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Home-range Dynamics and Resource Selection of American Marten (*Martes americana*) in Michigan's Northern Lower Peninsula

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Abstract

American marten (*Martes americana*) are typically associated with mature coniferous forests. Marten were extirpated from Michigan's Lower Peninsula due to human impacts, such as fire, logging, and over-harvest. Little is known about the resource selection and distribution of marten in Michigan's northern Lower Peninsula since their reintroduction in 1985-86. Resource selection functions are valuable tools to estimate the relative probability an animal will utilize an area and predict where they may occur. When creating a resource selection function, potential sources of variation in data collection methods and wildlife populations should be considered to ensure accurate results. We sought to create a resource selection function for marten across Michigan's northern Lower Peninsula to estimate their occurrence and identify habitat with higher probability of use by marten to maintain or with lower probability of use to improve. We also sought to determine whether home-range estimates derived across different seasons or collar types would impact marten home-range size and habitat selection. Marten were live-trapped, fitted with VHF or GPS collars, and locations were obtained via radio-tracking VHF collars or downloading data stored within GPS collars. We estimated 95% fixed kernel home-ranges for all marten with $\geq$ 30 locations from one collar type. Characteristics potentially indicative of marten habitat selection determined *a priori* were measured within each used home-range and surrounding available habitat. Kruskal-Wallis and ANOVA tests were used to compare habitat characteristics, size, and overlap among individuals with home-ranges from both VHF and GPS collars. Forward and backward selection were used to establish the best-fit logistic regression model explaining marten resource selection. Comparisons between home-ranges estimated for 5 marten based on collar type and season revealed no significant differences. Therefore, we combined home-range data across collar types and seasons. We used home-range data from 18

marten to generate the resource selection function, which predicted percent of canopy cover, coniferous forest, and mixed forest were the best indicators of marten habitat selection. We extrapolated our model to Michigan's northern Lower Peninsula and found ~38% was estimated to have a relatively high probability of being used by marten.

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Key to Symbols

β – Constants

X – Independent variables

Y – Probability of use

Abbreviations

AIC_c – Akaike's information criterion adjusted for a small sample size

ANOVA – Analysis of variance

GIS – Geographic information systems

GPS – Global positioning system

VHF – Very high frequency

Chapter 1 – Introduction

Introduction

American marten are mustelids typically associated with old-growth coniferous forests. Marten were historically found throughout the northern portion of North America, but human impacts such as logging, fire, and over-harvest resulted in their extirpation from much of their southern range, including Michigan's Lower Peninsula (Williams et al. 2007). Reintroduction efforts in 1985-86 brought 85 marten to the Manistee National Forest, Pigeon River Country State Forest, and Pere-Marquette State Forest (Williams et al. 2007). Marten are known to occur near these sites, but their full range throughout Michigan's Lower Peninsula is unknown, which provides a challenge when trying to manage for sustainable marten populations (Hillman et al. 2017). There are also few studies that have specifically examined marten habitat selection within Michigan's Lower Peninsula (L. McFadden, unpublished data, 2007; C. Buchanan, unpublished data, 2008; Sanders et al. 2017). Knowledge of where marten occur and what resources they are selecting for is crucial to effectively manage for their long-term viability in Michigan's Lower Peninsula.

Resource selection functions are models that predict the relative probability an animal will use an area (Manly et al. 2002). These models can be used to make predictions on wildlife habitat selection and occurrence (Guisan and Zimmermann 2000). Resource selection functions are built using presence-absence or presence-no detection data, which when compared to models using presence-only data were found to be more accurate (Brotons et al. 2004). A resource selection function can assist in identifying occupied areas, corridors for dispersal, and areas to translocate additional animals to improve connectivity between current populations. Therefore, they are valuable tools in wildlife management.

When creating a resource selection function, characteristics of the study animal and methods of data collection need to be considered. VHF and GPS collars are commonly used to make inferences on wildlife habitat selection. However, studies comparing VHF and GPS-derived home-range estimates have yielded inconsistent results on how they impact estimates of home-range size and habitat use (Ballard et al. 1998; Land et al. 2008; Kochanny et al. 2009). Therefore, each study must consider the specific behavior of their target species and the objectives of their study when employing radio collars.

Purpose

The purpose of this project was to make inferences on marten habitat selection that could be used to inform management in Michigan's Lower Peninsula. In Chapter 2.1, we sought to determine if methods of data collection impacted marten home-range estimates. We compared home-range estimates across collar type (VHF, GPS, and combined data) and seasons to determine if we could combine locations collected using different collars and across seasons. In Chapter 2.2, we sought to establish a resource selection function for marten across Michigan's northern Lower Peninsula. A resource selection function would allow us to estimate the relative probability a marten will utilize an area, estimate their occurrence, identify potential dispersal corridors, and regions to potentially translocate additional marten.

Scope

This study focused on marten resource selection in the Manistee National Forest of Michigan. We used habitat use characteristics of the Manistee National Forest population to estimate habitat use for marten across Michigan's northern Lower Peninsula. Marten habitat use is known to vary across their geographic range, so predictions made from this study should not be applied universally.

Assumptions

In Chapter 2.1, we assumed snow cover was more ecologically predictive of season than any other measurable variable (e.g., precipitation, month, etc.).

In Chapter 2.2, we assumed the logistic regression formula provided the relative probability of habitat use by a marten.

Objectives/Hypothesis

We aimed to estimate home-ranges for marten in the Manistee National Forest of Michigan to compare to their surrounding habitat and make inferences about their habitat selection. We compared home-ranges derived from different collar types and in different seasons. We predicted collar type and season would not impact the size of home-ranges estimated from them or the habitat use measured within them. Then, we generated a resource selection function to estimate the relative probability a marten will use an area. We predicted that marten would select habitat more characteristic of mature forests than what was available to them. Marten were hypothesized to select home-ranges in areas with more coniferous forest, denser canopy cover, lower road density, older stand age, and greater basal area than what was randomly available to them.

Significance

American marten are ecologically, socially, and economically significant animals. Marten are used as umbrella species to manage for healthy forest ecosystems (Buskirk and Ruggiero

1994; Zielinksi and Kucera 1995). Several Native American tribes in the Midwest associate themselves with marten as a culturally significant clan animal (Dumyahn et al. 2007). Marten are also a fur-bearer species and restoration of the population may allow for a reinstated legal harvest, which would indicate successful management (Clark et al. 1987; Hiller et al. 2011).

This study provides a resource selection function, which can inform managers on regions that have a higher probability of being used by marten. It can be used to target survey efforts to understand the full range of marten in Michigan as well as direct management effort to maintain high quality marten habitat and improve lower quality habitat. This model may also be used to identify regions to translocate additional marten to supplement the population if deemed necessary.

Definitions

Home-range – area an animal traverses in its normal activities to gather food, mate, and care for young (Burt 1943).

Resource selection function – model that predicts the relative probability than an area will be used by an animal (Manly et al. 2002).

Chapter 2.1

Comparison of VHF and GPS collar-delineated home-ranges of American marten (*Martes americana*) in Michigan

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Abstract

Ensuring accurate data collection on wildlife habitat use is essential to effective management, yet studies on whether very high frequency (VHF) and global positioning system (GPS) collars result in comparable home-ranges have yielded inconsistent results. We estimated 95% fixed kernel-based home-ranges for American marten (*Martes americana*), a forest health indicator species, in Michigan to determine whether VHF collars, GPS collars, or a combination of the two estimated comparable home-range size and resource use. Five marten were equipped with a VHF and GPS collar at different time intervals. We compared habitat variables potentially indicative of marten resource selection within each home-range and determined home-range area and amount of overlap by VHF and GPS delineated home-ranges. Number of locations from VHF and GPS collars differed, but did not result in different home-range size estimates. Habitat variables also did not differ across VHF, GPS, or the combined location home-ranges. Home-ranges estimated by VHF collar, GPS collar, or combinations of both locations can be used to accurately determine marten habitat and space utilization. Key words: American marten, *Martes americana*, home-range, VHF, GPS, resource use, habitat, Michigan.

Introduction

Radio telemetry has been used to track wild animals and make inferences about habitat selection since the 1960s (Cochran and Lord 1963; Chadwick et al. 2010). Historically, very high frequency (VHF) collars have commonly been used across taxa to delineate home-ranges and determine habitat use and preference (McLoughlin et al. 2002; Kay 2004; Dumyahn et al. 2007). Recent technological advancements have led to increased use of global positioning system (GPS) collars to monitor wildlife (Johnson et al. 2008). GPS collars do not require active radio telemetry to obtain locations, they can record locations more frequently, but they are more costly than VHF collars (Girard et al. 2006). For a more detailed review of differences between GPS and VHF collars see Cooke et al. (2004) and Hebblewhite and Haydon (2010). It is unclear, however, whether data collected from the two collar types leads to different estimations of home-ranges and habitat use within the same study.

VHF and GPS-derived home-range estimates and habitat use have been compared in previous studies, with conflicting results. Kochanny et al. (2009) observed similar home-range size and large spatial overlap when white-tailed deer (*Odocoileus virginianus*) were equipped with VHF and GPS collars. Land et al. (2008) also found locations of Florida panthers (*Puma concolor coryi*) from VHF and GPS collars resulted in comparable home-range size, but habitat within the home-ranges differed. GPS home-ranges included more non-forested habitat than VHF home-ranges. Ballard et al. (1998) reported gray wolf (*Canis lupus*) locations reached an asymptote, indicating territories did not change with added points, when using satellite-based collars. However, when VHF collars were used, asymptotes were not reached, indicating more data was necessary to accurately estimate complete territories (Ballard et al. 1998). Home-ranges delineated by VHF and GPS collars may vary depending on species and user effort, and should be investigated within any study utilizing both technologies.

American marten (*Martes americana*) are mustelids historically found throughout the northern forests of North America, including Michigan (Williams et al. 2007). Marten are often considered habitat specialists, associated with old-growth, coniferous forests, with complex physical structure (Clark et al. 1987; Buskirk and Powell 1994). These high-quality forest requirements make them sensitive to habitat loss, typically by fire or logging, which when coupled with over-harvest led to their extirpation from Michigan's Lower Peninsula in the early 20th century (Clark et al. 1987; Thompson 1991; Williams et al. 2007). Marten were reintroduced to Michigan's Lower Peninsula in 1985-1986, when 85 individuals were translocated from Canada to the Manistee National Forest, Pere-Marquette State Forest, and Pigeon River Country State Forest (Williams et al. 2007). Currently, little is known about the habitat use of marten within Michigan's Lower Peninsula since their reintroduction (L. McFadden, unpublished data, 2007; C. Buchanan, unpublished data, 2008; Sanders et al. 2017).

