

**Changing snow conditions and shifts in American marten (*Martes americana*)
Occurrence in Michigan's Upper Peninsula**

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Table of Contents

Acknowledgements	ii
List of Tables	iv
List of Figures	v
List of Appendices	vi
Abstract	vii
Chapter 1 – Introduction.....	1
Chapter 2 – Methods	4
2.1 Study Area.....	4
2.2 Marten Occurrence.....	5
2.3 Environmental Covariates.....	6
2.4 Species Distribution Models.....	7
2.5 Stability Score Creation.....	8
Chapter 3 – Results	9
3.1 Model Performance.....	9
3.2 Model Trends.....	9
3.3 Model Projections.....	12
3.4 Stability Scores.....	13
Chapter 4 – Discussion	14
4.1 Temporal Changes to Marten Occurrence Probability	14
4.2 Winter Abiotic Conditions and Marten Occupancy.....	16
4.3 Land Cover and Marten Occupancy.....	17
4.4 Management Implications.....	18
Appendices	19
References	24

List of Tables

Table 1: Ensemble distribution model accuracy.....	9
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List of Figures

Figure 1: Study area and landmarks.....	5
Figure 2: Environmental covariate ensemble model effect-size.....	10
Figure 3: Ensemble model response curves.....	11
Figure 4: Ensemble model occupancy projections.....	12
Figure 5: Stability score maps.....	13
Figure 6: Occurrence area comparison.....	15

List of Appendices

Appendix A: Environmental Covariate Metadata.....	19
Appendix B: Correlation matrix.....	21
Appendix C: Marten presence and pseudoabsence data.....	22

Abstract

Climate change is forcing many species to shift their ranges northward and to higher altitudes. Information on the extent of these shifts and the mechanisms driving them are urgently needed to inform conservation planning. Here, we explore the impact of changing climatic conditions on American marten (*Martes americana*) occupancy in Michigan's Upper Peninsula, part of the greater Northwoods, where they are of high economic, cultural, and ecological importance. Using marten harvest data reported to the Michigan Department of Natural Resources between 2005 and 2020 we employ ensemble species distribution models aggregated into 5-year periods to investigate if the occurrence and projected distribution of American marten has shifted over time in Michigan's Upper Peninsula in response to changing climatic conditions. Our results show a gradual decrease over time in marten occupancy in the southern Upper Peninsula facilitated by a decrease in suitable abiotic conditions over the last two decades. Average winter temperature was the most important variable across models, with average winter snow depth increasing in occupancy effect-size over the study period. Areas containing suitable snow depth and winter temperature conditions in the Upper Peninsula have decreased by nearly 10% over the study period coupled with an overall decrease in overall occupancy probability across the region. These observed changes in marten occupancy and abiotic conditions will likely impact ecosystem processes and services in the Northwoods moving forward. Future research will focus on identifying regions in the Upper Peninsula that will continue to have suitable climatic conditions for martens under varying climate projections.

Introduction

Climate change is forcing many species to shift their ranges northward and to higher altitudes. Extinction risk for such species continues to intensify as their future habitable climate space often has the possibility to become too small or isolated from current geographical ranges (Wilson et al., 2005). Chen et al., 2011 suggests that range shifts of individual species is dictated by individualistic physiological constraints and responses to climatic factors such as differing sensitivity to maximum and minimum temperatures. Despite this individual variation in response, species have moved away from the equator at a median rate of 16.9 km per decade (Chen et al., 2011). Changes to species distributions and trophic networks brought about by changing climate are likely to severely impair ecosystem functioning, further accelerating global biodiversity loss and eliminating crucial ecological services that humans rely on (Bellard et al., 2012). Understanding how climate change is influencing biodiversity and human livelihoods is critical to recognizing future ecological risks and can support the adoption and development of proactive biodiversity conservation strategies (Pereira et al., 2010).

