained supportive snow.

<table>
<thead>
<tr>
<th>Model Candidate</th>
<th>K</th>
<th>AICc</th>
<th>Delta_AICc</th>
<th>AICcWt</th>
<th>Cum.Wt</th>
<th>LL</th>
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</tr>
<tr>
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<td>4.01</td>
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<td>0.83</td>
<td>-547.94</td>
</tr>
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<td>4.27</td>
<td>0.05</td>
<td>0.88</td>
<td>-544.66</td>
</tr>
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<td>13.75</td>
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<td>1</td>
<td>-545.85</td>
</tr>
</tbody>
</table>

| Model-averaged coefficients: | Estimate | SE     | z-value | Pr(|z|) |
|-------------------------------|----------|--------|---------|-------|
| (Intercept)                   | 5.475    | 6.208  | 0.882   | 0.378 |
| elevation                     | 0.003    | 0.001  | 2.313   | 0.021*|
| Hardwood                      | -1.325   | 1.982  | 0.669   | 0.504 |
| Mixed                         | 3.547    | 1.252  | 2.834   | 0.005**|
| Road                          | 0.795    | 2.160  | 0.368   | 0.713 |
| Snowmobile                    | 3.296    | 2.252  | 1.464   | 0.143 |

* P <0.05
** P <0.01
coyotes were encountered most often along roads (73% and 20%) and snowmobile trails (47% and 32%); conversely, marten were encountered most often along snowshoe trails (67%; Table 4-5, Fig. 4-4).

Red fox were encountered along roads more than snowmobile trails ($P = 0.0014$) and snowshoe trails ($P < 0.0001$) (Table 4-5). Coyotes were not encountered along specific survey routes more than expected; however, roads and snowmobile trails were used 4x more than snowshoe trails (Table 4-5). Marten were encountered more often than expected on snowshoe trails than roads ($P < 0.0001$) and snowmobile trails ($P < 0.0001$) (Table 4-5).

The direction of travel for each species varied depending on the route type ($\chi^2 < 0.0001$). Fox and coyotes crossed snowshoe trails more often than expected, and rarely travelled along them ($\chi^2 < 0.0001$) (Table 4-6). Fox often crossed snowmobile trails and roads yet travelled along them more often than snowshoe trails ($\chi^2 < 0.0001$), and coyotes travelled up and across snowmobile trails and roads more often than travelling down them ($\chi^2 < 0.0001$) (Table 4-6). Marten rarely went up or down any survey routes; they were often detected crossing snowshoe trails ($\chi^2 < 0.0001$) (Table 4-6).

The distance predators travelled along survey routes was calculated to determine if deeper snow would cause predators to utilize compacted trails in response to an increasing snowpack. Fox travelled a total of 13,125 m ($\bar{X} = 190 \pm 30$ m) along survey routes; coyotes traveled a total of 4,605 m ($\bar{X} = 170 \pm 74$), marten 157 m ($n = 1$), and fisher were only observed crossing survey routes (Table 4-6). The distance coyotes travelled along survey routes was correlated positively with snow penetrability ($r =$
Table 4-5. Total carnivore counts (tracks) and average off-trail snow depth and penetration measurements for 6 surveys along 3 survey routes from 12 December 2011-31 March 2012. Count totals, % of species total (red), and % contribution for species by each survey route type (black). Count totals and average snow measurements for each survey route type are in bold. Detection along survey routes varied by species ($\chi^2 < 0.0001$), and there was a positive correlation for coyote counts vs. snow depth ($r = 0.679$).

<table>
<thead>
<tr>
<th>Survey Route</th>
<th>total tracks</th>
<th>red fox</th>
<th>coyote</th>
<th>marten</th>
<th>fisher</th>
<th>Depth</th>
<th>Penetration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Snowshoe</strong></td>
<td><strong>122 (25.4%)</strong></td>
<td><strong>27 (10%, 22%)</strong></td>
<td><strong>10 (10%, 8%)</strong></td>
<td><strong>82 (67%, 67%)</strong></td>
<td><strong>3 (60%, 3%)</strong></td>
<td><strong>48.57</strong></td>
<td><strong>17.05</strong></td>
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<tr>
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<td>-</td>
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<td><strong>Snowmobile</strong></td>
<td><strong>118 (24.2%)</strong></td>
<td><strong>55 (21%, 47%)</strong></td>
<td><strong>38 (39%, 32%)</strong></td>
<td><strong>23 (19%, 19%)</strong></td>
<td><strong>2 (40%, 2%)</strong></td>
<td><strong>52.78</strong></td>
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<td>-</td>
<td>20.55</td>
<td>7.18</td>
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<tr>
<td><strong>Road</strong></td>
<td><strong>242 (50.4%)</strong></td>
<td><strong>176 (68%, 73%)</strong></td>
<td><strong>49 (51%, 20%)</strong></td>
<td><strong>17 (14%, 7%)</strong></td>
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<td><strong>17.27</strong></td>
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<td>10.33</td>
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<td><strong>Totals</strong></td>
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<td><strong>258 (54%)</strong></td>
<td><strong>97 (20%)</strong></td>
<td><strong>122 (25%)</strong></td>
<td><strong>5 (1%)</strong></td>
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Table 4-6. Distance travelled (m) and direction of travel (up, down, across) for survey carnivores, and average snow and penetration for 6 surveys along 3 survey routes from 12 December 2011-31 March 2012. Species totals and average snowpack measurements for each survey route type are in bold. Direction of travel varied for each survey species ($\chi^2 < 0.0001$), and distance traveled for coyotes was positively correlated with snow penetrability ($r = 0.431$).