Marten are considered forest health indicators, making them a priority for management (Buskirk and Ruggiero 1994). The United States Forest Service has designated marten as a Regional Forester Species of Special Concern and an ecological indicator (Buskirk and Ruggiero 1994; P. Huber, personal communication, 2018). Therefore, managing for marten habitat has interspecific benefits, making proper marten habitat classification and management crucial for effective community management. As part of a larger project, we wanted to determine whether marten home-range estimates and habitat use were comparable among three methods of data collection, using VHF collars, GPS collars, or a combination of both. We hypothesized home-range estimates generated from VHF and GPS collar locations or a combination of the two collar types would not significantly impact home-range size or habitat variables within.

Materials and methods

Our study took place in the Manistee National Forest within the northern Lower Peninsula of Michigan (Figure 1). The Manistee National Forest covered 218 026 ha, which spanned 120 km north to south and 64 km east to west. Our focus was within Lake, Manistee, and Wexford counties, where marten were successfully located and live-trapped. The Manistee National Forest sat along a transitional area with the northern land largely forested and southern boundary bordered by agricultural land (USDA 2006). The forest was fragmented by several cities, private land, and highways. Elevation in the forest ranged from 140 to 521 m (USGS 2016). Climate data were taken from the nearest weather station in Manistee, Michigan, where climate varied seasonally with an average fall/winter (October-March) temperature of 1.0 ± 0.06 °C and spring/summer (April-September) temperature of 16.0 ± 3.8 °C (NCEI 2017). Seasonal designations were based on snow cover for the area, with generally no snow in the spring/summer and moderate to heavy snowpack in the fall/winter. Forest composition included a mixture of coniferous and deciduous trees, with prominent species including red pine (*Pinus resinosa*), jack pine (*P. banksiana*), white pine (*P. strobus*), red oak (*Quercus ruba*), white oak (*Q. alba*), black oak (*Q. velutina*), sugar maple (*Acer saccharum*), red maple (*A. rubrum*), black cherry (*Prunus serotina*), bigtooth aspen (*Populus grandidentata*), quaking aspen (*P. tremuloides*), witch hazel (*Hamamelis virginiana*), iron wood (*Carpinus caroliniana*), yellow birch (*Betula alleghaniensis*), and American beech (*Fagus grandifolia*). Several areas contained large plantations of predominately red pines scattered with some remnant deciduous trees (Sanders et al. 2017).

We live-trapped and fitted American marten with VHF or GPS collars from 2011-2016. Live traps (Tomahawk Live Trap Company, Tomahawk, Wisconsin, model 103 and 105) were baited with meat (usually pork) and scented with "Gusto" (Minnesota Trap Line, Pennock, Minnesota), a long-distance call lure. Traps were covered with forest debris in the summer or half of a 208.2 L (55 gal) barrel filled with straw in the winter to provide protection and bedding. Traps were checked daily and bait and scent were replaced as needed.

Upon capture, we removed marten from the trap using a denim restraining cone (Desmarchelier et al. 2007) which allowed access to the snout to apply anesthesia (gaseous isoflurane and oxygen). While anesthetized, we monitored heart rate, respiratory rate, and temperature to ensure the marten was not overly stressed. All individuals were implanted with a passive integrated transponder tag (AVID Identification Systems Inc., Norco, California) with a unique identification number subcutaneously between the shoulder blades. Healthy, adult marten were fitted with a VHF or GPS collar (Holohil Systems Ltd., Ontario, Canada, modified model RI-2D or Advanced Telemetry Systems, Isanti, Minnesota, model M1555). Marten were placed in a recovery box for monitoring until anesthesia wore off, then they were released near the point of capture. Capture and handling protocols were conducted following protocols established by Grand Valley State University Institutional Animal Care and Use Committee (protocol 12-05-A) under the guidance of a licensed veterinarian and the Little River Band of Ottawa Indians governance.

We tracked collared marten on foot using handheld receiver and antennae. VHF-collared marten were typically located at least once a week. Locations of marten equipped with VHF collars were confirmed by one or more of the following criteria: localized signal, visualization, vocalizations, tracks, scat, prey remains, or chew marks surrounding a resting or denning site (e.g. tree cavities, snags, or hollow logs). Marten were generally un-impacted by human presence, but locations were not recorded if animals appeared to be fleeing (e.g. when seen running on ground or through the tree canopy). When equipped with GPS collars, mortality signals (indication of no movement for 8 hours) were checked approximately weekly. Individuals with GPS collars were targeted during live-trapping to remove collars and download location data.

Fixed kernel density home-ranges were estimated for VHF collar locations, GPS collar locations, and the combination of both collar types. Only marten with locations obtained from both VHF and GPS collars were used for analysis. Ninety-five percent probability contour home-ranges were estimated using Geospatial Modelling Environment (Version 0.7.4.0) using a threshold of $\geq$ 30 locations to delineate a home-range (Seaman et al. 1999). Ninety-five percent contours allowed for the inclusion of most locations, but excluded outliers which could be due to exploratory events and did not represent part of a home-range (Burt 1943; Powell 2000).

Variables potentially important for marten habitat selection were measured using ArcGIS (Version 10.3.1) within each home-range. Variables of interest were determined *a priori* based on previous marten studies and included canopy cover (Gosse et al. 2005), mean and range of elevation (Buskirk and Powell 1994), road density (Robitaille and Aubry 2000), percent of forest composition (percent coniferous, deciduous, and mixed forest; Slauson et al. 2007), stand basal area (Payer and Harrison 2003), stand age (Powell et al. 2003), and percent of edge (forest-wetland, forest-open, and open-wetland edge; Chapin et al. 1998). Canopy cover and land cover (used to measure percent of forest composition and edge) data were acquired from the National Land Cover Database 2011 (USDI 2011). Elevation data were from the United States Geological Survey National Elevation Dataset 2016 (USGS 2016). Road data were obtained from the

Michigan Geographic Framework 2016 (DTMB 2016). Stand basal area and age data were provided by the United States Forest Service Stand data 2015 (USFS, unpublished data, 2015). Data were clipped to the area of each home-range and variables were measured within attribute tables or using focal statistics if attribute tables were unavailable. Edge was defined as a 30 m buffer around the edge between forest-wetland, forest-open, or open-wetland land cover types (Pereboom et al. 2008). Forest edge was defined as any area consisting of deciduous, mixed or coniferous forest. Open edge was defined as shrub/scrub, grassland/herbaceous, sedge/herbaceous, lichens, pasture/hay, or cultivated crops. Wetland edge was defined as woody wetlands or emergent woody wetland, and all other land covers were not considered indicative of marten habitat selection (e.g. open water, perennial ice/snow, barren rock, etc.). Area and the percent of VHF and GPS collar-based home-ranges that overlapped were also measured.

Using R (version 1.0.153) each habitat variable was tested for normality using the Shapiro-Wilks test ($\alpha = 0.05$). To determine how similar each variable was within the home-ranges delineated by VHF collars, GPS collars, or a combination of both, variables that met the assumption of normality were compared using ANOVA and those that failed the assumption were compared using Kruskal-Wallis ($\alpha = 0.05$).

Results

Five marten were fitted with VHF and GPS collars long enough to obtain ≥ 30 locations with each collar type. A total of 6315 locations were collected for all individuals, with 6037 from GPS collars and 278 from VHF collars (Table 1). We obtained locations from marten over 13 to 21 months with VHF collars. We considered VHF collar data to estimate year-long home-ranges since it included locations from every month, and therefore every season throughout the year. Locations were not always continuous as collars were changed as batteries died and marten were recaptured. We obtained locations continuously from marten over two to five months using GPS collars. We considered GPS collar data to estimate single-season home-ranges (i.e., fall/winter or spring/summer). GPS home-ranges were established completely within a fall/winter (March-October) or spring/summer (April-September) season, except one which overlapped by one month.

Number of locations from VHF, GPS, and the combined collar home-range estimates was significantly different, with many fewer locations derived from the VHF collars (Table 2). However, area, stand age, road density, basal area, percent of tree species composition, percent canopy cover, elevation, and percent of edge were not significantly different across home-ranges estimated by VHF collars, GPS collars, or the combined collars (Table 2).

Discussion

Collar type did not impact habitat variables we measured within marten home-ranges delineated from VHF collars, GPS collars, or the two combined. Road density, stand basal area, stand age, canopy cover, average elevation, range of elevation, percent of edge, and percent of forest composition were not significantly different among home-ranges estimated by VHF collars, GPS collars, or the combined dataset. This result was likely due to the similar home-range area and amount of overlap (49.2-78.9%) between VHF and GPS-based home-ranges. Home-ranges delineated from GPS collars may be slightly smaller due to the increased frequency of locations being collected in regions of high use over a shorter time interval. We did not correct for the larger amount of locations from GPS collars to determine if this difference would lead to variation in the home-range characteristics. The use of VHF and GPS collar locations separately or combined yielded similar inferences on marten resource use and space utilization in our Michigan study area.

Marten home-range estimates delineated from VHF collars, GPS collars, or a combination of the two collar types did not significantly differ in size even though sample size for each was significantly different. Although sampling size was greatly reduced when using VHF collars, they still covered a comparable area to GPS collars. VHF collars estimated slightly larger home-ranges than GPS collars, but this difference was not significant. This suggests enough locations were obtained using VHF collars to properly identify a marten's home-range. Our results suggest VHF and GPS locations may be combined to create home-ranges without concern that the GPS points will outweigh the VHF points and skew the home-range size or measured resource use.

The duration of time collars were deployed also did not cause significant differences in home-range characteristics. VHF collars collected locations over 13 to 21 months and GPS collars over two to five months. Even with this large temporal variation, habitat variables did not differ within home-ranges estimated for the same marten by VHF and/or GPS collars. These findings are consistent with those of Girard et al. (2006), who found the number of individuals was more indicative of habitat selection than frequency of locations. Kolodzinski et al. (2010) also reported accurate home-range estimates with low sampling frequency when using kernel-based methods. Once a home-range has been established, adding more locations will not impact the area it covers (Plotz et al. 2016). Similar home-range size and resource utilization across marten home-ranges suggest the minimum threshold was met and additional locations across a longer temporal scale did not impact the estimated home-range.

