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Climate Change and Metapopulation Implications for Species Re/introductions: A Spatial Analysis of Suitable Habitat for the American Marten (*Martes americana*) in Northern Michigan

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Climate Change and Metapopulation Implications for Species Re/introductions:

A Spatial Analysis of Suitable Habitat for the American Marten (*Martes americana*) in Northern Michigan

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Dedication

I dedicate this master's thesis to my loving wife, Sarah,
for her support, encouragement, and love through it all.

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Abstract

CLIMATE CHANGE AND METAPOPULATION IMPLICATIONS FOR SPECIES RE/INTRODUCTIONS: A SPATIAL ANALYSIS OF SUITABLE HABITAT FOR THE AMERICAN MARTEN (*MARTES AMERICANA)* IN NORTHERN MICHIGAN

By Joshua Green

The American marten (*Martes americana*), which was extirpated from Michigan by 1939 due to logging and trapping, has cultural significance as a clan animal to Great Lakes Native American Tribes and ecological significance as a forest health indicator. Sleeping Bear Dunes National Lakeshore (SBD) is considering reintroduction, but several factors must first be considered in assessing the habitat suitability. The goals of this study were to 1) enhance an existing habitat suitability model by including additional relevant variables, 2) conduct a spatial analysis of the habitat within the study area using a metapopulation perspective and 3) incorporate climate change predictions to determine future habitat availability for marten. Coarse woody debris measurements (CWD) were collected in areas of known marten occurrence, along with Michigan Forest Inventory and Analysis data in order to validate an existing Penrose habitat suitability model. The Corridor Designer toolset was utilized in ArcMap to identify patches of most suitable habitat throughout the study area. Future habitat suitability was derived from a Forest Service model, which predicted distribution of tree species in the Eastern United States by 2100 at high and low CO_2 emissions scenarios. I found that additional variables did not enhance the original Penrose Distance model. Corridor Designer indicated large

patches of suitable habitat currently present in Manistee National Forest (MNF) with smaller patches between SLBE and MNF. Climate change predictions indicate that most conifer species in Michigan's Northern Lower Peninsula will exhibit a loss of suitable habitat, except the eastern redcedar (*Juniperus virginiana*), which could increase in importance value (IV) by 450% at most, based on the HI scenario. Oak species such as black oak (*Quercus* velutina) and white oak (*Quercus alba*) could exhibit large increases in IV of 168% and 93%. The combination of these changes could lead to an overall increase in mixed forest stands of 38%. Therefore, habitat is expected to change, but not extensively enough to hinder marten habitat use. I recommend that SBD reintroduce marten in cooperation with the Michigan Department of Natural Resources and local Native American tribes into the Pere Marquette State Forest adjacent to their boundary.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

FIGURE PAGE

CHAPTER 1

INTRODUCTION

Wildlife biologists recognized the importance of reintroductions as a tool for species conservation in the early 1900s, but they did not typically assess habitat suitability or monitor post-release success of the reintroduced individuals (Seddon et al. 2006). Reintroduction papers between the early 1900's and 1988 primarily discussed post-reintroduction events and answered research questions using available data instead of collecting data to answer predetermined research questions (Armstrong and Seddon 2007). In response to this lack of planning and monitoring, the Reintroduction Specialist Group was formed in 1988, as part of the World Conservation Union. Since then, pre-planning and monitoring of projects has increased substantially (Seddon et al. 2006 and Armstrong and Seddon 2007). Armstrong and Seddon (2007) recommend that planning for a species reintroduction should include a set of research questions, which they categorize into population, metapopulation, and ecosystem level questions. In this study, I examined *a priori* research questions regarding the potential availability of suitable habitat for the reintroduction of the American marten (*Martes americana*) in Michigan's Northern Lower Peninsula by conducting a spatial analysis of the habitat in the study area using a metapopulation and climate change perspective.

Study species and habitat requirements

The American marten is a small carnivorous mammal of the Mustelid family. In the Western United States, American marten are habitat specialists and have been found to prefer mature conifer forests with ground cover containing 25-50% coarse woody debris (CWD) (Allen 1982; Gieck 1986). A historical analysis of the American marten (Williams et al. 2007) includes studies indicating that marten may also occur in mixed hardwood forests in Eastern North America. Although marten utilize a variety of habitats, it is common that CWD and snags are important habitat characteristics that marten may select for (Bull and Heater 2000; Buchanan 2008). Mature forests take centuries to develop, making it difficult for these forest types to recover from habitat fragmentation resulting from development and logging. Logging can also take away many of the forest habitat characteristics important to marten. In the late 1800s and early 1900s, land settlement and heavy logging, as well as trapping throughout Michigan's Lower Peninsula led to fragmentation of the American marten habitat and ultimately their extirpation from the Lower Peninsula (Swanson et al. 2006). The last sighting of an American marten in the Lower Peninsula of Michigan was in 1911 near Lewiston in Montmorency County and they were eventually extirpated from the Upper Peninsula by 1939 (Williams et al. 2007).

Based on their habitat requirements in the American west, marten are regarded as an indicator species for old growth forests. In Michigan's Lower Peninsula, where old growth forests are largely absent, marten would likely select for high snag and CWD densities. These characteristics are preferred by many other species and could therefore indicate high biodiversity, which is a measure of forest health. Marten are primarily carnivores in the winter and prey on small mammals, such as voles (*Clethrionomys* and *Microtus)*, squirrels (*Sciurus/Tamiusciurus*), and rabbits (*Silvilagus*) (Harris and Chester 1997; Gieck 1986; Buskirk and Zielinski 1997), therefore, they can influence the population dynamics of these species in similar ways that other carnivores affect their prey populations (e.g. wolves and deer). Some marten prey species such as the red squirrel (*Sciurus vulgaris*), are considered a pest species in Michigan (Rubin 2012). Additionally, lyme disease is becoming an increaseing concern in the eastern United States, including Michigan (CDC 2007), thus population control of small mammal species that ticks depend on as hosts (Keirans 1996) would be beneficial in controlling tick populations and reducing the risks of lyme disease transmission to humans. Marten also have cultural significance for Great Lakes Native American tribes, such as the Ojibway Tribes, and are positively protrayed in their mythology (Basil 1982). This cultural significance means that there is a source of funding from interest groups associated with these Native American tribes that could assist with reintroduction projects.

As a result of these ecological benefits and the cultural significance of marten, muliple reintroductions of the American marten in Michigan began in the Porcupine Mountains State Park of the Upper Peninsula in 1955 and proceeded until 1992. These reintroductions were coordinated by the Michigan Department of Conservation (Williams et al. 2007). Additional reintroductions occurred, through collaboration between the Michigan Department of Natural Resources and the U.S. Forest Service, in the Pigeon River Country State Forest in Michigan's Lower Peninsula in 1985 and in Lake and Wexford counties within the Manistee National Forest (MNF) in 1986 (Williams et al. 2007). The majority of introduced marten came from Ontario, Canada and they were reintroduced into areas of suitable habitat observed at that time. These reintroductions into the Lower Peninsula involved about 40 marten each and research indicates that the MNF population is showing signs of inbreeding (Tamara Hillman, unpublished data). Currently, organizations such as the Little River Band of Ottawa Indians are interested in reintroducing additional marten into the Lower Peninsula (Bob Sanders, Little River Band of Ottawa Indians, personal communication). Park officials at Sleeping Bear Dunes National Lakeshore (SBD) are also considering reintroducing marten into the National Lakeshore boundaries (Sue Jennings, Sleeping Bear Dunes National Lakeshore, personal communication).

Sleeping Bear Dunes National Lakeshore contains 28,851 ha of land and is located in the Northwest corner of Michigan's Lower Peninsula. It is composed of 57% upland deciduous, 3% upland coniferous, 7% upland mixed, 6% lowland forests, and 12% historic agricultural fields. A highway passes through the middle of SBD, but only 1% of its landscape is composed of roads, parking lots, and other developed areas (Mechenich et al. 2009). On March 13, 2014, about 13,175 ha (45%) of SBD was designated as wilderness (S. 23, www. congress.gov). This designation increases the level of protection of select areas within SBD by prohibiting the use of motorized equipment. American marten do not currently reside within SBD; however the habitat may be able to sustain populations if they were reintroduced. Sleeping Bear Dunes National Lakeshore was established to protect its natural resources and the wildlife that utilize them within its boundaries. This protection includes species that have historically lived in the area, but have been pushed out as a result of human settlement.

For this study, plots were located in Lake County in MNF, which is in the western central portion of Michigan's Lower Peninsula. Manistee National Forest is about 218,026 ha in size and is comprised of upland coniferous, upland deciduous, upland mixed, and lowland forests interspersed with roads, which range from highways to forest two-tracks, as well as privately owned land.