<table>
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<th>Survey route</th>
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<th>marten</th>
<th>depth</th>
<th>penetration</th>
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<td>distance</td>
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<td>down</td>
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<td>distance</td>
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<tr>
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<td>17</td>
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<td>4</td>
<td>3</td>
<td>-</td>
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<tr>
<td>4-Mar-12</td>
<td>-</td>
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<td>304</td>
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<td>1149</td>
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<td>31-Mar-12</td>
<td>1068</td>
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<td>2</td>
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<td>67</td>
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<td>-</td>
<td>9</td>
<td>-</td>
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<td>10-Mar-12</td>
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<td>13125</td>
<td>94</td>
<td>73</td>
<td>135</td>
<td>4605</td>
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</table>
Fig. 4-4. Locations of survey species detections along road, snowmobile and snowshoe survey routes on Kelsey and Dixville Mountains during winter 2011-2012. High elevation habitat is ≥823 m.
Similarly, a strong positive correlation existed between coyote counts and snow depth ($r = 0.679$); correlations between distance travelled, counts, and snowpack data were weak for other species (Table 4-5).

The mean elevation that species were detected over the entire winter varied ($P < 0.0001$; Fig. 4-5). Marten were detected at higher elevations ($\bar{X} = 872 \pm 8$ m) than fox ($\bar{X} = 839 \pm 6$ m) ($P = 0.004$), and fox were detected at higher elevations than coyote ($\bar{X} = 773 \pm 9$ m) ($P < 0.0001$; Table 4-7, Fig. 4-5). There were different trends for 2 surveys; fox ($\bar{X} = 818 \pm 23$ m) and marten ($\bar{X} = 825 \pm 26$ m) were detected at similar elevations during the 12 December survey characterized by minimal snow depth ($P = 0.846$), and fox ($\bar{X} = 869 \pm 9$ m) were detected at higher elevations ($\bar{X} = 779 \pm 18$ m) on 10 March survey with deep snow ($P < 0.0001$; Table 4-7).

**Discussion**

**Snowpack Analysis**

As expected, the snowpack along survey routes was more compacted than measured off-trail. It was deeper and less supportive at higher elevations and in mixed wood stands, and shallower and more supportive in hardwood stands (at lower elevations) and along road routes. Similarly, snowpack was deeper and less supportive in mixed stands in Maine and softwood stands held snow longest; shallow and supportive snow in open areas were attributed to wind and sun exposure that limits snow accumulation and creates crusting conditions (Halpin and Bissonette 1988). The hardwood stands were at lower elevations and heavily harvested in the study area, and these stands and road routes were more exposed to wind and sun than the other route types. Interestingly, the canopy closure model ("closure") ranked relatively high
Table 4-7. Mean (±SE) elevation survey species were detected for 6 surveys from 12 December 2011-31 March 2012. Overall, marten were detected at higher elevations ($P = 0.004$) than fox; and fox were detected at higher elevations than coyote ($P <0.0001$).

<table>
<thead>
<tr>
<th>Survey</th>
<th>Marten</th>
<th>Fox</th>
<th>Coyote</th>
</tr>
</thead>
<tbody>
<tr>
<td>12-Dec-11*</td>
<td>825 (±26)</td>
<td>818 (±23)</td>
<td>-</td>
</tr>
<tr>
<td>9-Jan-12</td>
<td>878 (±14)</td>
<td>669 n = 1</td>
<td>722 (±43) n = 8</td>
</tr>
<tr>
<td>19-Feb-12</td>
<td>917 (±18)</td>
<td>746 (±24)</td>
<td>672 (±12) n = 9</td>
</tr>
<tr>
<td>4-Mar-12</td>
<td>882 (±23)</td>
<td>750 (±14)</td>
<td>-</td>
</tr>
<tr>
<td>10-Mar-12**</td>
<td>779 (±18)</td>
<td>869 (±9)</td>
<td>789 (±7) n = 92</td>
</tr>
<tr>
<td>31-Mar-12</td>
<td>908 (±16)</td>
<td>820 (±10)</td>
<td>743 (±27) n = 6</td>
</tr>
<tr>
<td></td>
<td>872 (±8) n = 165</td>
<td>839 (±6) n = 302</td>
<td>773 (±10) n = 115</td>
</tr>
</tbody>
</table>

* Marten and fox were detected at similar elevations during this survey ($P = 0.846$)
** Fox were detected at higher elevations during this survey ($P <0.001$).
Fig. 4-5. Mean elevation (m) of 3 survey species during 6 snow track surveys on Kelsey and Dixville Mountains during winter 2011-2012. High elevation habitat is >823 m (red horizontal line). Confidence intervals are in blue. Survey species were all detected at different elevations ($P < 0.0001$).
compared to other models, inferring indirectly that a shallower and more supportive snowpack existed in open stands (see “closure”, Tables 4-4 and 4-5).

The deeper and less supportive snowpack found along snowmobile trails was probably attributed to their narrowness; overall, their character more closely resembled snowshoe trails than roads. Although they were often located in areas with the deepest snowpack as were snowshoe trails, they were used more by fox and coyote than snowshoe trails.

It is likely that interacting effects existed between and among model parameters; for example, strong correlations existed between “forest type”, “elevation”, and “closure”. This is unsurprising as most mixed and softwood stands were at higher elevations and uncut, and most hardwood stands were partially harvested and had reduced canopy closure during winter. The primary purpose of the snow stations were to compare off- and on-trail measurement and to evaluate if survey data were correlated with an increasing snowpack. To fully evaluate these interactions, greater sampling would be required.