Michigan's Upper Peninsula is part of the greater Northwoods, a management area expected to face significant changes in the next century due to climate change (Danielle & Clark, 2014). This area is expected to experience an increase in winter temperatures and decreases in overall snowfall, the frequency of snowfall days, and snow depth. In addition, studies project a 31% - 47% decline in snowfall by the end of the century in Northern Wisconsin (Danielle & Clark, 2014). An increase in overall winter precipitation, coupled with a 4.5 to 6.9 °C expected increase in winter temperature by the end of the century, indicate more rain-on-snow events and associated snowmelt, leading to further reduced snow depth and cover across the Northwoods (Notaro et al., 2010). The greatest snowfall reductions are projected at the flanks of the snowfall season (November, March) representing an overall shortening of the season, with 22-34 less days of snow cover expected by the end of the century (Notaro et al., 2010). Thus, changing winter climatic conditions are likely to drive changes in species distribution, biotic interactions, and trophic structures within the Northwoods Management Area.

Climate change is expected to affect many aspects of landscape ecology in the Northwoods. Boreal ecosystems, a dominant habitat type for American marten (*Martes americana*) are among the most vulnerable to land use and climate induced change (Danielle & Clark, 2014). In addition, marten and other mesocarnivores within boreal ecosystems can be greatly affected by rapid shifts in climate (Marcot et al., 2015). It has been observed that snow conditions play a significant role in determining species specific mesocarnivore occupancy in Northern boreal regions with changing snow conditions potentially affecting intraguild interactions (Pozzanghera et al., 2016). Specifically, Snow characteristics such as compaction and depth have been found to strongly affect the energetics of predation risk and locomotion of mesocarnivores (Crête & Larivière, 2011; Pozzanghera et al., 2016). Additionally, snow cover and snowpack have been observed to influence Pacific marten (*Martes caurina*) occupancy in California, with researchers concluding that martens select for habitat features differently during snow-covered periods. (Martin et al., 2021). Resource use and habitat selection of martens has been researched in length (Drew, 1995; Godbout & Ouellet, 2010; Raine, 1983; Roloff et al., 2020; Thompson et al., 2017; Wiebe et al., 2014). However, our understanding of the response of marten to rapid changes in abiotic winter conditions within southern boreal regions is not fully understood (Lawler et al., 2012; Suffice et al., 2020). Understanding this relationship and the abiotic factors driving changes in distribution will guide future conservation strategies and allow for assessment of marten habitat suitability in the face of changing regional climate.

Martens play a key role in forest social-ecological systems in North America. Their conservation is critical to many, including tribal organizations, fur trappers, and recreationalists (Danielle & Clark, 2014; Suffice et al., 2017). In addition, marten pelts are among the most valuable of furbearers with over 6,000 harvest tags distributed to trappers across Michigan in 2018 (Frawley, 2020). Marten are indicators of a healthy boreal forest ecosystem and conservation of marten habitat can benefit overall biodiversity (Wasserman et al., 2012). Increased understanding into marten ecology will allow for better future management in the face of climate change (Danielle & Clark, 2014; Pauli et al., 2022). Martens were extirpated from Michigan's Upper Peninsula by 1936 due to overharvest and habitat change. They were then reintroduced to several areas

across the Upper Peninsula from 1959 to 1992 (Williams et al., 2007). Martens were listed as a state threatened species from 1978 through 1999 where legal harvest was resumed in Michigan. Although marten in Michigan are not currently listed as a threatened species, they are heavily monitored by the Michigan DNR and Michigan tribal organizations, and it is expected that climate change will shrink and degrade marten habitats in the state (Lawler et al., 2012).