A few studies have been done on habitat selection and suitability of marten in MNF at both the landscape and home range core area scales (McFadden 2007 and Buchanan 2008). McFadden (2007) measured habitat selection involving forest composition and structure using GIS patch metrics and created a model based on these variables using the Penrose Distance statistic in Michigan's Northern Lower Peninsula. Penrose Distance is an equation that was used to compare habitat between known marten home ranges and potential marten home ranges, which were represented by hexagons that were 1.6 km^2 in size. These hexagons were overlaid across Michigan's Northern Lower Peninsula (McFadden 2007). This equation indicates how similar potential home ranges are to the actual home ranges as a measure of suitable habitat. Based on track surveys, it seemed that more marten were utilizing what was predicted to be the second and third most suitable habitat categories than expected based on availability (McFadden 2007). This descrepancy could indicate that factors influencing habitat suitability for marten are not being accounted for in McFadden's model, which limits the ability to predict suitable locations for marten reintroduction. Another study further measured habitat selection at the mesoscale and found that marten core areas contained an average density of 60 CWD pieces of at least 15 cm in diameter per hectare (Buchanan 2008).

Metapopulation and Climate Change Implications for Species Re/introductions

When studying the species distribution and potential reintroduction, it is important to consider not only the habitat characteristics of an area, but also the metapopulation potential of the landscape that surrounds the area of interest (Armstrong 2005). Metapopulations are a matrix of subpopulations within a given landscape that have the potential for migration to occur between them. The theory of metapopulation dynamics suggests that populations in small, isolated patches are at a greater risk of extinction and certain life history strategies make some populations prone to extinction when habitat fragmentation occurs (Lawes et al. 2000). An additional consideration for the factors that affect metapopulation viability includes identifying which patches of suitable habitat could support source populations and which patches could support sink populations. Source populations are subpopulations that have enough individuals to sustain themselves and supplement other subpopulations through migration. Sink populations are subpopulations that are declining in size and may go extinct at times (Howe, Davis, and Mosca 1991).

Climate change is becoming increasingly relevant to ecosystem management today with the advancement of technology that can be used to predict how the climate could change and how species might respond to the change. Drought and extreme temperature predicted by some climate models are associated with the mortality of eastern tree species such as sugar maple (*Acer saccharum*), paper birch (*Betula paperifera*), white ash (*Fraxinus americana*), American beech (*Fagus grandifolia*), and quaking aspen (*Populus tremuloides*). Many of these species form large components of Michigan's forests and their loss could further fragment the habitat for marten populations. Commercially important tree species north of Michigan's tension zone have experienced times of regional forest decline, which has been attributed to climatic stress as a causal factor (Reed and Desanker, 1992).

Site selection for species introductions and reintroductions is typically based on the current availability of suitable habitat. However, climate change is likely to cause range shifts in habitat and species distributions and it is important for conservation and reintroduction projects to consider the predicted impacts of climate change on habitat. For example, a comparison of biodiversity surveys at key sites in California a century apart documented upward elevational shifts of approximately 500 m in half of the mammal species with a contraction of some ranges and expansion of others (Moritz et al. 2008, Tingley et al. 2009). Wasserman et al. (2012) modelled climate change impacts on marten in the Rocky Mountains by associating warming temperatures with increases in elevational limits to gene flow. They found that warming that is predicted to occur by 2040 to 2080 could lead to an upward shift of marten populations by 300-500m and result in the genetic isolation of populations in the Rocky Mountains (Wasserman et. al. 2012). Historically, marten distribution extended only as far south as southern Michigan (Williams et al. 2007, Figure 1), which suggests that cooler temperatures of the Northern United States may influence their distribution. Wasserman et al. (2012) associated a strong relationship between gene flow and elevation with snow pack or species composition. Both of these variables could be heavily impacted by warming temperatures in Michigan and in the absence of an elevational gradient, suitable habitat could be pushed northward, which may influence the habitat available for martens at Sleeping Bear Dunes. In order to determine the feasibility of introducing a species back into an area, it is instructive to consider the habitat changes that are likely to occur in that area due to climate change. Due to the effort and resources required for a successful reintroduction (Fischer and Lindenmayer 2000), metapopulation and climate change considerations are useful and relevant.

The objectives of this study were to:

1) Enhance a habitat suitability model created by McFadden (2007) and apply the enhanced model to Manistee National Forest and Sleeping Bear Dunes National Lakeshore and surrounding areas,

2) Measure size of suitable habitat patches within and between Sleeping Bear Dunes National Lakeshore and Manistee National forest, as well as distance between patches, and

3) Predict climate change effects on suitable habitat and forest structure at Sleeping Bear Dunes and the surrounding area in order to determine the feasibility of reintroducing the American marten.

The hypotheses tested in this study were as follows:

1) Adding a critical habitat variable (i.e. CWD and stand age) would significantly improve the predictive ability of the habitat suitability model. I expected that there would be more coarse woody debris in the hexagons that are predicted to be moderately suitable than the hexagons predicted to be most suitable, which would help explain validation errors. I also expected that incorporating coarse woody debris and stand age as variables in the habitat suitability model could improve the model validation

2) I also predicted that looking at the contiguity of the top three Penrose Classes will reveal patches of suitable habitat located between and within SBD and MNF due to habitat fragmentation and SBD will provide habitat likely to support a sink population of marten due to the small size of the National Lakeshore.

3) Projected changes in tree species and habitat distribution due to climate change would not alter the availability of suitable habitat for marten at SBD. Climate change is likely to alter the species composition of potential marten habitats. I expected a reduction in the number of available tree species, such as sugar maple and American beech, with the potential for other tree species from farther south, such as oak (*Quercus spp.*) and silver maple (*Acer saccharinum*) to become the dominant species, which could maintain suitable habitat for the American marten at Sleeping Bear Dunes.

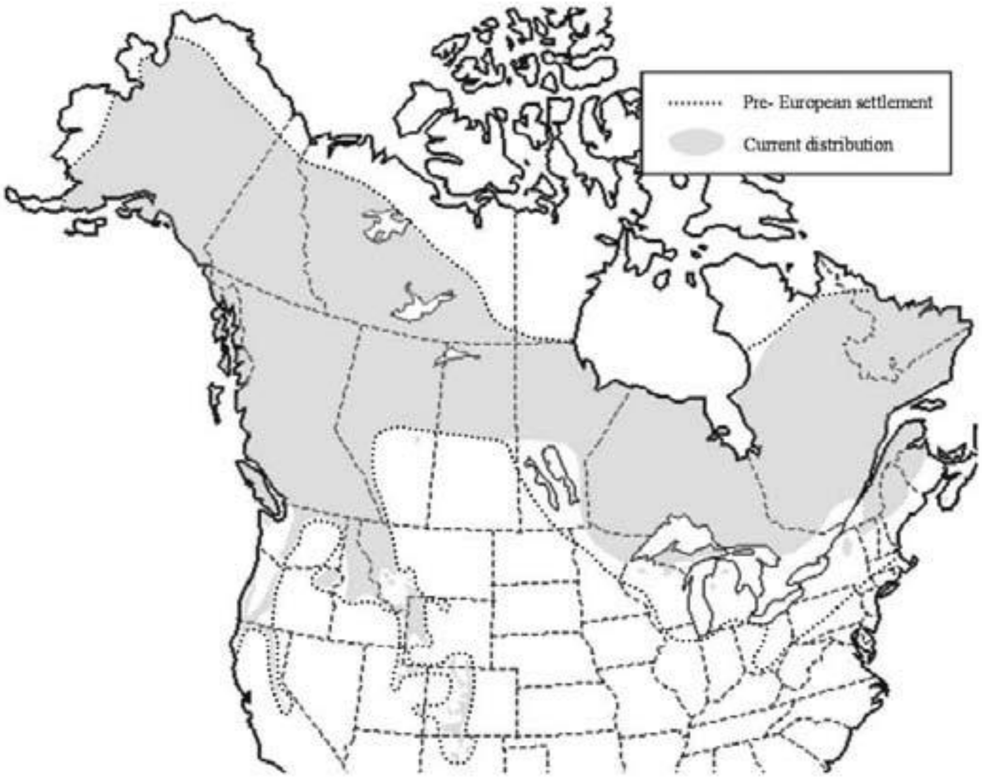

Figure 1. American marten distribution in North America. Historical distribution is indicated by dotted line. Current distribution is indicated by the shaded areas (Image from Williams et al. 2007, USDA Forest Service, Northern Research Station).

CHAPTER II

HABITAT SUITABILITY MODEL AND POTENTIAL IMPLICATIONS FOR METAPOPULATIONS

Introduction

American martens have been reintroduced only twice in Michigan’s Lower Peninsula, with the MNF reintroduction approximately 64.4 kilometers (km) from SBD. No studies have been done to estimate the population size of marten near SBD. The only evidence of marten in the area is one confirmed road kill in Benzie county (Steve Griffith MDNRE personal communication) less than 16.1 km east of SBD. Before reintroducing marten into SBD, it is important to consider the potential for metapopulation structure between SBD and MNF. Although the reintroductions in MNF and Pigeon River Country State Forest were about 129 km apart, genetic evidence suggests that there is a low level of migration occuring between the two subpopulations (Nelson 2006).