Carnivore Detections

As expected, the roads allowed competing species to access high elevation habitat. Roads and snowmobile trails were used more frequently by fox and coyote than marten; conversely, both were rarely detected along snowshoe trails, typically only crossing them. Canine encounters were markedly high, whereas fisher were encountered infrequently. Live and camera trapping data from 2010-2012 also resulted in few fisher captures. The snowpack was deepest during mid-winter surveys as was the greatest difference between off-trail and on-trail snow measurement; this corresponded with the
greatest use of roads and snowmobile trails by fox and coyotes. Further, snowfall during winter 2011-2012 was below average suggesting that use might increase during deep snow winters.

Pre-construction track surveys were conducted by Stantec Consulting Inc. during winter 2007. High elevation forest habitat, including the specific study area, was surveyed 3x by snowshoe to document presence of carnivores and prey species with paired high and low elevation survey routes. Species totals for these surveys were 94 marten, 66 fisher, 4 coyotes, and 1 fox, a measureable difference from this study; canines were only detected along low elevation transects (Stantec 2007). The differences between the detection total of pre (Stantec)- and post-construction surveys (this study) could be explained by a number of factors including: 1) population fluctuations of survey species (Thompson et al. 1989, Fryxell et al. 1999, Jensen et al. 2012), 2) survey lengths of pre-construction surveys were shorter (1 km) and missed detecting larger survey species (Thompson et al. 1989), 3) pre-construction survey routes were not located along roads or trails, 4) effort was less (3 versus 6 surveys) on the pre-construction surveys, and 5) the winter of 2007 was characterized by a deep and unsupportive snowpack (Adam Gravel, Stantec Consulting) favoring smaller carnivores adapted for deep snow. Interestingly, fisher were detected more often along high elevation (n = 42) than low elevation (n = 23) transects. However, 4 of the 5 high elevation transects were either at or below the lower range of high elevation habitat (i.e., ~823 m); 83% of fisher detections occurred along these 4 transects or at low elevation (Stantec 2007).

Fox and coyote use roads and edge habitat because of increased prey abundance (Arjo and Pletscher 2004, Atwood et al. 2004, Silva et al. 2009, Boisjoly et al. 2010),

It is possible that high elevation spruce-fir waves contain the highest quality habitat for snowshoe hare in New Hampshire (pers. comm., Will Staats, New Hampshire Fish and Game Department), and increased access to this resource by competing carnivores could be detrimental to marten from a competitive standpoint. Further, fox might be forced into higher elevation habitat to avoid competing with coyotes (Harrison et al. 1989) and this separation is further exacerbated and/or compounded by high elevation roads. Fox were found at higher elevations than coyotes at the study site, and are better designed for deep snow (Buskirk et al. 2000, Krohn et al. 2004).

This study provides evidence that high elevation roads and snowmobile trails probably provide access for fox and coyote into high elevation habitat otherwise unused in typical snow conditions. It follows that an increasing likelihood of predation and competition with marten exists. Although access does not guarantee that species will
compete for resources (Kolbe et al. 2007, Dowd 2010), the potential for increased interaction seem likely because marten crossed roads and snowmobile trails. Further, the snowpack along the margins of the roads was more compacted allowing red fox to travel outside the survey route and along edges; fox tracks were observed leaving the survey routes and entering high elevation habitat on several occasions. Also, coyotes use open areas adjacent to young dense conifer stands to hunt snowshoe hare (Boisjoly et al. 2010) and these conditions were prominent along the high elevation ridgelines.

The roads and snowmobile trails clearly provided ease in travel during winter, but they also attract other predators during snow-free months. Species adapted to edge environments and generalist species will presumably capitalize on the road habitat required for wind farm construction and maintenance, providing the potential for a broader predator community. For example, birds of prey not typically associated with contiguous forests (e.g., red-tailed hawks [Buteo jamaicensis]) and coyotes were observed travelling and resting in high elevation habitat during summer following the post-construction period and 3 mortalities (2 fox, 1 coyote) were documented within 200 m of the road in high elevation habitat (see Chapter 1). Such community shifts might reduce the resiliency of specialized high elevation forest communities that typically are associated with relatively undisturbed conditions. High elevation habitat is believed important for marten because such areas are contiguous, roadless, and have a deeper and less supportive snowpack. The roads required for wind farm construction and maintenance provide year-round access to competing predators, create edge habitat, and remove habitat; combined, these factors increase the likelihood of competition and predation, which has the potential to reduce marten fitness over time. Given the current
expansion of wind farms in northern New England, continued monitoring is warranted to best evaluate these impacts in high elevation communities.
CONCLUSIONS AND RECOMMENDATIONS

This study indicated that high-elevation forest habitat characterized by deep snow and contiguous, mature mixed-wood and coniferous stands was preferentially used in winter by American marten. Wind farm construction temporarily disrupted use of this habitat, and permanent access roads provided unnatural winter access for competitor carnivores of marten. The wide turbine pads and roads associated with wind farm development that remain permanently open were selected against by marten at the stand scale, and regenerating forest was selected against during both seasons. Although the landscape was comprised of ~25% regenerating forest and despite the measured impacts, the study area supported a high density adult population similar to that measured in core marten range in the northeastern United States. Statewide population estimates ranged from ~700-3000 marten based on a GIS habitat-based occupancy model. The specific wind farm development did not cause marten to permanently abandon the study area, but negative impacts were documented including temporary displacement of habitat use, reduced available habitat, and increased predator access and presumably competition/predation. Given that most northeastern states will experience continual wind farm development while marten populations recolonize their historic range, the following specific results and conclusions should aid in assessing and balancing potential conflicts in the northeast.
Chapter 1: American Marten Demography in Northern New Hampshire

1) A total of 34 marten (17M, 17F) were captured 121 times from 28 October 2010-9 August 2012 during live-trapping; 28 were adult (>1 yr old; 15 M, 13 F) and 6 were juvenile (<1 yr old; 2 M, 4 F).