In this study, we seek to investigate how the occurrence of American marten has shifted over time in Michigan's Upper Peninsula in response to changing climatic conditions. To address this goal, we ask the following questions: What are the effects of average winter snow depth, maximum temperature, normalized difference snow index and precipitation on American marten occupancy change over time? What climatic variables are most influential to American Marten occupancy over time? Is American Marten distribution changing temporally in response to rapid changes in climatic conditions? We will test the following hypothesis: Marten populations in Michigan's Upper Peninsula are experiencing a northward shift in occupancy compared to their historical range in the region due to rapidly shifting winter abiotic conditions. Multiple climate-change scenarios consistently project northward range shifts for marten in the US over the next century and Northern Michigan sits at the southern boundary of marten's Midwest distribution (Lawler et al., 2012). Understanding the drivers of marten occupancy at this range border will advance habitat monitoring techniques and provide wildlife managers with critical information for conservation of marten populations in Michigan's Upper Peninsula under changing climate conditions.

Methods

2.1 Study Area

The study area consists of an approximately 42,420 km² area containing Michigan's mainland Upper Peninsula, USA (Figure 1). Land cover in this area is primarily composed of deciduous forest, woody wetlands, mixed forests, conifer forests, open water, grasslands, and developed land. Dominant forest types include upland spruce-fir, pine, lowland conifers, northern hardwoods, and aspen-birch (Danielle & Clark, 2014). The study area is bordered by Northern Wisconsin and the Lower Peninsula of Michigan via the Mackinac Bridge. Elevation across the study area ranges from 176 to 603 meters with 2,700 km of continuous shoreline along The Great Lakes (Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data, 1977). Average temperatures range from -10 °C in the winter to 20 °C in the summer. This is greatly affected by proximity to the Laurentian Great Lakes, with land temperatures averaging 5 °C to 8 °C cooler near the shoreline. Snowfall in the area ranges from 198 cm to 635 cm per year due to the influence of lake effect snow in areas such as the Keweenaw Peninsula (NOAA, 2021).