Knowing temporal scale does not impact marten home-range estimates is important for managing Michigan's population. Shirk et al. (2014) found marten in Washington and Oregon alter their resource use in different seasons. However, when marten in Michigan were monitored for roughly one season their home-range selection and habitat use within did not vary from home-ranges and habitat selected over the course of one or more years. These findings are consistent with those from Phillips et al. (1998) who found marten in Maine did not seasonally shift their habitat use. Brainerd and Rolstad (2002) also found pine marten (*Martes martes*) in Scandinavia to exhibit similar habitat use across seasons. The lack of seasonal home-range shifts suggest marten in Michigan are selecting regions of habitat that support their needs year-round. Buskirk and McDonald (1989) found no pattern to explain geographical variations in marten home-range size, but resource availability has been shown to be inversely related to home-range size (Thompson and Colgan 1987). Buskirk and McDonald (1989) found marten across the globe to have home-ranges between 0.6 km^2 to 27.5 km^2, with a mean of 6.7 km^2. Marten in Labrador were found to have exceptionally large mean home-ranges, with 45 km^2 for males and 25 km^2 for females (Smith and Schaefer 2002). Marten in Michigan had a mean home-range estimate of 11.6 ± 1.9 km^2, which fell within the range of reported home-ranges sizes, but was roughly twice as large as the global mean. Buskirk and McDonald (1989) and Smith and Schaefer (2002) used minimum convex polygons rather than fixed kernel home-range estimates which tend to estimate larger home-ranges (Powell, 2000). Marten in our study area still had home-ranges estimated to be larger than the global mean home-range size, indicating habitat is likely suitable but may not be optimal.

In our study area, home-range estimates did not significantly differ based on the type of collar used to collect locations. Our sample size of five individuals was low, so we advise caution when interpreting these results. Collaring the same animal with a VHF and GPS collar reduced potential bias due to variations in individual habitat selection, but largely limited our sample size. At least 30 locations should still be required before a home-range can be accurately estimated (Seaman et al. 1999). GPS collars may be able to collect data more quickly, but are more expensive, (Cooke et al. 2004) while VHF collars are relatively inexpensive, but require extensive field work (Girard et al. 2006). Study objectives can also dictate what collar type is better suited. For example, Ruth et al. (2010) found GPS collars were needed to accurately determine kill sites for large mammals given their ability to record locations at short time intervals. Studies not requiring such a fine time scale, such as habitat use evaluations for elk, can still obtain useful information using only VHF collars, or a combination of the two (Allen et al. 2008). We analyzed Johnson's (1980) second order resource selection characteristics at the home-range scale and it is possible that looking at finer scales, such as third or fourth order selection may result in variations based on collar type used to collect data. Any study should consider the possible sources of variation within the wildlife being studied and the technology being used. VHF and GPS collars alone or combined are sufficient to determine estimates of marten home-range size and resource use in Michigan.

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Table 1. Area, sample size, and percent overlap of American marten home-ranges estimated using locations from VHF collars, GPS collars, and a combination of both. Data were collected on five marten from 2012-2016 in the Manistee National Forest of Michigan. Home-range estimates were 95% fixed kernel contours. Area of overlap was the region shared between VHF collar and GPS collar delineated home-ranges for each marten.

Animal ID	**VHF location count**	**GPS location count**	**Combined location count**	**VHF area (km^2)**	**GPS area (km^2)**	**Combined area (km^2)**	**Area overlap (%)**
010	48	1868	1916	14.9	9.3	9.4	59.0
124	75	2907	2982	12.4	13.6	12.4	78.9
314	44	348	392	25.8	17.0	17.4	64.4
317	56	615	672	12.9	13.0	12.9	65.4
523	55	299	354	7.4	5.0	5.9	49.2
Mean	55	1207	1263	14.7	11.6	11.6	63.4

Table 2. American marten resource use in 95% fixed kernel home-range estimates using locations from VHF collars, GPS collars, and a combination of both. Mean and standard error of each variable are shown. Variables that met the assumption of normality using Shapiro Wilks tests (significant p-value) were compared using ANOVA and those that failed the assumption of normality using Kruskal-Wallis. Data were collected from five marten in the Manistee National Forest of Michigan from 2012-2016.

Variable	**Mean VHF**	**Mean GPS**	**Mean combined**	**Shapiro-Wilks p-value**	**ANOVA or Kruskal-Wallis p-value**
Location count	55.6 ± 5.3	1207.4 ± 511.9	1263.0 ± 515.6	< 0.01	0.01*
Basal area (m^2/ha)	19.6 ± 1.2	19.9 ± 1.2	19.8 ± 1.2	0.05	0.75
Mixed forest (%)	7.7 ± 0.04	8.3 ± 0.04	8.2 ± 0.04	< 0.01	1.00
Deciduous forest (%)	50.0 ± 0.17	51.1 ± 0.18	50.1 ± 0.18	< 0.01	0.96
Coniferous forest (%)	42.3 ± 0.16	40.6 ± 0.16	41.1 ± 0.16	< 0.01	0.88
Canopy cover (%)	77.9 ± 0.06	78.4 ± 0.06	78.5 ± 0.06	< 0.01	0.82
Average elevation (m)	381.6 ± 22.4	382.6 ± 22.6	382.9 ± 22.7	< 0.01	0.90
Range of elevation (m)	86.8 ± 17.8	74.1 ± 13.1	75.5 ± 13.3	0.04	0.65
Forest-open edge (%)	6.5 ± 2.4	6.7 ± 2.6	6.5 ± 2.7	< 0.01	0.93
Forest-wetland edge (%)	0.21 ± 0.11	0.18 ± 0.10	0.18 ± 0.10	< 0.01	0.69
Open-wetland edge (%)	0.02 ± 0.01	0.04 ± 0.03	0.02 ± 0.01	< 0.01	0.96
Stand age	72.6 ± 1.9	74.0 ± 2.2	73.8 ± 2.2	0.02	0.84
Road density (km/km^2)	0.06 ± 0.01	0.08 ± 0.03	0.07 ± 0.02	0.09*	0.83
Area (km^2)	14.7 ± 3.0	11.6 ± 2.0	11.6 ± 1.9	0.22*	1.00

* Indicates significant values ($\alpha = 0.05$) prior to rounding

Figure 1. Location of the Manistee National Forest and approximate study area within Michigan.

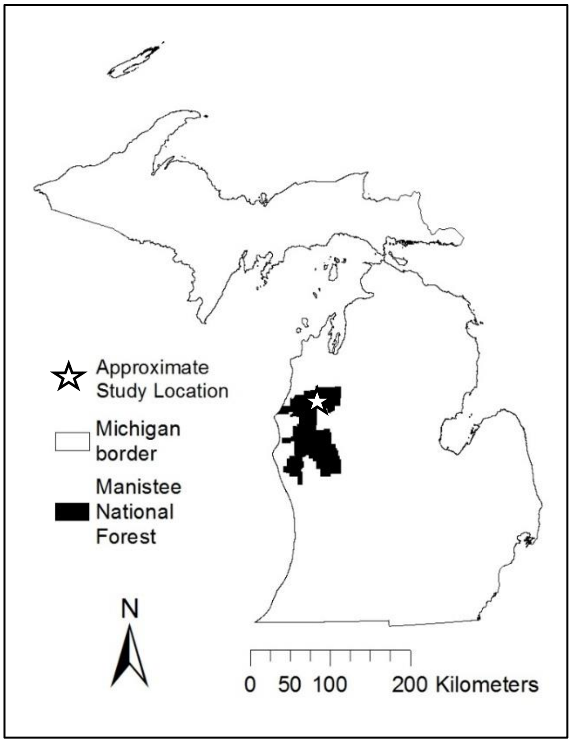
Approximate
Study Location
Michigan
border
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Figure 1.

Chapter 2.2

Characteristics of American marten (*Martes americana*) habitat: A resource selection function for Michigan's northern Lower Peninsula

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Characteristics of American marten (*Martes americana*) habitat: A resource selection function for Michigan's northern Lower Peninsula

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Abstract

American marten (*Martes americana*) are typically associated with old growth coniferous forests. However, habitat use varies across their range and studies should consider possible variations within each population. Little is known about the resource selection and distribution of marten in Michigan's northern Lower Peninsula since their reintroduction in 1985-86. Resource selection functions are valuable tools to estimate the relative probability an animal will utilize an area and predict where they may occur. Our objective was to create a resource selection function for marten in Michigan's northern Lower Peninsula. Marten were live-trapped and fitted with VHF or GPS collars to estimate their home-ranges and habitat utilization. We estimated 95% fixed kernel contour home-ranges for 18 marten. Characteristics potentially indicative of marten resource selection were measured within the home-ranges marten were using and the surrounding areas available to them. The best-fit logistic regression model indicated percent of coniferous forest, canopy cover, and mixed forest were the top predictors of marten resource selection. We extrapolated our resource selection function to Michigan's northern Lower Peninsula and ~38% was estimated to have a high probability of being used by marten. Key words: American marten, *Martes americana*, resource selection function, habitat use, model, logistic regression, Michigan.

Introduction

American marten (*Martes americana*) are a cryptic species typically considered habitat specialists associated with structurally complex, mature, coniferous forests (Hagmeier 1956; Buskirk 1992; Buskirk and Powell 1994). How specialized marten habitat requirements are has been questioned by past studies, which found them utilizing more generalized habitat, including recently logged and deciduous stands (Potvin et al. 2000; Hearn et al. 2010). Marten habitat use has also been found to differ across geographic area, and only in some populations have marten exhibited seasonal resource selection (Buskirk and Ruggiero 1994; Phillips et al. 1998; Shirk et al. 2014). Therefore, when modelling resource selection for marten, it is vital to consider the geographic area and seasonality of the study population to ensure accurate results. Due to these potential variations, it is not feasible to apply any model predicting marten habitat universally.