When considering factors that affect metapopulation viability in a fragmented habitat, it is important to keep in mind that a matrix of subpopulations will generally have a greater risk of extinction than a single population with contiguous habitat (Reed 2004). This is not to say that metapopulations cannot persist in a fragmented habitat. Other factors can contribute to metapopulation persistance and allow for such metapopulations to have a lower extinction risk. Such factors include the spatial autocorrelation of subpopulations and dispersal between subpopulations (Reed 2004). Spatial autocorrelation is the correlation in fluctuations of subpopulation size with environmental conditions. The farther apart the subpopulations are, the less correlated they are (Reed 2004). If subpopulations are highly spatially correlated then the extinction risk of smaller populations would be higher than that of a single, large population. Alternatively, if the subpopulations are uncorrelated, then subpopulations that remain would be able to supplement those subpopulations that are in decline and reduce the extinction risk of the metapopulation below that of a single, large population (Reed 2004). Thus, it is important to assess the status of habitat patches in the study area and their connectivity in order to determine how to best manage this population of martens. Habitat suitability modeling and spatial analysis can provide useful insight on the potential of the landscape in Northern Michigan to support a metapopulation of marten and the locations of potential source or sink populations.

The objectives of our study were to enhance and corroborate the habitat suitability model created by McFadden (2007) and apply the enhanced model to MNF, SBD, and the surrounding area to examine the potential for SBD to sustain reintroduced populations of the American marten. I predicted that adding critical habitat variables (i.e. CWD and stand age) would improve the predictive ability of the habitat suitability model. I expected to find more CWD in hexagons predicted to be moderately suitable than in hexagons predicted to be most suitable, which would explain validation errors and incorporating this variables in the habitat suitability model would better validate the model. I also predicted that looking at the contiguity of the top three Penrose Classes will reveal patches of suitable habitat located between and within SBD and MNF due to habitat fragmentation and SBD will likely provide habitat to support a sink population of marten due to the small size of the National Lakeshore.

Methods

Compilation of Spatial Database

I compiled a spatial database, which included GIS layers of American marten occurrence and land cover types in Michigan and in SBD. GIS points of 334 marten radio telemetry locations were obtained from ongoing research by Bob Sander, Masters Student at Grand Valley State University. Additional layers of home ranges and Penrose Classes were obtained from McFadden (2007). A 2001 IFMAP grid layer for vegetation and land cover type of Michigan's Lower Peninsula with 30m resolution and the MNF boundary layer was accessed from the Michigan Geographic Data Library (http://www.mcgi.state.mi.us). I reclassified 34 original land cover types into 7 different classifications of upland deciduous, upland coniferous, upland mixed forest, lowland forest, agriculture/openland, urban, and wetland/water, which are consistent with the classifications used by McFadden (2007). The Sleeping Bear Dunes' boundary layer was obtained from Sleeping Bear Dunes' Natural Resources Division.

Habitat Suitability Model

McFadden (2007) measured habitat selection involving forest composition and structure using GIS patch metrics and created a model based on these variables with the Penrose Distance statistic. She accomplished this by overlaying 1.6 km^2 hexagons on Michigan's Northern Lower Peninsula. Hexagon size was determined based on the average marten core area home range. Marten core area habitat metrics were compared with habitat metrics from the hexagons to assign a Penrose Distance class to each hexagon.

The equation for the Penrose statistic is

$$P_{ij} = \sum_{k=1}^{p} \frac{\left(\mu_{ki} - \mu_{kj}\right)^2}{pV_k}$$

Where P is the habitat suitability, i represents the marten core areas, j represents the hexagon areas, k is each observation, p is the number of variables, μ is the variable value, and V is the variance (Manly 1986). This equation was a modification of the Mahalanobis Distance Statistic (Manly 1986) by Nielson and Woolf (2002). As the Penrose Distance value approaches 0, the hexagon is more similar to marten core area home ranges and thus most suitable (McFadden 2007).

Habitat variables were chosen by McFadden based on which variables marten appeared to select for or avoid using home range data. These variables were percent cover of upland deciduous forest, upland coniferous forest, upland mixed forest, wetland/water habitat, and urban, as well as the number of habitat patches and the area weighted mean patch fractal dimension. A habitat patch is defined as a contiguous area of a single habitat type. The area weighted mean patch fractal dimension measures how complex the shape of each patch is relative to its size (Elkie et al. 1999). She then classified these values into quartiles, in which the 0 to 25th quartile was most suitable (hereby classified as 1), 25th to 50th quartile was second most suitable (2), followed by the 50th to 75th (3), 75th to 100th (4), and then above the 100th quartile (5). This model was corroborated with track surveys which revealed significantly higher than expected densities of marten tracks occurring in Penrose Classes 2 and 3 based on their vailability (Figure 2).

Table 11. Chi square analysis of American marten track survey results in the Manistee National Forest. An asterisk (*) indicates marten tracks were found significantly more often than expected ($\alpha = 0.05$) within a Penrose distance class, and a double asterisk (**) indicates martens tracks were found significantly less often than expected.

Penrose Distance Class	Total number of hexagons in MNF	Proportion of total hexagons in MNF	Number of tracks observed	Expected number of tracks	Proportion in each area (p_i)	Bonferonni Confidence Intervals
0 - 0.90	130	0.0543	7	7	0.0355	$0.0027 \leq p_i \leq 0.0684$
0.91 - 1.43	279	0.1166	68*	12	0.4467	$0.3585 \leq p_i \leq 0.5349$
1.44 - 2.23	631	0.2637	71*	25	0.3604	$0.2752 \leq p_i \leq 0.4456$
2.24 - 8.19	998	0.4170	31**	94	0.1574	$0.0928 \leq p_i \leq 0.2220$
8.19 <	355	0.1483	0**	59	0.0000	$0.0000 \leq p_i \leq 0.0000$
Total	2393		197	138		

Figure 2: Results from track surveys to validate the American marten Penrose Distance habitat suitability model. More tracks than expected were found in the 2nd and 3rd Penrose classes based on their availability (Table obtained from McFadden 2007).

Spatial analyses of marten Penrose Classes were performed using ArcMap 10.0 (ESRI, Redlands, California) and the patch analyst extension (Patch Analyst Version 5.1, www.cnfer.on.ca/SEP/patchanalyst/, accessed 18 Dec 2012) to determine potential reasons for the validation errors in McFadden's model. Using these Penrose hexagon layers, habitat suitability was assessed between the two sites and within SBD.

Sleeping Bear Dunes' property is narrow and more sensitive to fragmentation caused by roads. Therefore, habitat suitability of the surrounding area was included in order to determine the implications for supporting a sustainable metapopulation in the region. Additionally, suitable Penrose hexagons were used to assess the carrying capacity for marten in SBD to determine if it can sustain a viable population. This was done by calculating the area of contiguous hexagons of the top three Penrose classes and comparing it with the average home range for marten in Michigan.

Pilot study for CWD field analysis

Coarse woody debris (CWD) is an important component of marten habitat, which may not have been accounted for in McFadden's model. The goal of the field analysis was to determine if hexagons in the most suitable Penrose Class contain more CWD than nearby hexagons of subsequent Penrose Classes. To determine this, I measured CWD density within Penrose Hexagons to compare the densities between classes. I selected the number of CWD measurement plots in each hexagon based on a pilot study performed within three hexagons. During my pilot study, one 8m radius plot was placed in the geometric center (Method A), two 4m radius plots were set up in the North and South hemispheres of the hexagon (Method B), and six 4m radius plots were set up in each corner of the hexagon (Method C, Figure 3). I compared estimates of CWD density between the plots to determine how many plots are necessary for a good approximation to be used for comparison purposes. Data were collected following methods by Buchanan (2008) and included CWD length, width classification, and physical condition rank. Pilot studies measured all CWD found within a plot, but further plot measurements were made on CWD greater than 7.6cm (3in.) in diameter based on the amount of time required to measure all CWD. The size limit was determined from the minimum diameter that provides use for a marten for foraging or shelter during the winter (Allen 1982). It seems intuitive that the largest number of plots (Method C) would yield the most accurate density estimate.