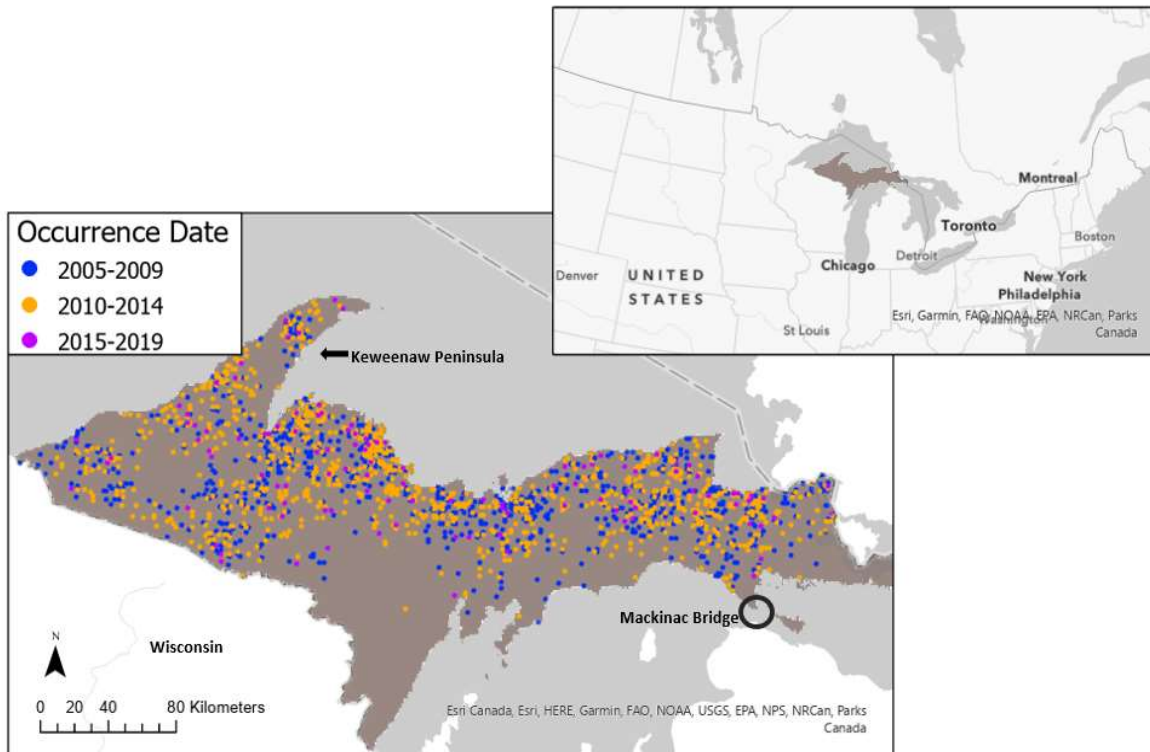


Figure 1. The study area which encompasses the entirety of Michigan's Upper Peninsula, United States. Each colored dot represents a marten harvest between 2005 and 2019 with 5-year time periods partitioning the occurrence data into 3 groups for analysis.

2.2 Marten Occurrence

Harvest data was obtained by Michigan Department of Natural Resources via harvest records verified by state biologists and compiled into a spatially referenced database. Trappers in Michigan are limited to one marten tag per season and required to report locations of trapping and subsequent harvest within 1-kilometer accuracy. Marten harvest data reported to Michigan's Department of Natural Resources spans from 2005 to 2019 and the yearly harvest season occurs in mid-December. We partitioned these data into three distinct time periods: 2005-2009, 2010-2014, 2015-2019; to investigate whether marten occurrence changed over time. Each period contains 901, 1130, and 344 occurrence records, respectively (Figure 1). Marten occurrence data spanning from 2005 to 2019 was limited, with many tribal occurrence records only available for a handful of years and sparse citizen science data available. Due to these limitations, occurrence data

integration was not utilized in this study. Our use of harvest data assumes that this is an accurate proxy for marten occurrence. Though harvest records typically are not used to inform species distributions at fine scales, they can be used to investigate species-environment relationships at broad scales such as counties or entire states (Gilbert et al., 2021).

2.3 Environmental Covariates

We selected a suite of biotic and abiotic landscape covariates hypothesized to influence marten occupancy (Appendix A). All environmental covariates were tested for correlation using the Pearson correlation coefficient (Appendix B). Biotic covariates were derived from the National Land Cover Database compiled by the United States Geological Survey. The 2006 NLCD dataset was used for 2005-2009 models, while the 2011 and 2016 datasets were used for 2010-2014 and 2015-2019 models, respectively (Dewitz, 2019; U.S. Geological Survey, 2011, 2014). To match the 1-kilometer resolution abiotic covariates, we partitioned each land cover class of interest and calculated proportion of each type across a 1km fishnet grid in ArcGIS Pro. This provided us with proportional land cover estimates for six distinct land cover classes: deciduous forest, mixed forest, evergreen forest, woody wetlands, herbaceous wetlands, and developed (high-low intensity).

Abiotic covariates include climatic rasters derived from several remotely sensed and modeled 1-kilometer resolution sources. Snow depth was derived from the Snow Data Assimilation System created by the National Snow & Ice Data Center. This dataset provides daily estimates of snow depth across the continental United States in millimeters (National Operational Hydrologic Remote Sensing Center, 2004). Daily estimates were averaged from November through February of each year providing a metric of average winter snow depth across the study area for each year and then averaged across a consecutive 5-year period. Normalized Snow Difference Index (NSDI) was derived from the remotely sensed MODIS/Terra Snow Cover Daily dataset (Hall & Riggs, 2016). Daily estimates were averaged from November through February of each year and then averaged across a consecutive 5-year period providing a metric of average winter

normalized snow difference index for each 5-year period. Winter precipitation and winter maximum temperature were derived from Daymet, a monthly surface weather and climatological summary dataset created by Oak Ridge National Laboratory Distributed Active Archive Center (Oak Ridge National Laboratory Distributed Active Archive Center, n.d.). Monthly temperature and precipitation averages were averaged from November through February of each year to provide average winter total precipitation and average maximum winter temperature for each consecutive 5-year period. Average winter precipitation includes both rainfall and snowfall during winter months.