American marten were historically found across the range of boreal forests in the northern portion of North America (Hagmeier 1956). Human impacts, including over-harvest, logging, and fire extirpated marten from much of their southern range (Earle et al. 2001; Williams et al. 2007). Marten were once found as far south as Allegan County in Michigan's Lower Peninsula, but were extirpated from the Lower Peninsula in 1911 (Hagmeier 1956; Williams et al. 2007). Reintroduction efforts in the northern Lower Peninsula from 1985-1986 brought 49, 21, and 15 marten to the Pigeon River Country State Forest, Manistee National Forest, and Pere-Marquette State Forest, respectively (Williams et al. 2007). Hillman et al. (2017) used effective population size to estimate between 46–230 adult marten in the Pigeon River Country State Forest and 34–270 in the Manistee National Forest. Although marten are known to occur near these reintroduction sites, the extent of their range in the northern Lower Peninsula of Michigan is unknown (Williams et al. 2007; Hillman et al 2017). Understanding what resources marten are selecting for in the northern Lower Peninsula of Michigan would allow managers to estimate areas marten may inhabit and assist in identifying regions with a high probability of use to conserve and low-medium probability of use to potentially improve.

Managing for marten in Michigan has potential ecological, social, and economic benefits. Managers often use marten as ecological indicators of healthy forest ecosystems, therefore managing for marten benefits other species found in their community (Buskirk and Ruggiero 1994; Zielinksi and Kucera 1995). Deer mice (*Peromyscus maniculatus*), eastern chipmunks (*Tamias striatus*), red squirrels (*Tamiasciurus hudsonicus*), and northern flying squirrels (*Glaucomys sabrinus*) select for similar habitat as marten, utilizing conifer-dominated forests with closed canopies and coarse woody debris (Pearson and Ruggiero 2001). Marten are socially important in the Midwest for Native American communities that associate themselves with marten as a culturally significant clan animal (Dumyahn et al. 2007). Marten are also a furbearer species and can provide a source of income in regions where populations are viable to undergo harvest, such as in Michigan's Upper Peninsula (Clark et al. 1987; Hiller et al. 2011). Managing for marten habitat has widespread benefits, so a model that can predict where marten may occur and what resources they select for can be a valuable management tool.

Resource selection functions are models wildlife managers can use to estimate the relative probability of resource use by individuals or populations (Manly et al. 2002). Resource selection functions are created using presence-absence or presence-no detection data to compare the habitat animals are using to what is available to them and determine what resources they are selecting (Manly et al. 2002). When compared to presence-only modelling methods, Brotons et al. (2004) found presence-absence modelling out-performed presence only methods for all fourteen bird species investigated. Presence-only methods were also less conservative at predicting where species may occur, which could lead to costly over-estimates when trying to manage for improved habitat size and connectivity (Brotons et al. 2004). Resource selection functions are useful tools to predict how wildlife populations will react to management or natural habitat changes (McDonald and McDonald 2002). They are also a practical instrument in estimating species occurrence and distribution (Guisan and Zimmermann 2000).

A resource selection function for Michigan's northern Lower Peninsula will be useful to identify regions with a relatively high probability of by marten use to maintain. Marten are known to occur near the sites of reintroduction in the Manistee National Forest and Pigeon River Country State Forest, but it is not known how far they have expanded (Williams et al. 2007; Hillman et al 2017). This model can assist in identifying occupied areas, corridors for dispersal, and areas to translocate additional marten to improve connectivity between the current populations. Our objective was to create a resource selection function for American marten across the northern Lower Peninsula of Michigan to identify what resources marten are selecting and where marten may be present. We expected marten to select for habitat characteristics associated with more mature coniferous stands, such as denser canopy cover and lower road density than what is randomly available to them.

Materials and methods

Our study was conducted in the Manistee National Forest, located in the northern Lower Peninsula of Michigan (Figure 1). The Manistee National Forest was fragmented by highways, private lands, and cities. The forest was located along a transitional zone with a mostly forested northern portion and a southern portion bordered by agricultural land (USDA 2006). Elevation ranged from 140 to 521 meters within the Manistee National Forest (USGS 2016). Climate data were taken from the nearest weather station in Manistee, Michigan. Michigan had a temperate climate with a mean fall/winter (March-October) temperature of 1.0 ± 0.06 °C and spring/summer (April-September) temperature of 16.0 ± 3.8 °C (NCEI 2017). Mean precipitation was 36.8 ± 0.2 cm in fall/winter and 51.4 ± 0.07 cm in spring/summer (NCEI 2017). Forest composition was mixed with prominent species including red pine (*Pinus resinosa*), jack pine (*P. banksiana*), white pine (*P. strobus*), red oak (*Quercus ruba*), white oak (*Q. alba*), black oak (*Q. velutina*), sugar maple (*Acer saccharum*), red maple (*A. rubrum*), black cherry (*Prunus serotina*), bigtooth aspen (*Populus grandidentata*), quaking aspen (*P. tremuloides*), witch hazel (*Hamamelis virginiana*), iron wood (*Carpinus caroliniana*), yellow birch (*Betula alleghaniensis*), and American beech (*Fagus grandifolia*). Large regions within the forest were pine plantations, mainly red pine, with few remnant mature deciduous trees (Sanders et al. 2017).

We live-trapped for marten periodically from 2011 to 2016. Live traps (Tomahawk Live Trap Company, Tomahawk, Wisconsin, model 103 and 105) were baited with meat, and scented with a potent long-distance lure ("Gusto," Minnesota Trap Line, Pennock, Minnesota). We covered traps with half of a 208.2 L (55 gal) barrel filled with straw in the winter or natural forest debris in other seasons to protect captured animals from the elements. Traps were checked daily and bait and lure were replaced as needed.

Marten were removed from traps using an open-ended restraining cone (Desmarchelier et al. 2007) which allowed us to administer gaseous anesthesia (isoflurane and oxygen) to the snout. Temperature, heart rate, and respiratory rate were monitored throughout immobilization. A passive integrated transponder tag (AVID Identification Systems Inc., Norco, California) was implanted subcutaneously between the shoulder blades of each individual for identification. Adult marten were fitted with a VHF or GPS collar (Holohil Systems Ltd., Ontario, Canada, modified model RI-2D or Advanced Telemetry Systems, Isanti, Minnesota, model M1555) if determined healthy (no signs of injury, disease, or low weight). We placed marten in a recovery box where they could be monitored until the anesthesia wore off and we released them near the point of capture. Capture and handling protocols followed those established by Grand Valley State University Institutional Animal Care and Use Committee (protocol 12-05-A) under the guidance of a licensed veterinarian and the Little River Band of Ottawa Indians governance.

Marten were typically located once a week while collared. Marten with VHF collars were tracked on foot using a handheld receiver and antennae. If a visual on the marten was not possible, its location was identified via localized signal, vocalizations, tracks, scat, prey remains, or chew marks surrounding a tree cavity. Locations were generally unaffected by human presence, but were excluded if the marten was seen fleeing. When GPS collars were also equipped with a VHF component, marten were checked approximately weekly for a mortality signal (occurs when collar is stagnant for > 8 hours). Marten with GPS collars were targeted during live-trapping to remove collars and download the location data stored within.

We estimated 95% fixed kernel density home-ranges for all marten with ≥ 30 locations (Seaman et al. 1999). One home-range was estimated for each marten regardless of collar type or season, which were determined insignificant when delineating marten home-ranges in Michigan (A. Kujawa, unpublished data, 2018). Ninety-five percent probability kernel home-ranges were estimated (Geospatial Modelling Environment, Version 0.7.4.0) because they excluded outlying locations, which could be from exploratory events, while maintaining the majority of locations (Burt 1943; Powell 2000). Habitat characteristics potentially indicative of marten habitat selection were determined *a priori* from the literature and were measured within each home-range using ArcGIS (Version 10.3.1). Characteristics included canopy cover (Gosse et al. 2005), mean and range of elevation (Buskirk and Powell 1994), road density (Robitaille and Aubry

2000), percent of forest composition (percent coniferous, deciduous, and mixed forest; Slauson et al. 2007), stand basal area (Payer and Harrison 2003), stand age (Powell et al. 2003), and percent of edge (forest-wetland, forest-open, and open-wetland edge; Chapin et al. 1998). Home-range estimates were considered used marten habitat and the Manistee National Forest was considered available marten habitat. Three polygons the size of each marten's home-range were randomly selected within the Manistee National Forest for the available habitat and all habitat characteristics measured within each polygon.

Habitat characteristics were measured within used and available marten habitat using ArcGIS. Percent canopy cover (USDI 2011), mean and range of elevation (USGS 2016), percent of coniferous, deciduous, and mixed forest (USDI 2011), stand basal area and age (USFS, unpublished data, 2015), and road density (DTMB 2016) were clipped to the used and available habitat. Stand basal area and age data were limited to United States Forest Service stand records and did not include private lands, so portions of home-ranges and available habitat polygons had no data. Only forested regions were included in the stand data. Mean value was measured for each habitat variable within each polygon of used and available. Edge was measured by taking a 30 m buffer (Pereboom et al. 2008) of the boundary between forest-wetland, forest-open, and open-wetland land cover types. Forest was defined as any area consisting of deciduous, mixed or coniferous forest. Open was defined as shrub/scrub, grassland/herbaceous, sedge/herbaceous, lichens, pasture/hay, or cultivated crops. Wetland was defined as woody wetlands or emergent woody wetland, and all other land covers were not considered indicative of marten habitat selection (e.g. open water, perennial ice/snow, barren rock, etc.).