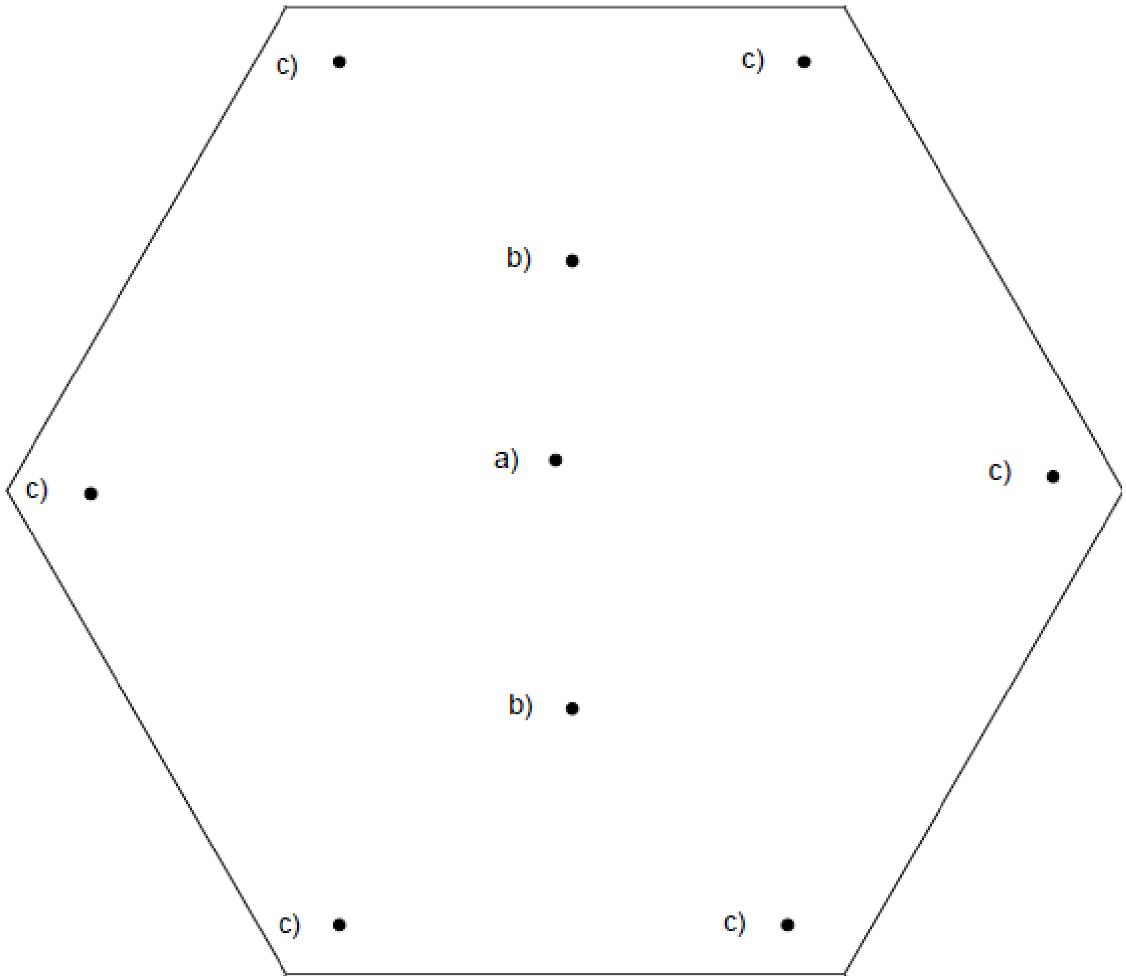

Figure 3. A Penrose Distance hexagon indicating the plot locations used in the pilot study for CWD field analysis. Plots were set up for three trial methods such that a) one 8m radius plot was placed in the geometric center b) two 4m radius plots were set up in the North and South hemispheres of the hexagon, c) and six 4m radius plots were set up in each corner of the hexagon.

Field Analysis for estimating CWD density

I used the Penrose Distance hexagons for habitat suitability calculated by McFadden (2007) to compare coarse woody debris occurrence for four hexagons in each distance class with a predetermined number of plots per hexagon based on the pilot study described above. I conducted further analysis to determine if the original model indirectly accounts for the amount of CWD. I ran a Kruskal-Wallis test on the volume (m^3/ha) of CWD larger than 10 cm, density (logs/ha) of CWD larger than 10 cm, and density (logs/ha) of CWD larger than 15cm in diam. between Penrose classes. There was more CWD in the most suitable Penrose Classes and this observation was consistent between all CWD size classes and quantity measurements, so 15 cm diameter logs were used in further statistical comparisons, because they are found to be most important to marten habitat (Buchanan 2008). I ran a Kruskal-Wallis test with post-hoc Wilcoxon tests on Michigan Forest Inventory and Analysis (MIFIA) data between number of CWD larger than 15 cm in diam. and habitat type to observe a general relationship between these factors in Michigan. I classified habitats as upland deciduous, upland coniferous, upland mixed, and lowland forest. The dataset is part of the National Forest Inventory and Analysis Program in which multiple points were established throughout Michigan collecting a number of forest characteristic data including CWD content, habitat type, and stand age at each point. This provided a pool of data from which I could assess the relationship between habitat types, CWD, and stand age in Michigan. Statistical analyses were performed using R statistical software (R version 2.15.1, www.r-project.org/, accessed 30 Aug 2012). Patch Analyst for ArcMap was used to further analyze the connectivity of patches of each Penrose Class.

Spatial Analysis to Explore Implications for a Metapopulation

Habitat suitability between sites was used to explore spatial factors that could support a viable metapopulation of marten between and within Sleeping Bear Dunes and Manistee National Forest. I considered the size of suitable habitat patches and the distance that they are apart in order to determine if the habitat patches might be able to support marten and facilitate dispersal. This was accomplished using the Corridor Designer tool (Majka et al. 2007) for ArcMap. This tool utilizes a habitat suitability model to create patch maps based on a specified habitat suitability threshold and area of contiguity necessary for breeding habitat and minimum population sizes specified by the user. For consistency, the habitat suitability model for the tool was created using the quartiles assessed by McFadden (2007), so that the most suitable habitats were assigned a value of 100, the second most suitable were assigned a value of 75, the third most suitable were assigned a value of 50, the fourth most suitable were assigned a value of 25, and the fifth most suitable habitats were assigned a value of 0. The habitat suitability threshold was set at 50, corresponding to the first, second, and third quartiles, which contained the most marten tracks in the validation study conducted by McFadden (2007). Values below the threshold were considered unsuitable habitat. Minimum patch size for breeding was set at 770 hectares (ha), which was the average home range of a female marten in Michigan, as reported by McFadden (2007). Majka et al. (2007) recommended that this value be set using the home range of the study species. Female home range was used because females raise their kits alone (Clark et al. 1987), thus an average home range size is what is required to raise their kits. The minimum patch size for a population was determined as approximately five breeding patches as recommended by Majka et al. (2007) and was set at 3850 ha.

In order to further validate the model created by McFadden (2007), I ran a chi-square test on 334 marten denning sites obtained using radio telemetry by Bob Sanders (Little River Band of Ottawa Indians, unpublished data). I generated 334 random points within the MNF boundary using the GIS tool "Create Random Points." In accordance with the Corridor Designer model, I determined marten and random points to be in suitable habitat or unsuitable habitat based on whether the points were completely within "Population Patches" or "Breeding Patches" (suitable habitat), or not (unsuitable habitat). This model validation took into account contiguous areas of the three most suitable Penrose hexagons.

Results

Pilot Study for CWD Field Analysis

The pilot study indicated that method B was the best method for quantifying CWD density. This was based on the observation that method B showed a large increase in CWD density estimates compared with method A, while there was a relatively small difference in density estimate between method B and method C (Table 1). An ANOVA revealed that there was no significant difference in density (logs/ha) estimates between methods ($F=1.7053$, $p=0.3052$, $df= 2$). Although method C appeared to measure a higher density of CWD in almost all plots, the amount of survey effort required for this method did not yield an equivalent increase in density estimate compared to method B. The selected method is not expected to yield an accurate density estimate, rather an index for comparison between hexagons.

Table 1. Average coarse woody debris (CWD) density (logs/ha) estimates with standard errors by Hexagon ID and method with CWD of all sizes. Data were collected in Manistee National Forest near Baldwin, MI. No significant difference was found between methods using an ANOVA ($F=1.7053$, $p=0.3052$, $df=2$). Method B was chosen for more consistent density estimates with minimum survey effort. Note that the high standard errors is likely due to small sample size.

Density (logs/ha) of coarse woody debris in Penrose hexagon plots in Manistee National Forest

Hexagon ID	Method A (logs/ha) ±SE	Method B (logs/ha) ±SE	Method C (logs/ha) ±SE
Plot 16746	199±0.00	298±298.42	829±309.98
Plot 42171	895±0.00	1790±0.00	2288±647.20
Plot 16972	1194±0.00	2984±281.35	2650±676.93
p-value		0.3052	

Field Analysis for estimating CWD Density

I found no significant differences between Penrose classes for average volume of logs larger than 10 cm, average density of logs larger than 10 cm, or average density of logs larger than 15 cm diam. ($\chi^2=0.376$, $p=0.829$; $\chi^2=2.289$, $p=0.318$; $\chi^2=3.922$, $p=0.141$; $df=2$). The average volume of logs larger than 10 cm in diam. appeared highest in Penrose Class 1 and relatively equal in Penrose Class 2 and 3 (Table 2). The average density of logs greater than 10 cm and 15 cm in diam. yielded similar observations as volume, in which class 1 also contained the most while class 2 had slightly more than class 3 (Table 2). Although these observations support the Penrose model, the data have low statistical power due to a small sample size. When analyzing the MIFIA dataset, I found a significant difference in the number of logs greater than 15 cm. in diam. between habitats (χ^2= 9.720, p=0.021, df= 3), with upland deciduous containing more logs than upland coniferous forests (W= 1637.5, p=0.043). Additionally, a generalized linear model was performed with number of logs as a response variable and habitat type and stand age as predictor variables with no significance at an alpha level of 0.05.