2) The average weight for both sexes (males = 871 ± 19 g; females = 529 ± 14 g) was similar to those in other regional studies.

3) An even sex ratio was found for all marten; the adult sex-ratio was slightly biased towards males (1.3). The adult-juvenile ratio was biased towards adults (28:6).

4) Reproduction was documented on 7 occasions either directly (i.e., kits were observed) or indirectly (i.e., teats of adult female marten were swollen and milk could be expressed).

5) Breeding potential (i.e., intersexual home range overlap) was documented for 5 pairs and was similar to that measured in Maine. Mean home range overlap was higher for females-males (87 ± 6%) than males-females (48 ± 8%). There were likely more breeding pairs but sample size was low for female home ranges.

6) There were 17 recorded mortalities (5 adult M, 7 adult F, and 5 juvenile F) of 15 radio-collared marten and 2 uncollared kits; predation was confirmed for 10 marten (2 fox, 2 coyotes, 1 marten/fisher, 5 unknown). Research-related mortality occurred with starvation associated with 2 of the 3 mortalities. Starvation was associated with 1 other female mortality, and 2 mortalities were directly human-caused (incidental trapping and gunshot).

7) Marten were more easily live-trapped in winter; catch-per-unit-effort (CPUE) was similar within seasons both years.
8) The proportion of marten identified using camera traps was 82% in winter 2011 and 90% in winter 2012. Identification would improve with better performing cameras, using settings that allow for continuous pictures, and standardizing trap configuration such that camera distance is fixed between 40-80 cm and trap height is 15-19 cm tall.

9) Population density analyses were conducted both winters using photographic-mark-recapture (PMR) and compared with live-trapping in 2012 to assess the reliability of the PMR technique and the precision of estimates. Capture rates were higher and similar during winter 2012 for both techniques; 13 marten were captured 120 x in 45 d (2.7 captures/d) during PMR 2011, 15 marten were captured 89 x in 19 d (4.7 captures/d) during PMR 2012 and 15 marten were captured 30 x in 6 d (5 captures/day) during live-trapping 2012. However, the proportion of marten recaptured was higher for PMR (14 of 15, 93%) compared to live trapping (10 of 15, 66%).

10) PMR density was 46 marten/100 km² (95% Bayesian C.L. = 27-69) in winter 2011 and 61 marten/100 km² (95% Bayesian C.L. = 35-90) in winter 2012, and live-trapping density was 41 marten/100 km² (95% Bayesian C.L. = 16-95) in winter 2012. PMR density was more precise compared to live-trapping due to higher recapture and longer effort.

11) The statewide population was estimated in winter 2011 and 2012 using the PMR density estimates and a statewide GIS occupancy model. There were 3 estimates for each year based on the mean, -1 SD, and -2 SD probability values of marten occurrence within the density sampling area. The mean population estimate was
701 (411-1,052) marten in winter 2011 and 930 (533-1,372) in winter 2012. The 
-1 SD population estimate was 1,332 (782-1,998) marten in winter 2011 and 
1,766 (1,013-2,606) in winter 2012. The -2 SD population estimate was 2,231  
(1,309-3,346) marten in winter 2011 and 2,958 (1,697-4,364) in winter 2012. The 
average PMR density during both winters (0.52) was similar to that estimated in a 
forest reserve in Maine (>0.52 marten/km²) considered near carrying capacity.

Chapter 2: Spatial Ecology and Resource Selection of a High Elevation American 
Marten Population in Northern New Hampshire

12) Aggregate 95% minimum convex polygon home range sizes for male (X = 2.95 ± 
0.27 km²) and female (X = 1.55 ± 0.20 km²) marten were small relative to 
previous studies; home range size of males was 20% larger during leaf-on than 
leaf-off seasons.

13) Seasonal home range shifts were similar to other studies in North America. The 
consecutive home range overlap (66%) used to measure home range fidelity was 
considered high indicating that the observed home range shifts were normal.

14) Habitat selection was more pronounced at the landscape scale compared to the 
stand scale with selection evident during both leaf-on and leaf-off seasons.

15) Marten positioned home range to include all mature forest types, while 
minimizing regenerating forest during both seasons, with greater selection for 
mature hardwood forests during leaf-on seasons.

16) Stand scale selection was evident during leaf-off seasons with stronger selection 
for mixed-wood and coniferous stands and less use of regenerating and hardwood 
stands, whereas minimal selection occurred during leaf-on seasons.
17) Home range size increased during the leaf-on season, and for marten with a higher proportion of regenerating and softwood forest within their home range.

Chapter 3: Impact of Wind Farm Development on Use of High-Elevation Habitat by American Marten

18) Use of high elevation habitat was influenced by seasonal patterns and specific phases of the wind farm development.

19) Marten were more likely to be detected and detection rates were higher \( (P < 0.0001) \) during leaf-off seasons when 87% (104,473) of detections occurred. There was greater nocturnal use of high elevation habitat during leaf-off seasons (52%) and greater diurnal use during leaf-on seasons (69%).

20) Marten were less likely to be detected during road construction when detection rates were 21% lower than in other operational periods.

21) Measures of proximity were lower in all periods following pre-construction monitoring, with the greatest declines \( (P < 0.001) \) in construction periods. The disturbance associated with construction displaced marten from high elevation habitat temporarily as use post-construction gradually returned to the pre-construction level.