Statistical tests were conducted using R (version 1.0.153). All variables were tested for correlation and when correlation $\geq \pm 0.70$ (Shirk et al. 2014) one was excluded. We referred to past findings on marten habitat selection to determine which variable to retain. Range and mean elevation were removed from analyses due to an inherent sampling bias. Elevation in the Manistee National Forest had a natural decline east to west, towards the coast of Lake Michigan. Data for this study were limited to the northeastern portion of the Manistee National Forest where elevations were highest and therefore may show selection for high elevations when it was not present. Percent of edge was also removed due to its low occurrence within the marten home-ranges, never exceeding 5.5% for any edge type. All remaining variables, percent canopy cover, road density, percent coniferous forest, percent mixed forest, stand basal area, and stand age, were included in the model selection process. One year-round model was created because marten within our study area were determined to not exhibit seasonal habitat variation (A. Kujawa, unpublished data, 2018). Forward and backward selection were used to establish a best-fit logistic regression model (Manly et al. 2002). The general formula for the model was:

$$Y = \frac{Exp(\beta 0 \ + \ \beta 1X1 \ + \ \beta 2X2 \ + \ \dots \ \beta pXp)}{1 + Exp(\beta 0 \ + \ \beta 1X1 \ + \ \beta 2X2 \ + \ \dots \ \beta pXp)}$$

where Y was the probability of marten use, βs were constants, and Xs were independent habitat variables probability of marten use was related to. Models were ranked using AICc, due to small sample size, and those within two AICc units of the best-fit model were averaged (Arnold 2010) to establish the final resource selection function model. For each variable within the final model, we created a layer for that variable across the study area using ArcGIS. The Raster Calculator tool was used to apply the final logistic regression model across the entire study area and establish a map of the resource selection function. The resource selection function model assigned each pixel a number on a scale of zero to one, with zero having a low probability of marten selecting that area and one having a high probability of marten selecting that area. We assigned probability of use into equal interval categories where regions with values from 0-0.33, >0.33-0.66, and >0.66-1.0 were considered to have a relatively low, medium, or high probability that marten would select that area, respectively.

We attempted to validate our resource selection function using non-invasive remotely-triggered camera survey. A hexagonal grid was established across the Manistee National Forest with 2 km^2 grid cells. Cells were made smaller than the mean home-range within the study area (12.4 ± 3.0 km^2) to reduce the risk of false negatives and to approximate smaller home-ranges found in past studies (Buskirk and McDonald 1989; Poole et al. 2004). The mean relative probability of marten occurrence value was taken within each hexagon and it was assigned to a category of low, medium, or high probability of use. We sampled fifty hexagons assigned to each probability of use categories, for a total of 150 hexagons. Remotely-triggered cameras (Browning BTC-5HDE and BTC-12HD, Reconyx Hyperfire HC500, Moultrie MCG-12592, and Primos Ultra Blackout) were placed near the center of each hexagon approximately 0.3 m off the ground and checked once a week for three weeks. Zielinksi (1995) recommended 12 survey nights to detect marten and Moriarty et al. (2016) had over 75% probability of detection after 14 days so cameras were left for 21 days to improve detectability. Camera stations were baited with a mesh bag of pork or venison suspended approximately 1.8 meters high to reduce consumption. A potent scent lure (“Gusto,” Minnesota Trap Line, Pennock, Minnesota) was used nearby and on a stick immediately in front of the camera to improve capture rates. Cameras were visited once a week to replace lure each time and bait when needed. If an animal was absent from the camera frame for more than ten minutes it was considered a new capture. The resource selection function was considered valid if marten were detected proportionally more in the high category of use than medium and low. We then extrapolated the resource selection function model across the northern Lower Peninsula of Michigan.

Results

Eighteen marten were monitored long enough to provide the minimum 30 locations to estimate a home-range (Seaman et al. 1999). Home-range area ranged from 3.5 km^2 to 60.5 km^2 with a mean of 12.4 ± 3.0 km^2 (Table 2). On average, marten used areas with 1.8 ± 2.5% more mixed forest, 42.9 ± 8.0% more coniferous forest, and 44.7 ± 8.3% less deciduous forest than what was available (Table 2). Mean canopy cover was 18.3 ± 4.6% greater in marten home-ranges than what was available to them (Table 2). Marten never selected home-ranges that averaged less than 55% canopy cover. Stands used by marten had a mean age 4.8 ± 3.1 years younger than those available to marten (Table 2). Basal area in home-ranges had a mean 3.7 ± 2.1 m^2/ha greater than that in the available areas (Table 2). Mean road density was similar for used and available areas with a difference of less than 0.01 ± 0.03 km/km^2 (Table 2).

Percent of deciduous and coniferous forest were the only highly correlated variables, with a correlation coefficient of -0.97. Percent of deciduous forest was removed from future analyses based on past studies which found coniferous forest to be a better predictor of marten habitat selection (Clark et al. 1987; Buskirk and Powell 1994; Slauson et al. 2007). The best-fit model included percent of coniferous forest and percent canopy cover as predictors of marten resource selection (Table 1). One model was within two AICc of the best-fit model and included percent of coniferous forest, percent canopy cover, and percent of mixed forest (Table 1). The two top models explained 83% of the variation within the data (Table 1). After averaging models within two AICc of the best-fit model, the final model was:

$$Y = \frac{Exp\begin{pmatrix} -25.03 + 0.14 \times Percent\ coniferous + \\ 0.26 \times Percent\ canopy\ cover + 0.05 \times Percent\ mixed \end{pmatrix}}{1 + Exp\begin{pmatrix} -25.03 + 0.14 \times Percent\ coniferous + \\ 0.26 \times Percent\ canopy\ cover + 0.05 \times Percent\ mixed \end{pmatrix}}$$

Validation of the model occurred in the Manistee National Forest from August 14, 2017 to November 3, 2017. Each of the 150 camera trap sites were left for 21 days, for a total of 3150 trap nights. During validation, no marten were detected in areas of medium or low probability of use. Three marten detections were found in one hexagon with a high probability of use. We also identified seven additional confirmed marten locations, all of which fell within the high probability of use category (R. Sanders, personal communication, 2018; Figure 2). The resource selection function was extrapolated across 38 292.7 km^2 of the northern Lower Peninsula of Michigan. High, medium, and low probability of use areas comprised 37.6%, 7.6%, and 54.8% of the northern Lower Peninsula, respectively (Figure 2).

Discussion

American marten have exhibited large variation in resource use across their range (Potvin et al. 2000; Smith and Schaefer 2002; Hearn et al. 2010). In our northern Lower Peninsula of Michigan site, marten selected for habitat with greater percentages of canopy cover, coniferous forest, and mixed forest than what was available to them. Marten in our study were found to select for areas slightly younger with similar road densities to their surrounding areas, which may be considered features of suboptimal habitat. Marten also selected for regions with larger basal area, percent coniferous forest, and percent canopy cover in Michigan, which are common associations with optimal marten habitat (Hagmeier 1956; Buskirk and Powell 1994). These findings suggest habitat in Michigan is acceptable but may be suboptimal for marten. In Oregon, marten selected for areas with dense canopy cover and large diameter trees in winter and summer, but selected for drier areas in the summer (Shirk et al. 2014). In Washington, marten selected riparian regions with coarse woody debris (Shirk et al. 2014). In New Hampshire, marten selected for mixed forests in winter or hardwood dominated stands in summer (Sirén et al. 2016). Variation in habitat selection for marten may vary based on geographic area or resource availability. Several studies suggest marten may be more adaptable to habitat considered suboptimal based on historic habitat suitability than previously thought (Potvin et al. 2000; Hearn et al. 2010). Marten within Michigan's northern Lower Peninsula were found in regions with characteristics considered suboptimal based on traditional marten habitat paradigms, suggesting they may be more adaptable than historically recorded.

Marten home-range size has been found to vary greatly throughout their geographic range. Shirk et al. (2014) found marten in Oregon and Washington had average home-ranges that were 11.0 km^2 and 11.5 km^2, respectively. In Labrador, marten had exceptionally large home-ranges with a mean size of 36.3 km^2 (Smith and Schaefer 2002). Even within the Great Lakes Region, marten show large variation in home-range size. Marten in our study area in Michigan had a mean home-range of 12.4 ± 3.0 km^2. In Wisconsin, mean marten home-range size was 3.3 km^2 (Dumyahn et al. 2007), while in Minnesota mean home-range size was 12.8 km^2 (Mech and Rogers 1977). Buskirk and McDonald (1989) found no evidence for a geographic or climatic relationship for marten home-range size variation, but home-range size has been associated inversely with resource availability (Thompson and Colgan 1987). Buskirk and McDonald (1989) and Smith and Schaefer (2002) used minimum convex polygons which tend to estimate larger home-ranges than 95% fixed kernel density home-range estimates (Powell 200). However, marten home-ranges in Michigan's northern Lower Peninsula were within the range of reported home-range sizes, although they were roughly twice the size of the global mean. This result may indicate marten habitat in our study area is suitable but may not be optimal.

When estimating resource use across a large geographic area some finer scale features may be lost since models may be limited by the scale of available geospatial data. Therefore, when we modelled marten resource selection, some stand-level characteristics could not be incorporated. Marten are often associated with forests that have complex structure and large amounts of coarse woody debris (Bull and Heater 2000; Buskirk and Powell 1994; Payer and Harrison 2003). However, geospatial data on forest complexity and woody debris are not available, so proxies such as basal area and stand age were used instead. Unfortunately, basal area and stand age data were limited to public lands, so complete stand-level data were not available for habitat that encompassed private property. Another limitation to large-scale modelling is the inability to distinguish natural conifer stands from man-made conifer plantations. Within the Manistee National Forest, there are large tracts of pine plantations which marten may use differently than natural stands. However, Sanders et al. (2017) found marten in the northern Lower Peninsula of Michigan were using these stand types but frequently selected resting sites in older deciduous trees within the stand. Ground-truthing a course-scale resource selection function model to ensure stand-scale characteristics are also present is an important step before enacting management efforts based on the model.

In the Manistee National Forest, marten were found to select for regions with slightly larger basal area and slightly younger stand age than what was available. Basal area estimates within the portions of home-ranges on public land had a mean 3.7 ± 2.1 m^2/ha larger than surrounding regions, which was expected based on past findings of marten selecting forested areas with larger trees (Bull and Heater 2000; Slauson et al. 2007). We acknowledge basal area may increase in regions with large numbers of small diameter tress or due to small numbers of large diameter trees, but there is no way to determine this from our stand data. Based on our experience in the region and average forest age in the Manistee National Forest being 78.7 ± 1.7 years, we assume basal area is likely larger in regions with a few older, larger diameter trees. A basal area difference of 3.7 ± 2.1 m^2/ha between used and available habitat is not very large. This may indicate lack of variation in the size of trees available to marten, but they select for regions with remnant large diameter trees, such as the oaks in red pine plantations. Stand age, however, unexpectedly had a mean age approximately 5 years younger within home-ranges than surrounding regions. This could be due to the large tracts of available and used habitat without available data or stand age may not be a good proxy in Michigan for the resources marten select, such as tree cavities and coarse woody debris. However, the Manistee National Forest is a highly managed timber resource and stand age does not vary much within the forest, which ranged from 46 to 116 years. Also, a five year age difference for trees is unlikely to cause much difference in tree diameter or presence of cavities. However, all tree species do not age equally, and an 80 year old aspen is more likely to provide the cavities marten select their denning and resting sites in than an equally aged oak, which takes longer to mature. Marten likely do not have access to many old-growth stands in the Manistee National Forest and are selecting for areas that have some large diameter trees to meet their resting and denning needs.