Table 2. Average volume per ha of coarse woody debris (CWD) greater than 10cm in diam. with standard error, as well as average density (logs/ha) of CWD greater than 10 cm and 15 cm in diam. by Penrose Class (four hexagons per class) using estimates from method B. No significant differences were found between Penrose classes (n=3). Penrose Class 1 has the highest average volume per ha and the highest density of CWD across both class sizes. Note that the high standard errors are likely due to small sample size. Data were collected in Manistee National Forest near Baldwin, MI.

Volume (m^3/ha) and Density (logs/ha) of coarse woody debris between Penrose classes in Manistee National Forest

Penrose Class	Average Volume >10cm (m^3/ha) ±SE	Average Density (>10 cm logs/ha) ±SE	Average Density (>15 cm logs/ha) ±SE
1	66.85±0.18	422.76±238.09	149.21±95.24
2	26.07±0.05	273.55±117.52	49.74±28.72
3	37.66±0.13	223.81±130.80	24.87±24.86
p-value	0.829	0.809	0.544

Patch analyst metrics on the Penrose Classes indicated that there are more hexagons of Penrose Classes 2, 3, and 4 than class 1 (Figure 4). In addition, the mean nearest neighbor statistic was measured for each Penrose Class to determine the average distance between patches of the same Penrose Class measured from edge to edge

(Rempel 2012). This statistic found that patches of Penrose Class 1 were over twice as far apart from each other than patches of Penrose Classes 2 and 3 (Figure 4).

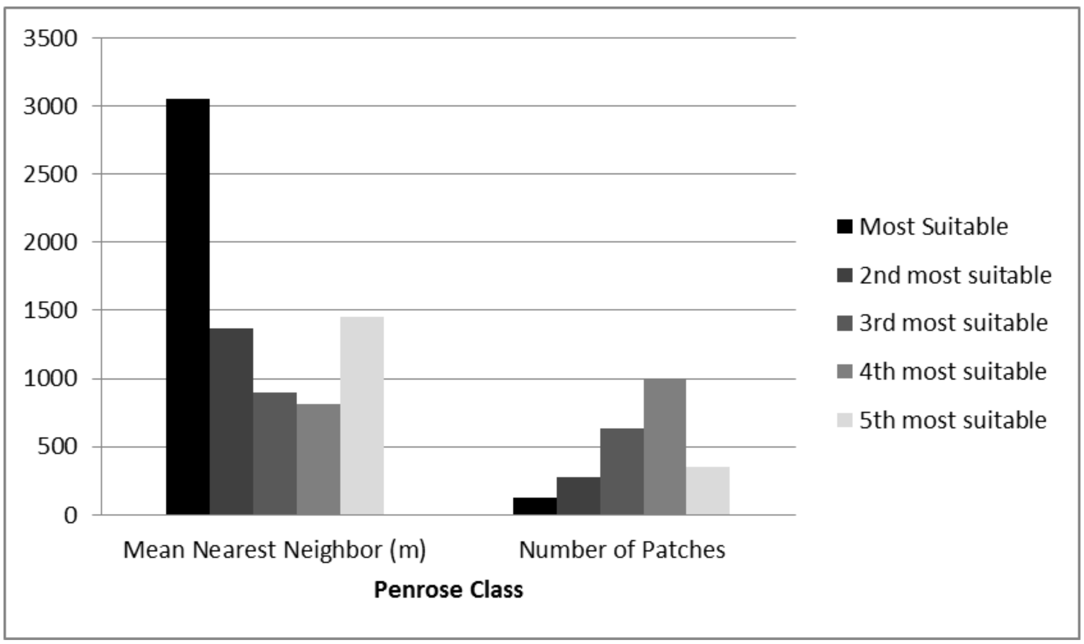

Figure 4. Total number of patches and mean nearest neighbor (m) of hexagons in each Penrose class in the Manistee National Forest. A patch is defined as a contiguous area of the same Penrose Class. Mean nearest neighbor is a measure of the average distance between two patches of the same Penrose Class from edge to edge. The higher the value, the farther apart the patches are from each other.

Metapopulation Assessment

The Corridor Designer tool created a layer depicting three different patches based on our specifications: population patches, breeding patches, and less than breeding patches. This layer indicated two large patches in MNF located in the northern section and the central section that are 46676 and 43956 ha, respectively. The northern patch is capable of supporting approximately 41 male home ranges (1123 ha) and 60 female home ranges (770 ha), which could overlap male home ranges as observed in Wyoming (Clark et al. 1987). The central patch could support approximately 39 male home ranges and 57 female home ranges. These large patches overlay known marten locations based on home ranges and track surveys. There are also a few smaller patches of suitable habitat throughout the MNF (Figure 5). For the chi-square test within MNF, I found that there were more marten locations in suitable population and breeding patches than expected based on a random distribution (X^2-192.42, p<2.2e^-16). Sleeping Bear Dunes contains suitable habitat in a single large patch that is 1833 ha in size, which is adjacent to a larger patch just outside of the SBD boundary that is 14879 ha in size. The area just within SBD is large enough to sustain one male home range and two female home ranges. The area of suitable habitat adjacent to SBD could support approximately an additional 13 male home ranges and 19 female home ranges. Although, this area is more vulnerable to encroachment, its connection to SBD and overlap with Pere Marquette State Forest could reduce the risk with coordinated management by the MDNR. Additionally, there are two patches of suitable habitat between SBD and MNF (Figure 6). The patch just south of

SBD is 14727 ha in size, which can sustain approximately 13 male home ranges and 19 female home ranges. The patch just north of MNF is 22133 ha in size, which equates to 19 male home ranges and 28 female home ranges. These are conservative estimates of population threshold, which assumes strong intrasexual territoriality. These multiple smaller suitable habitat patches located between MNF and SBD also overlap with State Forest land.