Chapter 4: Potential Influence of Wind Farms on Mobility and Presence of Carnivores at High Elevation

22) Roads and snowmobile trails provided competing predators access to high elevation habitat normally inaccessible in winter. Red fox and coyotes were detected most often (74%), followed by marten (25%); fisher were rarely detected (1%).
23) The detection along survey routes differed among species ($\chi^2 < 0.0001$); canids were detected on roads and snowmobile trails more than on snowshoe trails, and marten were detected along snowshoe trails more often than on roads and snowmobile trails.

24) Canines travelled along survey routes more often than expected ($\chi^2 < 0.0001$) and marten crossed survey routes more often than expected ($\chi^2 < 0.0001$).

25) There were elevational differences ($P < 0.0001$) in the location of surveyed species with mean elevation of marten ~35-100 m higher than fox and coyote; however, such differences are biologically irrelevant given the predation of marten by these canids.

26) Snow was deeper and less supportive off-trail ($P < 0.0001$) than on-trail providing evidence that snow was compacted along survey routes. Snow was generally deeper ($P = 0.06$) and less supportive ($P = 0.021$) at higher elevation and mixed-wood stands contained deep and unsupportive ($P = 0.005$) snow, whereas hardwood stands contained the shallowest ($P = 0.002$) and most supportive snow. These results indicate the ecological separation normally provided by snow conditions at high elevations that limit seasonal competition and predation among/by these carnivores.

**Recommendations**

This project was conducted in response to the development of a wind farm park in high-elevation forest that provides unique habitat for marten, a wildlife species of concern in northern New England. Because wind power development will likely continue to increase in similar areas throughout the region, and that this study identified
certain negative influences on marten, it is imperative to institute effective and reasonable assessment procedures to identify baseline conditions and potential impact of such developments. Minimally, I recommend using the PMR technique described in Chapter 1 for pre- and post-construction monitoring as it is cost effective, easy to implement and repeat, minimally invasive, and provides fine scale data of presence, seasonal use, and density estimates of marten. Ideally, a local control site with similar site conditions should be established for comparison, to ensure data integrity, and to identify unassociated environmental influences that influence marten behavior and habitat use.
LITERATURE CITED


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APPENDIX A. INSTITUTIONAL ANIMAL CARE AND USE COMMITTEE (IACUC) APPROVAL FOR HANDLING AND CARE OF ANIMAL SUBJECTS

University of New Hampshire
Research Integrity Services, Office of Sponsored Research
Service Building, 51 College Road, Durham, NH 03824-3585
Fax: 603-862-3564

29-Sep-2010

Pekins, Peter J
Natural Resources & The Environment, James Hall
Durham, NH 03824

IACUC #: 100807
Project: Ecology of American Marten
Category: D
Approval Date: 28-Sep-2010

The Institutional Animal Care and Use Committee (IACUC) reviewed and approved the protocol submitted for this study under Category D on Page 5 of the Application for Review of Vertebrate Animal Use In Research or Instruction - Animal use activities that involve accompanying pain or distress to the animals for which appropriate anesthetic, analgesic, tranquilizing drugs or other methods for relieving pain or distress are used.

Approval is granted for a period of three years from the approval date above. Continued approval throughout the three year period is contingent upon completion of annual reports on the use of animals. At the end of the three year approval period you may submit a new application and request for extension to continue this project. Requests for extension must be filed prior to the expiration of the original approval.

Please Note:
1. All cage, pen, or other animal identification records must include your IACUC # listed above.
2. Use of animals in research and instruction is approved contingent upon participation in the UNH Occupational Health Program for persons handling animals. Participation is mandatory for all principal investigators and their affiliated personnel, employees of the University and students alike. A Medical History Questionnaire accompanies this approval; please copy and distribute to all listed project staff who have not completed this form already. Completed questionnaires should be sent to Dr. Glad! Porsche, UNH Health Services.

If you have any questions, please contact either Dean Elder at 862-4629 or Julie Simpson at 862-2003.

For the IACUC

Jessica A. Bolker, Ph.D.
Chair

cc: File
APPENDIX B. DATALOGGER MONITORING HISTORY FOR 3 TOWERS (SOUTH (S), MIDDLE (M), AND NORTH (N)) DURING 11 WIND FARM CONSTRUCTION/OPERATION PERIODS, FROM 5 DECEMBER 2010 – 23 DECEMBER 2012. MONITORING AFTER PRE-CONSTRUCTION WAS CHARACTERIZED BY 3 TOWERS MONITORING FOR A $\bar{X} = 90 \pm 4\%$.

<table>
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</tr>
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</tr>
<tr>
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<td>22</td>
<td>32%</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>36</td>
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<td></td>
<td>S, M</td>
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<td></td>
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<td>2</td>
<td>2%</td>
</tr>
<tr>
<td></td>
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<tr>
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<td>Operational 3</td>
<td>S, N, M</td>
<td>49</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>49</td>
<td></td>
</tr>
<tr>
<td>Operational 4</td>
<td>S, N, M</td>
<td>104</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>104</td>
<td></td>
</tr>
<tr>
<td>Operational 5</td>
<td>S, N, M</td>
<td>66</td>
<td>92%</td>
</tr>
<tr>
<td></td>
<td>S, M</td>
<td>5</td>
<td>7%</td>
</tr>
<tr>
<td></td>
<td>S, N</td>
<td>1</td>
<td>1%</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>72</td>
<td></td>
</tr>
<tr>
<td>Operational 6</td>
<td>S, N, M</td>
<td>25</td>
<td>60%</td>
</tr>
<tr>
<td></td>
<td>S, M</td>
<td>13</td>
<td>31%</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>4</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>42</td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX C. DATALOGGER MONITORING HISTORY FOR 3 TOWERS (SOUTH (S), MIDDLE (M), AND NORTH (N)) DURING 5 SEASONS, FROM 5 DECEMBER 2010 – 23 DECEMBER 2012. MONITORING AFTER LEAF-OFF 1 WAS CHARACTERIZED BY 3 TOWERS MONITORING FOR A $\bar{x} = 88 \pm 8\%$.