Marten are known to occur near the reintroduction sites in the Manistee National Forest and Pigeon River Country State Forest in Michigan’s northern Lower Peninsula (Williams et al. 2007; Hillman et al 2017). Although our resource selection function was weakly supported by validation, the model predicts a high probability of use in these two forests with known populations (Figure 2). We would expect a high probability of use in the Manistee National Forest, where our home-ranges were estimated, but large areas of high probability of use habitat in the Pigeon River Country State Forest is a good sign of model validation. There have also been at least seven confirmed marten sightings in areas the resource selection function predicted to have a high probability of marten use within the Traverse City State Forest, Gaylord State Forest Area, and Pigeon River Country State Forest (R. Sanders, personal communication, 2018). Large amounts of area with a high probability of use by marten where known marten populations are present suggests the model can accurately predict marten occurrence and that validation methods may not have been optimal. Additional surveys across seasons may have improved marten detectability (Zielinski 1995). Also, cameras were left out for 21 days based on detection rates reported from studies in the western United States of America (Moriarty et al. 2016; Zielinksi 1995). Marten habitat is likely different in western states than Michigan, which could result in varying detection rates. Prey availability was not evaluated in our study, but marten may also be more likely to visit baited stations during years of lower prey availability when they are forced to traverse greater areas to meet their needs (Thompson and Colgan 1989). Due to these potential sources of variation in detection rates and the large amounts of area the model predicted to have a high probability of use that have confirmed marten locations, the model appears to be valid.

Since their reintroduction in the late 20th century, little research has focused on resource use of marten in Michigan’s northern Lower Peninsula (L. McFadden, unpublished data, 2007; C. Buchanan, unpublished data, 2008; Sanders et al. 2017). McFadden (unpublished data, 2007) developed a model using Penrose distance for the northern Lower Peninsula of Michigan to identify favorable marten habitat. This study found marten were selecting for deciduous-dominated forests at the home-range level, which contradicts our findings that coniferous-dominated forests were indicative of marten resource selection. Penrose distance models use presence-only data, which Brotons et al. (2004) found to be less accurate than models using presence-no detection data, such as resource selection functions. McFadden's (unpublished data, 2007) model predicted the Pigeon River Country State Forest had little similarity to the resources measured in marten's home-range core estimates. Our resource selection function model predicted a relatively high probability of use in both the Manistee National Forest and Pigeon River Country State Forest, where marten are known to occur. Our model also identified a relatively high probability of use by marten in regions where 10 marten detections were confirmed using remotely-triggered cameras, marten tracks, and marten visualizations (Figure 2). Therefore, we are confident in our use of coniferous-dominated forests as a predictor of marten selection at the home-range level. Buchanan (unpublished data, 2008) looked at habitat within marten home-ranges in Michigan's northern Lower Peninsula and found marten were selecting home-ranges with coniferous patches and large amounts of coarse woody debris. We were unable to assess coarse woody debris at the home-range level, but the selection of coniferous regions is consistent with our findings. Therefore, we believe our resource selection function model can accurately predict the relative probability of use by a marten in Michigan's northern Lower Peninsula.

A resource selection function is a valuable tool for managers to identify regions with a high probability of being used by marten and where marten may occur. This model can be a guideline to survey for potential marten to understand their distribution in Michigan's northern Lower Peninsula. It can also be used to identify regions that already have a high probability of being used by marten to conserve or regions with a low-medium probability of use that could be improved. The model identifies two possible corridors where habitat could potentially be managed to increase movement between the known Manistee National Forest and Pigeon River Country State Forest populations (Figure 2). Our model identified a large amount of high probability of use habitat in the eastern portion of Michigan's northern Lower Peninsula where marten are not known to occur. Surveying and ground-truthing these areas could identify if marten are already present or if management efforts could expand marten occupancy into this potentially viable region (Figure 2). Marten have ecological, social, and economic benefits so managing for marten can have widespread repercussions (Clark et al. 1987; Buskirk and Ruggiero 1994; Zielinksi and Kucera 1995; Dumyahn et al. 2007). Marten act as an umbrella species, so increasing marten resource availability has communal advantages (Buskirk and Ruggiero 1994; Zielinksi and Kucera 1995). Marten are also culturally significant to many Native American communities who personally identify themselves with marten as a clan animal (Dumyahn et al. 2007). Finally, the ability to support a legal harvest would indicate marten management has been successful in Michigan's Lower Peninsula. Therefore, a model to predict what resources marten may select for and where they may occur is beneficial to manage for long-term sustainable populations in Michigan.

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Table 1. Best-fit logistic regression models and their AICc values for an American marten resource selection function in the northern Lower Peninsula of Michigan.

Model variables	**K**	**AICc**	**Δ AICc**	**AICc weight**	**AICc cummulative weight**	**Log Liklihood**
Percent coniferous + Percent canopy cover	3	34.84	0.00	0.49	0.49	-14.23
Percent coniferous + Percent canopy cover + Percent mixed	4	35.59	0.75	0.34	0.83	-13.48
Percent coniferous + Percent canopy cover + Percent mixed + Stand age	5	36.90	2.06	0.17	1.00	-12.97
Percent coniferous	2	49.00	14.16	0.00	1.00	-22.41
Percent canopy cover	2	63.46	28.62	0.00	1.00	-29.64

Table 2. Mean values and standard errors for habitat characteristics of American marten in Michigan's northern Lower Peninsula. Used habitat was 95% kernel home-range estimates and available habitat was estimated from three polygons per individual, the same size as their home-range randomly selected within the Manistee National Forest.

Habitat	**Road density km/km^2**	**Basal area (m^2/ha)**	**Stand age**	**Mixed forest (%)**	**Deciduous forest (%)**	**Coniferous forest (%)**	**Canopy cover (%)**
Used	0.10 ± 0.2	20.1 ± 3.4	73.9 ± 0.97	8.8 ± 2.1	32.8 ± 7.9	58.4 ± 8.0	81.0 ± 2.1
Available	0.12 ± 0.01	16.5 ± 4.9	78.7 ± 1.7	7.0 ± 0.94	77.5 ± 2.1	15.5 ± 1.5	62.8 ± 2.5

Figure 1. Locations of American marten reintroduction sites to the northern Lower Peninsula of Michigan in 1985-1986.

Figure 2. Resource selection function for American marten in the northern Lower Peninsula of Michigan. Probability of use categories are relative and confirmed locations represent areas where marten tracks, visual sightings, or photographs occurred.

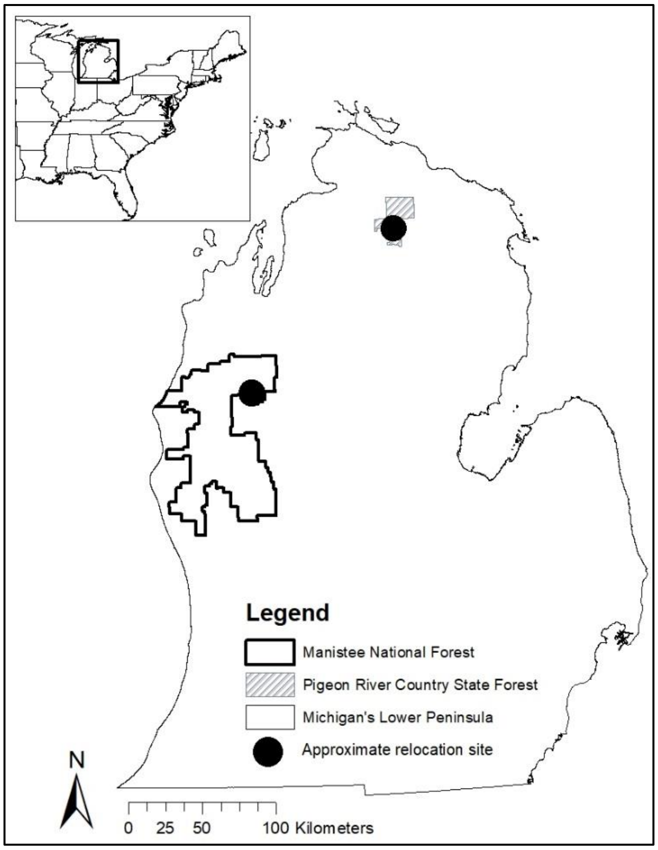
Legend
Manistee National Forest
Pigeon River Country State Forest
Michigan's Lower Peninsula
Approximate relocation site
N
0 25 50 100 Kilometers

Figure 1.