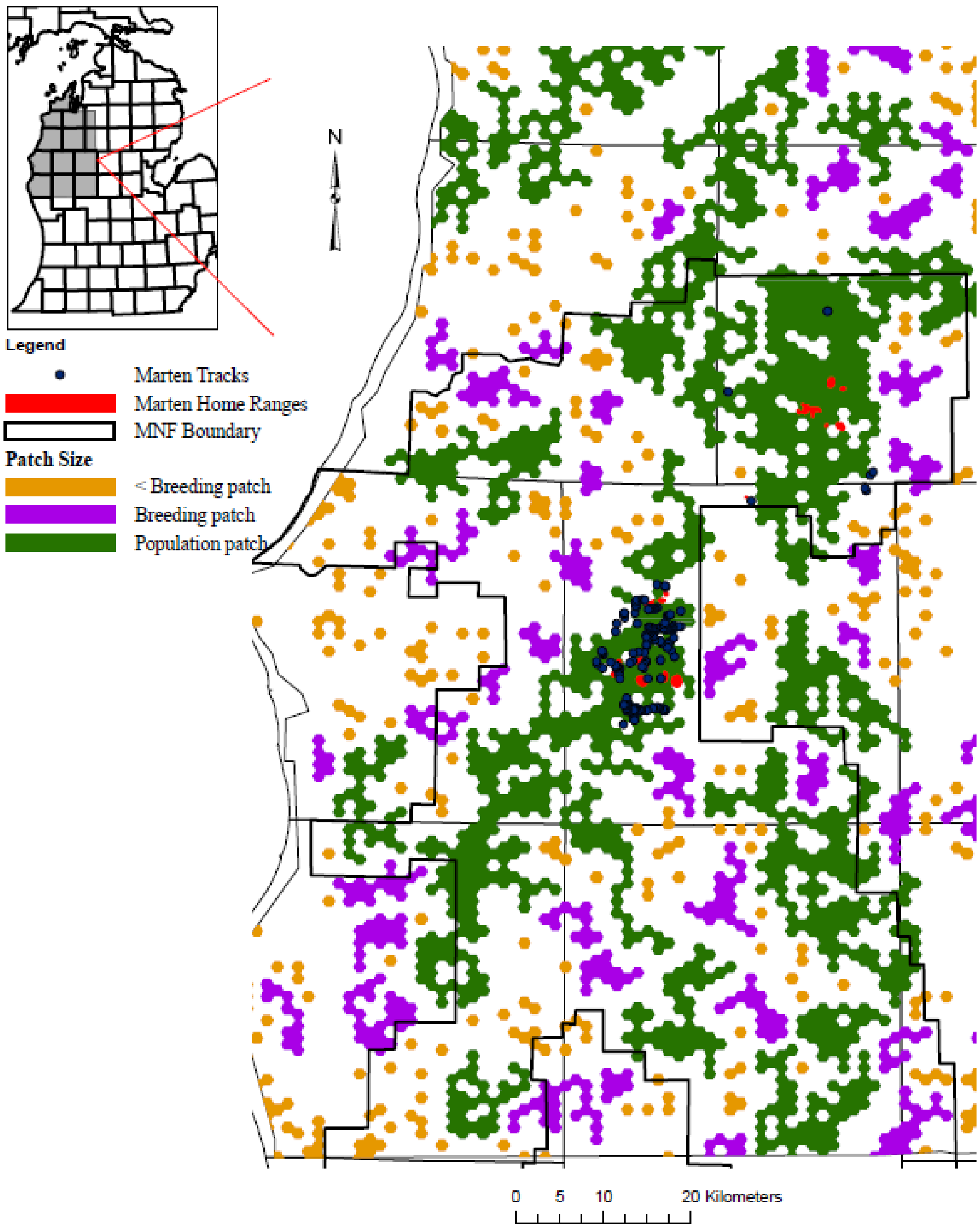

Figure 5. Map of Manistee National Forest comparing Penrose Distance habitat suitability patches with marten tracks and home ranges obtained from McFadden (2007). Map was created using the Corridor Designer tool (Majka 2007).

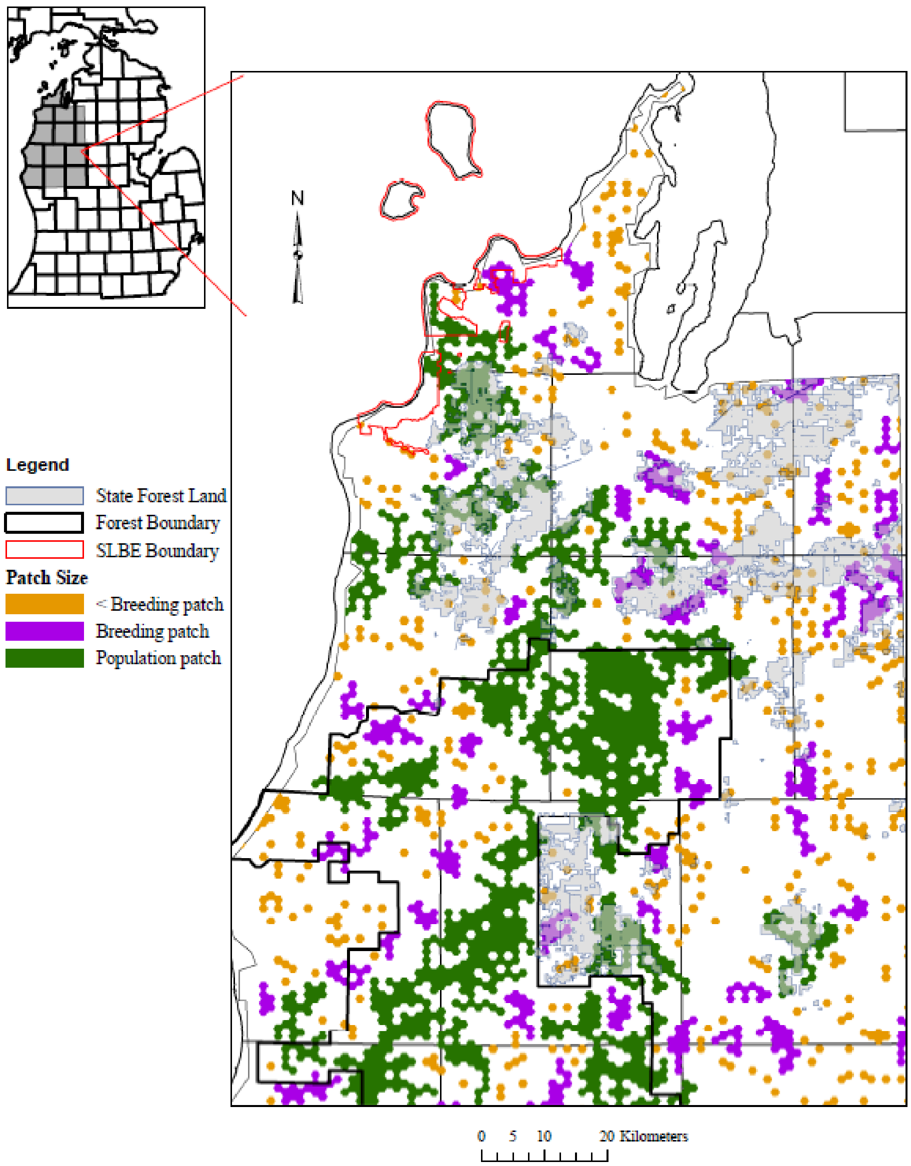

Figure 6. Map of suitable habitat patches for the American marten between Manistee National Forest (MNF) and Sleeping Bear Dunes National Lakeshore (SBD) with a layer of state forest land overlapping (transparent blue). Map was created using the Corridor Designer tool (Majka 2007).

Discussion

The current model made robust predictions about suitable marten habitat as confirmed by the CWD field estimates, MIFIA data, and the chi-squared test. Patch metrics of Penrose Classes revealed that there are fewer patches of the most suitable Penrose Class and that these patches are more isolated. Therefore, the validation error from the track surveys could be an artifact of the contiguity of the Penrose Classes across the landscape. Penrose Classes 2 and 3 were where the most tracks were found and they are more prevalent and closer together across the landscape.

Though it is difficult to know the exact threshold for habitat suitability, the Corridor Designer model used a conservative estimate by setting the value to incorporate the top three Penrose Classes and excluding the fourth class, which marten may occasionally use, indicated by the track surveys conducted by McFadden (2007). Not enough information related to carrying capacity and potential birth and death rates of the suitable habitats is currently available to determine which patches would be large enough to sustain a source population and which patches would be sink populations. However, relative patch sizes suggest that the two largest patches of suitable habitat located in the northern and central portions of MNF are large enough to be assumed as able to support source populations. The size of the patches of suitable habitat within SBD and the matrix connecting MNF to SBD indicates that they are likely suitable for sink populations. The distance between these patches ranges from approximately 8 to 13 km, which could encourage the dispersal of marten between them. A study by Howe et al. (1991) found that sink populations can be important to metapopulation sustainability by increasing the overall population size of the metapopulation and decreasing the extinction risk. Additionally, sink populations can increase the genetic diversity of metapopulations. This effect can be even greater if environmentally-caused population fluctuations are uncorrelated between the sink and source populations (Howe, Davis, and Mosca 1991). These benefits must be taken into account when considering the importance of establishing populations within suitable habitats that might support sink populations.

Marten dispersal distances may vary depending on many habitat factors. Johnson et al. (2009) found that females and males in regenerating forests dispersed an average of 6 km with a maximum of 209 km during their 4-year study. They also found that males in uncut forests dispersed an average of 18 km with a maximum distance of 214 km. Additionally, a study of 3 marten populations in Michigan's Upper Peninsula found distances of effective gene flow between 30 and 90 km (Williams and Scribner 2010). These results are consistent with the distances between suitable habitat patches observed in this study. The road-killed marten in Benzie county about 48 km away from the original reintroduction site in Manistee National Forest indicates that dispersal between these suitable habitat patches is already occurring.

CHAPTER III

CLIMATE CHANGE IMPLICATIONS

Introduction

Climate change is becoming increasingly relevant to ecosystem management because of potential impacts on species and ecosystem distribution, and survival based on their ability to adapt or disperse to a more suitable habitat. According to Peterson et al. (2010), many studies have documented an average advance of spring green up by 0.38 days/year and an average delay of fall brown down by 0.45 days/year, which increases the length of the growing season. Studies have also observed earlier spring migrations in North American birds with no change in return migrations. Additionally, studies of European birds indicate that bird populations which show no phenological change are declining (Peterson et al. 2010). This indicates that some species may have a limited response to climate change due to factors that limit their dispersal ability, such as low population growth rates or habitat fragmentation (Carroll et al. 2009).

Drought and extreme temperature that some climate models predict are also associated with the mortality of eastern tree species such as sugar maple (*Acer saccharum*), paper birch (*Betula paperifera*), white ash (*Fraxinus americana*), American beech (*Fagus grandifolia*), and quaking aspen (*Populus tremuloides*). Many of these species form large components of Michigan's forests and their loss could further fragment the habitat for marten populations. Commercially important tree species north of Michigan's tension zone have experienced times of regional forest decline, which has been attributed to climatic stress as a causal factor (Reed and Desanker, 1992). This tension zone is characterized by a change in soil types and a transition from southern to more boreal forest types (Myers et al. 2009).