<table>
<thead>
<tr>
<th>Season</th>
<th>Tower</th>
<th>Days</th>
<th>% of Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaf-off 1*</td>
<td>S, N</td>
<td>86</td>
<td>53%</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>22</td>
<td>14%</td>
</tr>
<tr>
<td></td>
<td>S, M</td>
<td>18</td>
<td>11%</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>162</td>
<td></td>
</tr>
<tr>
<td>Leaf-on 1</td>
<td>S, N</td>
<td>131</td>
<td>86%</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>13</td>
<td>8%</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>2</td>
<td>1%</td>
</tr>
<tr>
<td></td>
<td>S, M</td>
<td>5</td>
<td>3%</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>153</td>
<td></td>
</tr>
<tr>
<td>Leaf-off 2</td>
<td>S, M</td>
<td>210</td>
<td>99%</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>213</td>
<td></td>
</tr>
<tr>
<td>Leaf-on 2</td>
<td>S, N</td>
<td>153</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>153</td>
<td></td>
</tr>
<tr>
<td>Leaf-off 3</td>
<td>S, N</td>
<td>46</td>
<td>67%</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>1</td>
<td>1%</td>
</tr>
<tr>
<td></td>
<td>S, M</td>
<td>18</td>
<td>26%</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>4</td>
<td>6%</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>69</td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX D. DATA CONTRIBUTION FOR 3 DATALOGGER TOWERS DURING EACH CONSTRUCTION PERIOD. TOTALS DO NOT INCLUDE IMPUTED DATA.

<table>
<thead>
<tr>
<th>Overall Contribution</th>
<th>Pre-Construction*</th>
<th>Road Clearing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tower</td>
<td>Detections</td>
<td>Contribution</td>
</tr>
<tr>
<td>Middle</td>
<td>43,079</td>
<td>35.95%</td>
</tr>
<tr>
<td>North</td>
<td>29,976</td>
<td>25.01%</td>
</tr>
<tr>
<td>South</td>
<td>46,779</td>
<td>39.04%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Construction Lull</th>
<th>Road Construction</th>
<th>Tower Construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tower</td>
<td>Detections</td>
<td>Contribution</td>
</tr>
<tr>
<td>Middle</td>
<td>3,655</td>
<td>66.56%</td>
</tr>
<tr>
<td>North</td>
<td>731</td>
<td>13.31%</td>
</tr>
<tr>
<td>South</td>
<td>1,105</td>
<td>20.12%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Operational 1</th>
<th>Operational 2</th>
<th>Operational 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tower</td>
<td>Detections</td>
<td>Contribution</td>
</tr>
<tr>
<td>Middle</td>
<td>14,359</td>
<td>29.48%</td>
</tr>
<tr>
<td>North</td>
<td>14,631</td>
<td>30.03%</td>
</tr>
<tr>
<td>South</td>
<td>19,724</td>
<td>40.49%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Operational 4</th>
<th>Operational 5</th>
<th>Operational 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tower</td>
<td>Detections</td>
<td>Contribution</td>
</tr>
<tr>
<td>Middle</td>
<td>3,470</td>
<td>46.45%</td>
</tr>
<tr>
<td>North</td>
<td>699</td>
<td>9.36%</td>
</tr>
<tr>
<td>South</td>
<td>3,302</td>
<td>44.20%</td>
</tr>
</tbody>
</table>

* The middle tower only monitored for 16% of the Pre-construction period.
APPENDIX E. DATA CONTRIBUTION FOR 3 DATALOGGER TOWERS DURING EACH SEASON. TOTALS DO NOT INCLUDE IMPUTED DATA.

<table>
<thead>
<tr>
<th>Overall Contribution</th>
<th>Leaf-off 1*</th>
<th>Leaf-on 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tower</td>
<td>Detections</td>
<td>Contribution</td>
</tr>
<tr>
<td>Middle</td>
<td>43,079</td>
<td>35.95%</td>
</tr>
<tr>
<td>North</td>
<td>29,976</td>
<td>25.01%</td>
</tr>
<tr>
<td>South</td>
<td>46,779</td>
<td>39.04%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Leaf-off 2</th>
<th>Leaf-on 2</th>
<th>Leaf-off 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tower</td>
<td>Detections</td>
<td>Contribution</td>
</tr>
<tr>
<td>Middle</td>
<td>26,753</td>
<td>31.27%</td>
</tr>
<tr>
<td>North</td>
<td>22,334</td>
<td>26.10%</td>
</tr>
<tr>
<td>South</td>
<td>36,471</td>
<td>42.63%</td>
</tr>
</tbody>
</table>

* The middle tower monitored for only 64% of Leaf-off 1.
APPENDIX F. HIGH ELEVATION HABITAT MONITORING HISTORY FOR MARTEN DURING 5 SEASONS ON KELSEY AND OWLHEAD MOUNTAINS. DAYS DETECTED (MONITORED, AND % OF PERIOD), AND # OF DETECTIONS (RATE) FOR MARTEN EACH PERIOD. SEASONAL AVERAGES AND RANGE ARE IN BOLD.