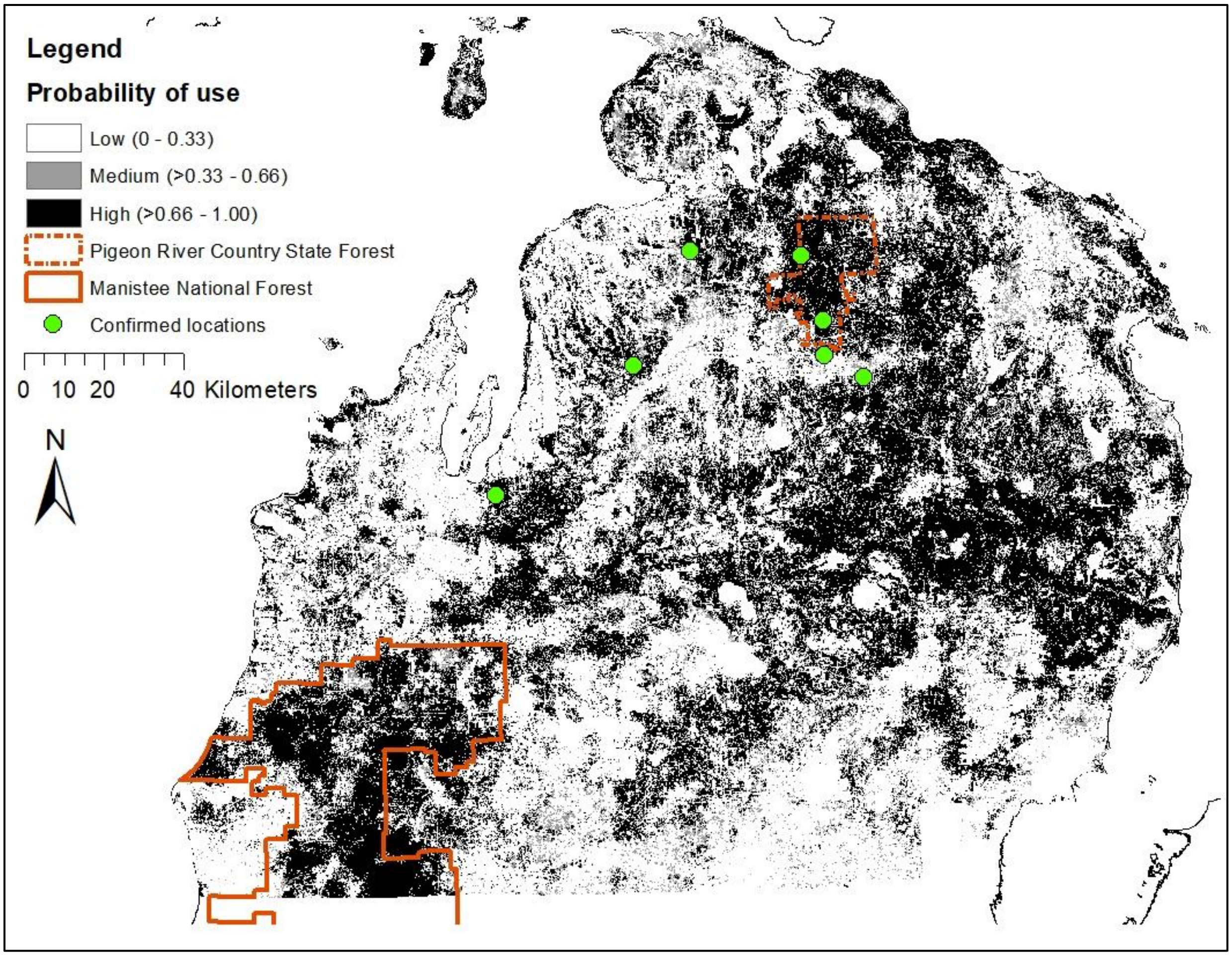
Legend
Probability of use
Low (0 - 0.33)
Medium (>0.33 - 0.66)
High (>0.66 - 1.00)
Pigeon River Country State Forest
Manistee National Forest
Confirmed locations
0 10 20 40 Kilometers
N

Figure 2.

Chapter 3 - Extended Review of Literature and Extended Methodology

Extended Review of Literature

Effective management of wildlife requires an understanding of habitat requirements. Wildlife habitat has been studied in numerous ways and no single way can be applied universally. Therefore, it is crucial to consider the specific objectives of each study and biology of each animal being studied to ensure accurate data is being collected. One factor to consider is the technology being used to collect data. Radio telemetry and very high frequency (VHF) collars have been used to track animals and estimate their habitat needs since the 1960s (Cochran and Lord 1963; Chadwick et al. 2010). VHF collars require active field work to track collared animals and record locations, which can require extensive time and effort. Global positioning system (GPS) collars are a recent technological advancement that can record locations without active tracking once deployed (Johnson et al. 2008). GPS collars can store locations within the collar or send locations electronically to the researcher, which saves time. However, GPS collars cost and weigh more than VHF collars which makes them limited to funding and animals that are large enough to bare their weight (Hebblewhite and Haydon 2010; Tomkiewicz et al., 2010). Moriarty and Epps (2014) found the rate at which a GPS collar attempted to record a location and the surrounding vegetation may affect how well the collar was able to signal satellites and establish a location. The decision to use GPS or VHF collars may not always be clear. VHF and GPS collars vary in data collection methodology, but it is unknown how that impacts habitat estimates derived from them.

Studies comparing VHF and GPS collars are limited, but those performed have varying results on how collar type impacts wildlife habitat inferences. Kochanny et al. (2009) found VHF and GPS collars estimated similar home-range size and large amounts of overlap within an individual's home-ranges estimated with each collar in white-tailed deer (*Odocoileus virginianus*). Land et al. (2008) found VHF and GPS collars estimated similar home-range sizes, but the habitat variables measured within the home-ranges varied across collar types for Florida panthers (*Puma concolor coryt*). Pellerin et al. (2008) found with proper subsampling of GPS locations VHF and GPS collars estimated comparable home-ranges for roe deer (*Capreolus capreolus*). Ballard et al. (1998) found VHF collars did not provide adequate location amounts to accurately estimate the territories of gray wolves (*Canis lupus*) when compared to GPS collars. These varying results indicate that which collar type chosen should be based on the individual study's wildlife needs and research goals.

Another factor that may impact wildlife habitat estimates is variability across geographic areas and seasons. Wildlife may have annual home-ranges that meet their year-round needs or shift their spatial use based on seasonality. American marten (*Martes americana*) have been reported to exhibit habitat seasonality in New Hampshire, Oregon, and Washington, but have also been found to exhibit home-range fidelity throughout the year in Maine and Scandinavia (Phillips et al. 1998; Brainerd and Rolstad 2002; Shirk et al. 2014; Sirén et al. 2016). Marten are also known to exhibit large variation in home-range size and habitat selection. Buskirk and McDonald (1989) looked at marten home-range size in Manitoba, California, Alaska, Yukon territory, Maine, Montana, Minnesota, New York, and Newfoundland and found they ranged from less than one to over 25 km^2. Smith and Schaefer (2002) found that marten in Labrador had extremely large home-ranges with mean sizes of 27.6 km^2 for females and 45.0 km^2 for males. Marten have historically been associated with old-growth coniferous forests (Hagmeier 1956; Buskirk 1992; Buskirk and Powell 1994). However, they have been found to utilize recently logged and deciduous-dominated stands (Potvin et al. 2000; Hearn et al. 2010). Buskirk and

McDonald (1989) found no evidence for a geographic or climatic explanation to marten home-range variability. Therefore, it is important to consider the habitat selection for each marten population being studied and not to over-apply any one population's behavior.

Resource selection functions are useful models to predict the relative probability that an animal will utilize an area (Manly et al. 2002). Resource selection functions use presence-absence or presence-no detection data to predict regions animals are likely to select (Manly et al. 2002). Brotons et al. (2004) compared models using presence only data to models using presence-absence data for fourteen species and found presence-absence models out-performed absence only data models in all cases. Resource selection functions have been used to make inferences about marten habitat selection in California, Oregon, Washington, and Wyoming. In California, marten were found to select for primarily coniferous stands with dense shrub cover, older age classes, and non-serpentine areas (Slauson et al. 2006). In Oregon, marten selected areas with dense canopy cover and large diameter trees throughout the year but selected for drier areas in the summer (Shirk et al. 2014). In Washington, marten selected riparian regions with coarse woody debris (Shirk et al. 2014). In Wyoming, Ruggiero et al. (1998) looked at marten denning sites and found squirrel middens were most common for natal dens (where parturition occurs) and middens, logs, snags, and rocks were equally selected for as maternal dens (where kits were present outside of parturition). These varying results provide additional support for the need to make population-specific estimates of resource selection.

American marten were historically found throughout the northern portion of North American (Williams et al. 2007). Marten were extirpated from much of the southern portion of their range due to human impacts such as fire, logging, and over-harvest (Earle et al. 2001; Williams et al. 2007). Marten were last seen in Michigan's Upper Peninsula in 1939 and

Michigan's Lower Peninsula in 1911 (Williams et al. 2007). From 1955-1989, 342 marten were reintroduced to the Upper Peninsula and 85 marten were reintroduced to the Lower Peninsula from 1985-1986 (Williams et al. 2007). Marten in the Upper Peninsula recovered enough to undergo a legal harvest in 2000, but numbers appear to be declining (Earle et al. 2001; Skalski et al. 2011). Not much is known about the populations in Michigan's Lower Peninsula (L. McFadden, unpublished data, 2007; C. Buchanan, unpublished data, 2008; Sanders et al. 2017). Marten are known to occur near the sites of reintroduction, but their full range is unknown, which provides a challenge when attempting to enact effective management (Williams et al. 2007; Hillman et al 2017). A greater understanding of marten resource selection in Michigan's Lower Peninsula is important in ensuring their long-term viability.

Extended Methodology

Our study took place in the Manistee National Forest within the northern Lower Peninsula of Michigan. The Manistee National Forest covered 218 026 ha, spanning 120 km north to south, 64 km east to west. Our focus was in the northeastern portion of the national forest within Lake, Manistee, and Wexford counties, where marten were successfully located and live-trapped. The Manistee National Forest sat along a transitional area with its northern land being largely forested and southern boundary bordered by agricultural land (USDA 2006). The forest was fragmented by several cities, private land, and highways. Elevation in the forest ranged from 140 to 521 m (USDA 2006). Climate data were taken from nearest weather station located in Manistee, Michigan. Michigan had a temperate climate with a mean fall/winter (March-October) temperature of 1.0 ± 0.06 °C and spring/summer (April-September) temperature of 16.0 ± 3.8 °C (NCEI 2017). Mean precipitation was 36.8 ± 0.2 cm in fall/winter and 51.4 ± 0.07 cm in spring/summer (NCEI 2017). Seasonal designations were based on snow cover for the area, with generally no snow in the spring/summer and moderate to heavy snowpack in the fall/winter. Forest composition included a mixture of coniferous and deciduous trees, with prominent species including red pine (*Pinus resinosa*), jack pine (*P. banksiana*), white pine (*P. strobus*), red oak (*Quercus ruba*), white oak (*Q. alba*), black oak (*Q. velutina*), sugar maple (*Acer saccharum*), red maple (*A. rubrum*), black cherry (*Prunus serotina*), bigtooth aspen (*Populus grandidentata*), quaking aspen (*P. tremuloides*), witch hazel (*Hamamelis virginiana*), iron wood (*Carpinus caroliniana*), yellow birch (*Betula alleghaniensis*), and American beech (*Fagus grandifolia*). Several areas contain large plantations of predominately red pines scattered with some remnant deciduous trees (Sanders et al. 2017).