In order to determine if it is worth the time and money to introduce a species back into an area, it is instructive to consider the habitat changes that are likely to occur in that area due to climate change. For example, climate change is predicted to cause species ranges to shift northward (Peterson et al. 2010). If a species were reintroduced into the southern-most part of its current range and experiences such range shifts, then the species would either move northward or become extirpated again. Therefore, the reintroduction attempt would be unsuccessful. Such adaptations are complex and a species response to changing environmental conditions can vary greatly depending on the latitude of their habitat (Guralnick 2006). Recent technological advances in spatial and predictive modeling are helping us predict how the climate will change and how species and ecosystems might respond to that change. It also allows us to consider options that take into account these predictions when thinking about species conservation. For example, Wasserman et al. (2012) used a landscape resistance model combined with climate change prediction models to determine the effect climate change might have on the Rocky Mountain marten populations. The researchers associated predicted increases in temperature with an increase in the minimum elevation that the marten could occupy. This model determined that the marten populations in the Rocky Mountains would become more isolated with predicted temperature increases due to the increase in landscape resistance to dispersal (Wasserman et al. 2012). Another example is the use of bioclimatic modeling by Carroll et al. (2009) to predict the suitability of the future climate in Britain for two butterfly species. Through this modeling technique, the authors were able to determine areas of Britain that could have the most suitable habitat for the two butterfly species in the future. These areas of suitable habitat comprised a small proportion of the total land area in Britain, which provides specific areas of focus for species reintroduction and conservation (Carroll et al. 2009). Martinez-Mayer et al. (2004) used niche modeling to predict the geographical distribution of 23 living mammal species and 8 extinct mammal species to determine if changes in climate have reduced niche availability. The authors collected climate data from the Pleistocene and the current climate to use in their prediction model. They found that species climatic niches are stable over time, which suggests niche modeling to be a good candidate for climate change research (Martinez-Mayer 2004).

I used a model created by the United States Forest Service to determine the predicted changes in forest stands in 100 years under multiple model scenarios. These predictions were applied to the habitat suitability model for marten in northern Michigan. The purpose of this study was to predict climate change effects on habitat and forest structure at Sleeping Bear Dunes and the surrounding area in order to determine the feasibility of reintroducing the American marten.

Methods

A habitat suitability modeled created by McFadden (2007) was used to assess the current habitat suitability and the potential of the study area to support a metapopulation (see chapter II). Once current habitat suitability was assessed, I obtained shapefiles of climate change models for 24 tree species from the U.S. Forest Service. The U.S. Forest Service modeled predicted changes in 134 tree species distributions in 100 years with multiple climate scenarios. They used 38 environmental variables to determine species distribution and predicted their Importance values (IV) by 2100 based on three general circulation models (GCM) under two emission scenarios, with current high levels of emissions (HI) and a significant reduction in emissions (LO). The HI scenario represented a tripling of pre-industrial CO_2 levels in the atmosphere and the LO emissions represented a doubling of CO_2. Prasad et al. (2007) associated the predictor variables with the IV of each tree species, evaluated the stability of the model, and then predicted current and future IV's based on the climate model scenarios (Prasad et al. 2007). Importance values were predicted for each tree species in a 20km by 20km grid cell. They presented IVs from each GCM and an average IV of the 3 GCMs (Prasad et al. 2007). I used the average values for predicted changes. The IFMAP layer and Forest Service species-stand associations were compared to find common categories from which I analyzed change (Table 3). Total IVs for tree species in each stand association were calculated for the current model, HI model, and LO model in each 20km by 20km cell. Relative percent change in habitat type was then calculated by subtracting the future IV from the current IV and dividing it by the current IV for each emissions scenario. I then averaged the percent change across the cells in the Northern Lower Peninsula.

Table 3. Forest stand classifications assigned based on 2001 IFMAP classifications and U.S. Forest Service classifications in their climate change model.

Forest Stand Classifications

Stand Classification	Tree Species
pines	jack pine, red pine, white pine
upland conifers	eastern hemlock, balsam fir, northern white cedar
upland mixed	eastern redcedar, eastern white pine, northern red oak, post oak, black oak, eastern hemlock, southern red oak
oak types	white oak, northern red oak, post oak, black oak, red maple, american elm, southern red oak
northern hardwood	red maple, american elm, sugar maple, yellow birch, black cherry, american basswood, american beech, white ash
aspen-birch	Bigtooth aspen, paper birch, pin cherry, quaking aspen

Results

In the LO scenario, the largest predicted forest stand loss was in aspen/birch at 60% with mixed upland conifers also predicting a large decrease of 57%. Northern hardwoods indicated the lowest predicted loss in this scenario at 1%. While these forest stands indicated a potential loss of habitat area, oak types and upland mixed forests predicted an increase in IV's of 14% and 26%, respectively, in this scenario. The HI scenario predicted the largest stand loss of aspen/birch at 69% and second largest loss of pines at 61%. The lowest predicted loss in this scenario was for northern hardwood, which indicated a loss of 21%. Oak types indicate a potential increase of 15% while upland mixed indicated a potential increase of 38% in the HI scenario (Figure 7).

The conifer species with the largest relative percent increase in IV was eastern red cedar (*Juniperus virginiana*) with a 286% increase under the LO scenario and a 450% increase in the HI scenario. The deciduous species with the highest relative percent increase of IV in the LO scenario were black oak (*Quercus velutina*), American elm (*Ulmus americana*), and white oak (*Quercus alba*) with a 130%, 117%, and 89% increase, respectively. The same tree species indicated a similar trend in predicted percent increase with a 168%, 160%, and 93% increase in the HI scenario, respectively (Figure 8).

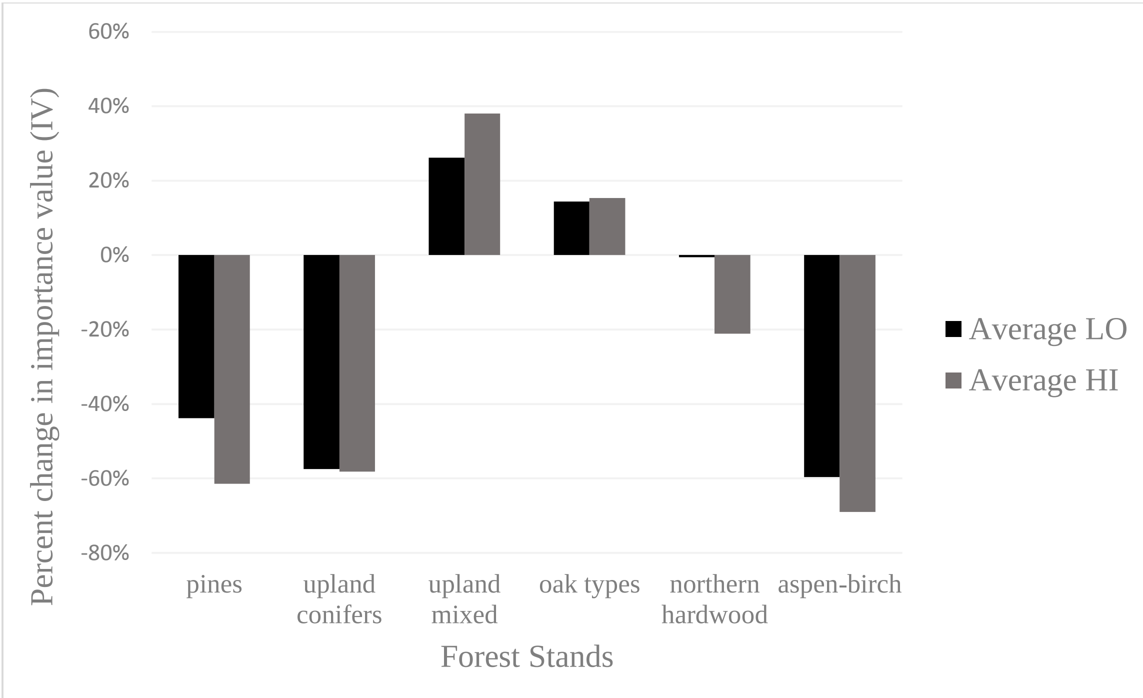

Figure 7. Average predicted percent change in importance value (IV) of forest stands relative to current IV based on the U.S. Forest Service's climate change model of the average of three General Circulation Models (GCMs) at two emissions scenarios. These scenarios are predicting a doubling of pre-industrial CO_2 concentrations (LO) and a tripling of pre-industrial CO_2 levels (HI) by 2100. Percent change is calculated per 20 km by 20 km grid cell and averaged over the grid cells across Michigan's Northern Lower Peninsula. Forest stands were classified according to the 2001 IFMAP classification and the U.S. Forest Service's stand classification.