2.4 Species Distribution Models

We used an ensemble modeling approach to model marten occurrence. This method requires fitting of individual species distribution models according to a collection of modeling algorithms. These fitted models are then combined to enhance the predictive power and often the accuracy of species distribution models (Thuiller et al., 2009). Species distribution models often benefit from pseudo-absence selection, a process of inputting artificial species absences to supplement presence-only point data. Per Barbet-Massin et al., 2012 we used the contrasting environment method for selecting pseudo-absences which utilizes the surface range envelope model (SRE) to select pseudoabsences with contrasting covariate condition to true presences. We then set the number of pseudoabsences equal to the number of presences in each model. We fit 5 models including: Generalized Additive Model (GAM), Generalized Boosted Model (GBM), Artificial Neural Network (ANN), Multiple Adaptive Regression Splines (MARS) and Random Forest (RF). To use these models, we needed to generate measures of accuracy from model training using the true skill statistic (TSS) and receiver operating characteristic (ROC). The GBM and RF were the only models with the area under the ROC curve (AUC) equal to or greater than 0.9 and TSS equal to or greater than 0.7 consistently, indicating better model fit and model projection accuracy. Generally, AUC greater than or equal to 0.9 indicates excellent model fit and TSS greater than 0.7 indicates a very low probability of false presences and absences (Allouche et al., 2006; Mandrekar, 2010). These two models were then combined using ensemble modeling

framework to create a single ensemble model for each 5-year time period. The 2005-2009 model accuracy was again assessed on the ensemble models using ROC and TSS. The final ensemble models were then evaluated for variable importance, variation, and model response before creating a projection of marten occupancy probability across the study area for each time period. Projections were created by applying a probability density function to model outputs. We used the R package BIOMOD2 to carry out the modeling and projection process (Thuiller et al., 2009).

2.5 Stability Score Creation

Following the creation of the ensemble species distribution models, variable response curves were analysed in order to understand how levels of each covariate influence marten occupancy. Each abiotic covariate was investigated and assigned a range of suitable conditions. Suitable range of conditions for each abiotic covariate were constrained by occurrence probability, with conditions greater than or equal to 80% probability of occurrence defined as suitable. Stability score was then determined using these defined suitable ranges and combining them across models. Each 1-kilometer grid cell was assigned a 0 or a 1 depending on if the particular environmental covariate contained suitable conditions for marten occurrence in each model. Each cell assignment was then combined with the other models, giving us a value from 0 to 3. These values provide a measure of spatial stability for each abiotic covariate across time-periods, with a score of 3 being the most stable and a score of 0 being the least.

Results

3.1 Model Performance

Table 1. The 2005-2009 model accuracy results for ensemble models. AUC: area under the receiver operating characteristic curve, TSS: true skill statistic, sensitivity: true positive rate, specificity: true negative rate.

Model	AUC	TSS	Sensitivity	Specificity
2005-2009	0.945	0.758	83.15	89.58
2010-2014	0.942	0.733	75.70	82.42
2015-2019	0.969	0.815	83.95	94.02

3.2 Model trends

Land cover covariates had low effect-size on marten occupancy at the 1-kilometer scale, with proportion of mixed forest providing the highest effect-size for land cover covariates across all three time periods with a maximum of 0.13 (Figure 2). Average maximum winter temperature had the highest effect-size on marten occupancy in the 2005-2009 model, average winter precipitation had the highest effect size in the 2010-2014 model, and average winter snow depth had the highest effect-size in the 2015-2019 model. Across model runs, the effect-size on occurrence probability of average winter max temperature, snow cover, and precipitation decreased, while the effect-size of average winter snow depth increased (Figure 2).