We live-trapped marten and fitted them with VHF or GPS collars from 2011-2016. Live traps (Tomahawk Live Trap Company, Tomahawk, Wisconsin, model 103 and 105) were baited with meat (usually pork) and scented with "Gusto" (Minnesota Trap Line, Pennock, Minnesota), a potent long-distance lure. Traps were covered with forest debris in the summer or half of a 208.2 L (55 gal) barrel filled with straw in the winter to provide protection and bedding. Traps were checked daily, and bait and scent were replaced as needed.

Upon capture, we removed marten from the trap using a denim restraining cone (Desmarchelier et al. 2007) which allowed access to the snout to administer anesthesia (gaseous isoflurane and oxygen). While anesthetized, we monitored heart rate, respiratory rate, and temperature to ensure the marten was not overly stressed. All individuals were implanted with a passive integrated transponder tag (AVID Identification Systems Inc., Norco, California) with a unique identification number subcutaneously between the shoulder blades. Healthy, adult marten were fitted with a VHF or GPS collar (Holohil Systems Ltd., Ontario, Canada, modified model RI-2D or Advanced Telemetry Systems, Isanti, Minnesota, model M1555). Marten were placed in a recovery box for monitoring until anesthesia wore off and they were released near the point of capture. Capture and handling protocols were conducted following protocols established by Grand Valley State University Institutional Animal Care and Use Committee (protocol 12-05-A) under the guidance of a licensed veterinarian and the Little River Band of Ottawa Indians.

Collared marten were tracked on foot using handheld receiver and antennae. VHF-collared marten were typically located at least once a week. Locations of marten equipped with VHF collars were confirmed by one or more of the following: localized signal, visualization, vocalizations, tracks, scat, prey remains, or chew marks surrounding a tree cavity. Marten were generally un-effected by human presence, but locations were not recorded if animals appeared to be fleeing (when seen running on ground). When equipped with GPS collars, mortality signals (indication of no movement for > 8 hours) were checked approximately weekly. Individuals with GPS collars were targeted during live-trapping to remove collars and download location data.

Fixed kernel density home-ranges were estimated for VHF collar locations, GPS collar locations, and the combination of both collar types. Ninety-five percent probability contour home-ranges were estimated using Geospatial Modelling Environment (Version 0.7.4.0) using a threshold of ≥ 30 locations to delineate a home-range (Seaman et al., 1999). Ninety-five percent contours allowed for the inclusion of most locations, but excluded outliers which could be due to exploratory events and did not represent part of a home-range (Burt 1943; Powell 2000). Only marten that had ≥ 30 locations obtained from both VHF and GPS collars were used for the home-range comparison across collars. All marten that had ≥ 30 locations, regardless or collar type, were used for the resource selection function.

Variables potentially indicative of marten habitat selection were measured using ArcGIS (Version 10.3.1) within each home-range. Variables of interest were determined *a priori* based on previous marten studies and included canopy cover (Gosse et al. 2005), mean and range of elevation (Buskirk and Powell 1994), road density (Robitaille and Aubry 2000), percent of forest composition (percent coniferous, deciduous, and mixed forest; Slauson et al. 2007), stand basal area (Payer and Harrison 2003), stand age (Powell et al. 2003), and percent of edge (forest-wetland, forest-open, and open-wetland edge; Chapin et al. 1998). Canopy cover and land cover (used to measure percent of forest composition and edge) data were acquired from the National Land Cover Database 2011 (USDI 2011). Elevation data were from the United States Geological Survey National Elevation Dataset 2016 (USGS 2016). Road data were obtained from the Michigan Geographic Framework 2016 (DTMB 2016). Stand basal area and age data were provided by the United States Forest Service Stand data 2015 (USFS, unpublished data, 2015). Data were clipped to the area of each home-range and variables measured within attribute tables or using focal statistics if attribute tables were unavailable. Edge was defined as any area where forest-wetland, forest-open, or open-wetland land covers met and a 30 m buffer (Pereboom et al. 2008) was extended into each land cover type. Forest edge was defined as any area consisting of deciduous, mixed or coniferous forest. Open edge was defined as shrub/scrub, grassland/herbaceous, sedge/herbaceous, lichens, pasture/hay, or cultivated crops. Wetland edge was defined as woody wetlands or emergent woody wetland, and all other land covers were not considered indicative of marten habitat selection (e.g. open water, perennial ice/snow, barren rock, etc.). Area and the percent of VHF and GPS collar-based home-ranges that overlapped were also measured.

Using R (version 1.0.153) each habitat variable was tested for normality using the Shapiro-Wilks test. To determine how similar each variable was within the home-ranges delineated by VHF collars, GPS collars, or a combination of both, variables that met the assumption of normality were compared using ANOVA and those that failed the assumption were compared using Kruskal-Wallis.

We considered home-range estimates as used marten habitat and the Manistee National Forest was considered available marten habitat. Three polygons the size of each home-range were randomly selected within the Manistee National Forest for the available habitat. All habitat characteristics were measured within the used and available habitat.

All variables were tested for correlation and when correlation $\geq \pm 0.70$ (Shirk et al. 2014) one was excluded. We referred to past studies on marten habitat selection to determine which variable to retain. Range and mean elevation were removed from future analyses due to inherent sampling bias. Elevation in the Manistee National Forest had a natural decline east to west, towards the coast of Lake Michigan. All data for this study was limited to the northeastern portion of the Manistee National Forest where elevations were highest and therefore may show selection for high elevations when it was not present. Percent of edge was also removed due to its low occurrence within the marten home-ranges, never exceeding 5.5%. All remaining variables, percent canopy cover, road density, percent coniferous forest, percent mixed forest, stand basal area, and stand age, were included in the model selection process. One year-round model was created because marten in our study area were found to not exhibit seasonal habitat variation (A. Kujawa, unpublished data, 2018). We used forward and backward selection to establish a best-fit logistic regression model (Manly et al. 2002). The general formula for the model was:

$$Y = \frac{Exp(\beta 0 \ + \ \beta 1X1 \ + \ \beta 2X2 \ + \ \ldots \ \beta pXp)}{1 + Exp(\beta 0 \ + \ \beta 1X1 \ + \ \beta 2X2 \ + \ \ldots \ \beta pXp)}$$

where Y was the probability of marten use, βs were constants, and Xs were independent habitat variables probability of marten use was related to. Models were ranked using AICc, due to small sample size, and those within two AICc units of the best-fit model were averaged (Arnold 2010) to establish the final resource selection function model. For each variable within the final model, a layer was created for that variable across the study area using ArcGIS. Raster Calculator tool was used to apply the final logistic regression model across the entire study area and establish a map of the resource selection function. The resource selection function model assigned each pixel with a number on a scale of zero to one, with zero having a relatively low probability of marten selecting that area and one having a relatively high probability of marten selecting that area. Regions with values from 0-0.33, >0.33-0.66, and >0.66-1.0 were considered to have a relatively low, medium, or high probability that marten would select that area, respectively.

We attempted to validate our resource selection function using non-invasive remotely-triggered camera survey. A hexagonal grid was established across the Manistee National Forest with 2 km^2 grid cells. Cells were made smaller than the mean home-range within the study area (12.41 ± 3.0 km^2) to reduce the risk of false negatives and to approximate smaller home-ranges found in past studies (Buskirk and McDonald 1989; Poole et al. 2004). The mean relative probability of marten occurrence value was taken within each hexagon and it was assigned to a category of low, medium, or high probability of use. We sampled fifty hexagons assigned to each probability of use categories, for a total of 150 hexagons. Remotely-triggered cameras (Browning BTC-5HDE and BTC-12HD, Reconyx Hyperfire HC500, Moultrie MCG-12592, and Primos Ultra Blackout) were placed near the center of each hexagon approximately 0.3 m off the ground and checked once a week for three weeks. Zielinksi (1995) recommended 12 survey nights to detect marten and Moriarty et al. (2016) had over 75% probability of detection after 14 days so cameras were left for 21 days to improve detectability. Camera stations were baited with a mesh bag of pork or venison suspended approximately 1.8 meters high to reduce consumption. A potent scent lure ("Gusto," Minnesota Trap Line, Pennock, Minnesota) was used nearby and on a stick immediately in front of the camera to improve capture rates. Cameras were visited once a week to replace lure each time and bait when needed. If an animal was absent from the camera frame for more than ten minutes it was considered a new capture. The resource selection function was considered valid if marten were detected proportionally more in the high category of use than medium and low. We then extrapolated the resource selection function model across the northern Lower Peninsula of Michigan.

Appendix 1 – Supplemental materials

Table 1. Home-range estimate smoothing parameters for 18 marten in Michigan's Manistee National Forest. Home-ranges were estimated using Geospatial Modelling Environment (Version 0.7.4.0). Marten ID, smoothing parameters, location count, collar used to collect data, and home-range size are provided. Locations were collected between 2011-2016.

ID	Variance X	Variance Y	XY Covariance	N	Collar type	Area (km^2)
009F	32598.7	190017.6	16154.0	47	VHF	5.7
010F	62082.9	51243.5	11434.4	1916	VHF & GPS	9.4
057M	96738.6	76942.7	-20606.3	51	VHF	6.5
100M	219916.2	130396.2	-23984.3	72	VHF	13.7
124M	50484.0	55349.3	12779.8	2982	VHF & GPS	12.4
181M	143107.8	65917.4	-26580.7	319	GPS	11.6
225F	30365.6	250656.4	14726.9	61	VHF	6.8
314M	153426.1	191657.8	89940.7	392	VHF & GPS	17.4
317M	61051.3	144430.5	10815.9	671	VHF & GPS	12.9
367F	142715.4	12122.2	1278.5	68	VHF	3.5
413F	115006.0	124960.5	36032.1	56	VHF	9.4
523M	185365.0	12240.8	-3018.9	354	VHF & GPS	5.9
554M	43704.0	71367.0	-12104.1	92	GPS	4.4
600F	127822.4	27760.2	9574.2	78	VHF	4.9
606M	1232289.3	789552.4	-548158.8	42	VHF	60.5
627F	59939.1	318548.8	-59663.4	37	VHF	8.1
798F	174206.8	106157.5	2911.3	76	VHF	13.0
889M	145645.1	434331.0	51941.3	38	VHF	17.4

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