<table>
<thead>
<tr>
<th>marten</th>
<th>Leaf-off 1*</th>
<th>Leaf-on 1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>days</td>
<td>total (rate)</td>
</tr>
<tr>
<td>F5</td>
<td>162 (77,48%)</td>
<td>621 (4)</td>
</tr>
<tr>
<td>F9</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>M1</td>
<td>162 (104,64%)</td>
<td>2,113 (13)</td>
</tr>
<tr>
<td>M3</td>
<td>162 (129,80%)</td>
<td>4,101 (25)</td>
</tr>
<tr>
<td>M5</td>
<td>162 (135,83%)</td>
<td>10,945 (68)</td>
</tr>
<tr>
<td>M7</td>
<td>124 (48,39%)</td>
<td>717 (6)</td>
</tr>
<tr>
<td>M8</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>M10</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>M11</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

63% (39-83) 23 (4-68) 33% (3-76) 6 (0-20)

<table>
<thead>
<tr>
<th>marten</th>
<th>Leaf-off 2</th>
<th>Leaf-on 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>days</td>
<td>total (rate)</td>
</tr>
<tr>
<td>F5</td>
<td>210 (201,96%)</td>
<td>14,518 (69)</td>
</tr>
<tr>
<td>F9</td>
<td>103 (27,26%)</td>
<td>263 (3)</td>
</tr>
<tr>
<td>M1</td>
<td>213 (206,97%)</td>
<td>37,848 (178)</td>
</tr>
<tr>
<td>M5</td>
<td>167 (155,93%)</td>
<td>6,293 (38)</td>
</tr>
<tr>
<td>M8</td>
<td>96 (69,72%)</td>
<td>6,406 (67)</td>
</tr>
<tr>
<td>M10</td>
<td>198 (195,98%)</td>
<td>16,495 (83)</td>
</tr>
<tr>
<td>M11</td>
<td>145 (93,64%)</td>
<td>3,101 (21)</td>
</tr>
<tr>
<td>M15</td>
<td>64 (29,45%)</td>
<td>620 (10)</td>
</tr>
<tr>
<td>M16</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

74% (26-98) 59 (3-178) 56 % (3-100) 20 (0-71)

<table>
<thead>
<tr>
<th>marten</th>
<th>Leaf-off 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>days</td>
</tr>
<tr>
<td>M1</td>
<td>69 (55,80%)</td>
</tr>
<tr>
<td>M11</td>
<td>69 (24,35%)</td>
</tr>
<tr>
<td>M15</td>
<td>69 (58,84%)</td>
</tr>
<tr>
<td>M16</td>
<td>69 (10,14%)</td>
</tr>
</tbody>
</table>

53% (14-84) 7 (1-20)

* Includes predicted values from the north tower.
APPENDIX G. HIGH ELEVATION HABITAT MONITORING HISTORY FOR MARTEN DURING 11 CONSTRUCTION/OPERATIONAL PERIODS ON KELSEY AND OWLHEAD MOUNTAINS. DAYS DETECTED (MONITORED, AND % OF PERIOD), AND # OF DETECTIONS (RATE) FOR MARTEN EACH PERIOD. SEASONAL AVERAGES AND RANGE ARE IN BOLD.