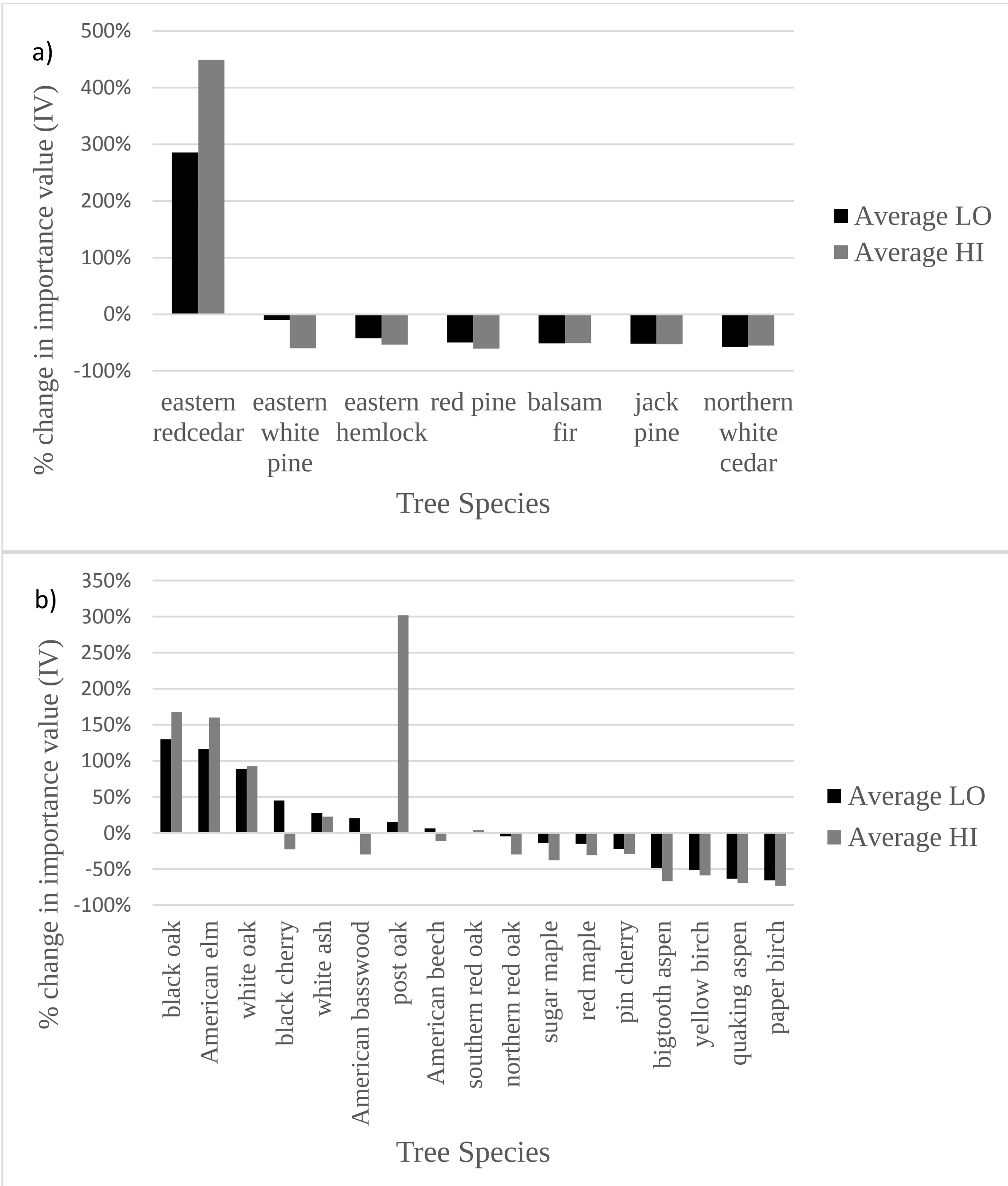

Figure 8. Average predicted percent change in importance value (IV) per tree species relative to current IV for a) 7 coniferous tree species and b) 17 deciduous species based on the Forest Service Climate Change model of the average of three General Circulation

Models (GCMs) at two emissions scenarios. These scenarios are predicting a doubling of pre-industrial CO_2 concentrations (LO) and a tripling of pre-industrial CO_2 levels (HI) by 2100. Percent change is calculated per 20 km by 20 km grid cell and averaged over the grid cells across Michigan's Northern Lower Peninsula.

Conifer species that have the largest predicted decrease in IV under the LO scenario were northern white cedar (*Thuja occidentalis*), jack pine (*Pinus banksiana*), balsam fir (*Abies balsamea*), red pine (*Pinus resinosa*), and eastern hemlock (*Tsuga canadensis*) with a decrease of around 50% for each species. Under the HI emissions scenarios, the same tree species indicated a slightly larger decrease in IV with the addition of eastern white pine declining in IV by 60%. Deciduous species that indicated the largest predicted decrease in IV were paper birch (*Betula papyrifera*), quaking aspen (*Populus tremuloides*), yellow birch (*Betula alleghaniensis*), and bigtooth aspen (*Populus grandidentata*) with a decrease of 65%, 63%, 51%, and 49%, respectively under the LO emissions scenario. The same tree species showed a larger decrease in IV under the HI emissions scenario with a decrease of 73%, 69%, 58%, and 67%, respectively (Figure 8).

Discussion

Based on the Forest Service climate change model, habitat suitability for many species of trees, including coniferous and deciduous, will decline by 2100 at both the low and high emissions scenarios. Some species have a predicted increase in habitat suitability, which contributes to the observed increase in mixed forests. Tree species that show such an increase are oak-type species such as post oak, black oak, white oak, and American elm, as well as eastern redcedar. These species are all predicted to increase in both scenarios, but the post oak is expected to increase more in the HI scenario than in the LO scenario. All conifers, except eastern redcedar, are predicted to decrease in IV along with aspen and birch species in both scenarios.

This model only predicts habitat suitability and not necessarily dispersal of a species and post oak would need to disperse from Southern Indiana in order to occupy the study area. In addition, the prevalence of American elm would depend on the dispersal ability of the individuals remaining from the Dutch elm disease outbreaks in the 1900s. Schlarbaum et al. (1998) estimated that 1 in 100000 American elms could be resistant to the disease. These resistant trees are being studied and cloned in order to produce trees resistant to the disease (Townsend 2005). If these studies are successful, then management objectives could focus on introducing these resistant strains throughout Michigan in order to promote the dispersal of American elm into these predicted increasingly suitable habitats. The Forest Service model also does not take into account disease outbreaks and recoveries, which will be a factor, as it is predicted that climate change will increase disease prevalence. Ash trees are another concern related to disease outbreaks with the infestation of the emerald ash borer in Michigan (Iverson et al. 2007). White ash (*Fraxinus americana*) is predicted to have a relatively small increase in IV in both scenarios, thus a larger loss of white ash than predicted would not heavily influence the predicted changes.

American marten in the Eastern United States have shown a large amount of plasticity in habitat use. Soutiere (1979) found that marten utilized more hardwood forests in stands that were being harvested and tended to utilize softwood forests in stands that were not harvested. This plasticity will likely contribute to the marten's ability to adapt to slight changes in forest composition. Predicted changes in conifer species appear to be drastic, but changes in deciduous species will be more subtle because similar species will have the ability to occupy new habitats and replace species that would be affected most by climate change. Additionally, changes will likely occur over an extended time period, which will make adaptability more feasible.

Management Implications

Based on the predictions derived from the U.S. Forest Service's climate change model, habitat in Michigan's Northern Lower Peninsula should remain suitable for the American marten. Adaptation by the marten is feasible given its plasticity and the predicted increase in mixed forests, which would still provide a small amount of conifer species in their habitat. It is recommended that Sleeping Bear Dunes National Lakeshore introduce American marten in coordination with the MDNR and local Native American Tribes. Given the patchiness of suitable habitat within SBD, I recommend that marten are introduced into Pere Marquette State Forest, adjacent to SBD's boundaries and allow for the marten to naturally disperse into SBD. Additionally, the introduction would add genetic differentiation to the population in Manistee National Forest. If such reintroductions occur, then it will be important for other organizations to implement additional reintroductions within MNF or adjacent suitable habitats. The sink population features of the area between MNF and SBD could be beneficial for genetic supplementation of MNF populations, increase the metapopulation size, and decrease the extinction risk of the metapopulation.

By answering *a priori* research questions related to metapopulation viability, and current and future habitat suitability, we can increase the chances that a second round of marten reintroductions in Michigan's Northern Lower Peninsula will be successful. In order to determine the fate of these reintroduction attempts, it is imperative to monitor post release success through radio tracking and additional trapping and radio collaring of future marten kits. By monitoring dispersal, reproduction, and genetic variability, managers will be able to determine if enough marten were introduced or if an additional reintroduction would be necessary.

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