<table>
<thead>
<tr>
<th>marten</th>
<th>Pre-Construction</th>
<th>Road Clearing</th>
<th>Construction Lull</th>
<th>Road Construction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>days total (rate)</td>
<td>days total (rate)</td>
<td>days total (rate)</td>
<td>days total (rate)</td>
</tr>
<tr>
<td>F5</td>
<td>69 (25,36%)</td>
<td>117 (2)</td>
<td>366 (8)</td>
<td>104 (15,14%)</td>
</tr>
<tr>
<td>F9</td>
<td>-</td>
<td></td>
<td>-</td>
<td>35 (0,0%)</td>
</tr>
<tr>
<td>M1</td>
<td>69 (54,78%)</td>
<td>1,322 (19)</td>
<td>588 (12)</td>
<td>227 (5)</td>
</tr>
<tr>
<td>M3</td>
<td>69 (41,59%)</td>
<td>535 (8)</td>
<td>1,560 (33)</td>
<td>2,125 (43)</td>
</tr>
<tr>
<td>M5</td>
<td>69 (47,68%)</td>
<td>3,369 (49)</td>
<td>5,178 (108)</td>
<td>2,450 (50)</td>
</tr>
<tr>
<td>M7</td>
<td>31 (12,39%)</td>
<td>67 (2)</td>
<td>99 (2)</td>
<td>551 (11)</td>
</tr>
<tr>
<td>M8</td>
<td>-</td>
<td></td>
<td>-</td>
<td>49 (8,16%)</td>
</tr>
<tr>
<td>M10</td>
<td>-</td>
<td></td>
<td>-</td>
<td>37 (20,54%)</td>
</tr>
<tr>
<td>M11</td>
<td>-</td>
<td></td>
<td>-</td>
<td>30 (1,3%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tower Construction</th>
<th>Operational 1</th>
<th>Operational 2</th>
<th>Operational 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>marten</td>
<td>days total (rate)</td>
<td>days total (rate)</td>
<td>days total (rate)</td>
</tr>
<tr>
<td>F5</td>
<td>72 (43,60%)</td>
<td>837 (12)</td>
<td>45 (41,91%)</td>
</tr>
<tr>
<td>F9</td>
<td>72 (1,1%)</td>
<td>76 (25,34%)</td>
<td>-</td>
</tr>
<tr>
<td>M1</td>
<td>72 (63,88%)</td>
<td>4,362 (61)</td>
<td>4,935 (54)</td>
</tr>
<tr>
<td>M5</td>
<td>-</td>
<td>92 (88,96%)</td>
<td>48 (38,79%)</td>
</tr>
<tr>
<td>M8</td>
<td>-</td>
<td>1,330 (19)</td>
<td>4,945 (54)</td>
</tr>
<tr>
<td>M10</td>
<td>-</td>
<td>77 (77,100%)</td>
<td>6,612 (86)</td>
</tr>
<tr>
<td>M11*</td>
<td>72 (28,39%)</td>
<td>1,739 (19)</td>
<td>4,184 (87)</td>
</tr>
<tr>
<td>M15</td>
<td>72 (52,72%)</td>
<td>1,155 (16)</td>
<td>1,478 (57)</td>
</tr>
<tr>
<td>M16</td>
<td>72 (2,3%)</td>
<td>116 (2)</td>
<td>317 (7)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Operational 4</th>
<th>Operational 5</th>
<th>Operational 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>marten</td>
<td>days total (rate)</td>
<td>days total (rate)</td>
</tr>
<tr>
<td>M1</td>
<td>104 (96,92%)</td>
<td>72 (63,88%)</td>
</tr>
<tr>
<td>M10</td>
<td>63 (63,100%)</td>
<td>4,398 (70)</td>
</tr>
<tr>
<td>M11</td>
<td>81 (34,42%)</td>
<td>289 (4)</td>
</tr>
<tr>
<td>M15</td>
<td>68 (27,40%)</td>
<td>57 (1)</td>
</tr>
<tr>
<td>M16</td>
<td>59 (2,3%)</td>
<td>5 (0)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>days total (rate)</th>
<th>days total (rate)</th>
<th>days total (rate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F5</td>
<td>117 (2)</td>
<td>104 (15,14%)</td>
<td></td>
</tr>
<tr>
<td>F9</td>
<td>35 (0,0%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M1</td>
<td>1,322 (19)</td>
<td></td>
<td>227 (5)</td>
</tr>
<tr>
<td>M3</td>
<td>535 (8)</td>
<td>1,560 (33)</td>
<td>2,125 (43)</td>
</tr>
<tr>
<td>M5</td>
<td>3,369 (49)</td>
<td>5,178 (108)</td>
<td>2,450 (50)</td>
</tr>
<tr>
<td>M7</td>
<td>67 (2)</td>
<td>99 (2)</td>
<td>551 (11)</td>
</tr>
<tr>
<td>M8</td>
<td></td>
<td></td>
<td>49 (8,16%)</td>
</tr>
<tr>
<td>M10</td>
<td></td>
<td></td>
<td>37 (20,54%)</td>
</tr>
<tr>
<td>M11</td>
<td></td>
<td></td>
<td>30 (1,3%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Tower Construction</th>
<th>Operational 1</th>
<th>Operational 2</th>
<th>Operational 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>F5</td>
<td>837 (12)</td>
<td>45 (41,91%)</td>
<td>2,111 (47)</td>
<td>47 (46,98%)</td>
</tr>
<tr>
<td>F9</td>
<td>76 (25,34%)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>M1</td>
<td>4,362 (61)</td>
<td>48 (46,96%)</td>
<td>5,160 (108)</td>
<td>49 (49,100%)</td>
</tr>
<tr>
<td>M5</td>
<td>92 (91,99%)</td>
<td>4,935 (54)</td>
<td>707 (15)</td>
<td>-</td>
</tr>
<tr>
<td>M8</td>
<td>1,330 (19)</td>
<td>48 (38,79%)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>M10</td>
<td>77 (77,100%)</td>
<td>48 (47,98%)</td>
<td>4,184 (87)</td>
<td>49 (49,100%)</td>
</tr>
<tr>
<td>M11*</td>
<td>1,739 (19)</td>
<td>26 (16,62%)</td>
<td>1,478 (57)</td>
<td>5,273 (108)</td>
</tr>
<tr>
<td>M15</td>
<td>1,155 (16)</td>
<td>18 (10,56%)</td>
<td>303 (17)</td>
<td>49 (19,39%)</td>
</tr>
<tr>
<td>M16</td>
<td>116 (2)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Operational 4</th>
<th>Operational 5</th>
<th>Operational 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>F5</td>
<td>2,755 (27)</td>
<td>1127 (16)</td>
<td>882 (21)</td>
</tr>
<tr>
<td>F9</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>M1</td>
<td>63 (63,100%)</td>
<td>4,398 (70)</td>
<td>-</td>
</tr>
<tr>
<td>M10</td>
<td>289 (4)</td>
<td>90 (1)</td>
<td>43 (17,40%)</td>
</tr>
<tr>
<td>M11</td>
<td>57 (1)</td>
<td>205 (3)</td>
<td>43 (39,91%)</td>
</tr>
<tr>
<td>M15</td>
<td>5 (0)</td>
<td>5 (0)</td>
<td>43 (8,19%)</td>
</tr>
<tr>
<td>M16</td>
<td>72 (3,4%)</td>
<td>72 (3,4%)</td>
<td>38 (1)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>days total (rate)</th>
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<tbody>
<tr>
<td>F5</td>
<td>20 (0-70)</td>
<td></td>
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</tr>
<tr>
<td>F9</td>
<td></td>
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</tr>
<tr>
<td>M1</td>
<td>289 (4)</td>
<td>90 (1)</td>
<td></td>
</tr>
<tr>
<td>M10</td>
<td>57 (1)</td>
<td>205 (3)</td>
<td></td>
</tr>
<tr>
<td>M11</td>
<td>5 (0)</td>
<td>5 (0)</td>
<td></td>
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<tr>
<td>M15</td>
<td>72 (3,4%)</td>
<td>72 (3,4%)</td>
<td></td>
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<tr>
<td>M16</td>
<td></td>
<td></td>
<td>38 (1)</td>
</tr>
</tbody>
</table>

56% (36-78) 16 (2-49) 73% (42-90) 33 (2-108) 60% (33-100) 22 (3-50) 29% (0-74) 3 (0-8)

55% (3-100) 20 (0-70) 46% (4-88) 5 (0-16) 57% (4-88) 8 (0-16)