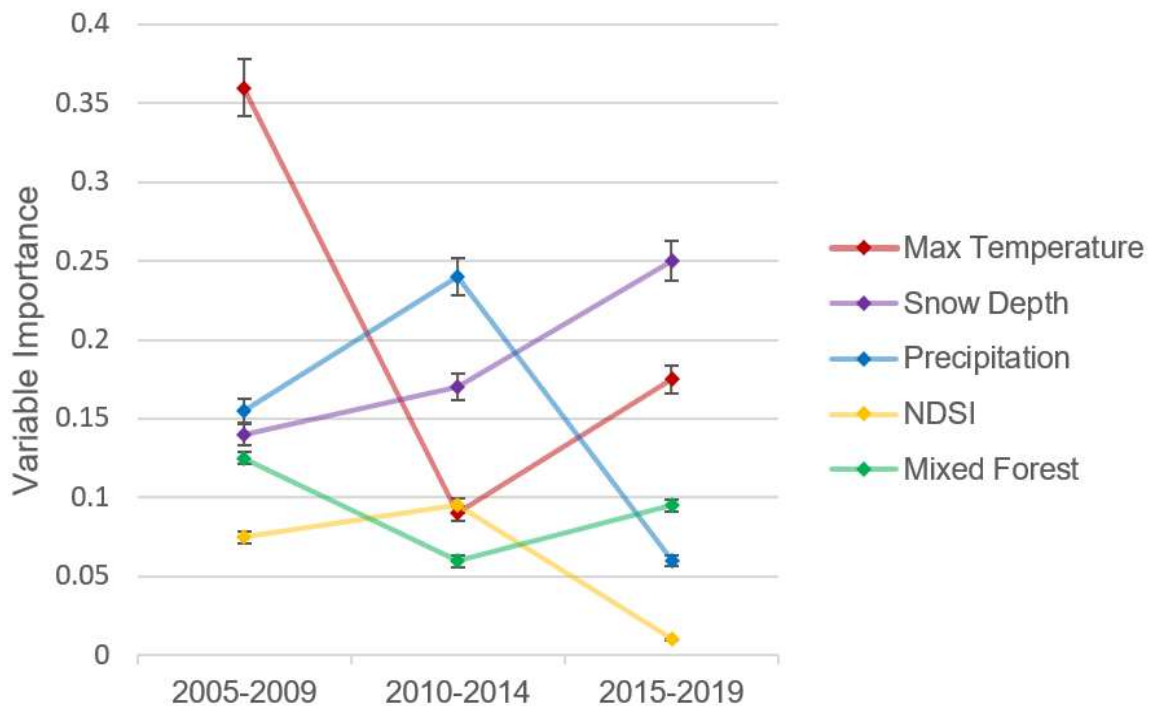


Figure 2. Variable importance of environmental covariates across model runs (Top 5) based on variable randomization permutations conducted using the R package BIOMOD2 (Thuiller et al., 2009). This score gives an estimation of the effect-size of a variable on marten occupancy probability in each model with error bars signifying standard error of each covariate within the set of all spatial grid cells. Max temperature indicates the mean winter maximum temperature. Snow depth indicates the mean winter snow depth. Precipitation indicates the mean winter total precipitation (snow & rain). NDSI indicates the mean winter snow cover index. Mixed forest indicates the proportion of each 1-kilometer grid cell containing the “mixed forest” NLCD land cover type (Dewitz, 2019; U.S. Geological Survey, 2011, 2014). Each metric was aggregated across 5 consecutive years of winters for each model output.

Response curves of marten distribution models indicate the response of marten occupancy to varying levels of each environmental covariate. In each model we recorded an increase in probability of occupancy at 200mm average winter snow depth, 40mm-80mm average winter precipitation, and -0.4 to 0.4 average winter snow cover index values (NDSI) (Figure 3). Additionally, we recorded a shift in occupancy response to average maximum winter temperature across time periods; high (≥ 0.8) probability of occurrence ranged from -3 to -1 °C in the 2005-2009 model, and -3 to 0 °C in the 2015-2019 model. Occupancy probability variation in response to land cover levels decreased across time periods, with the highest response to land cover variables recorded in the 2005-2009 model.

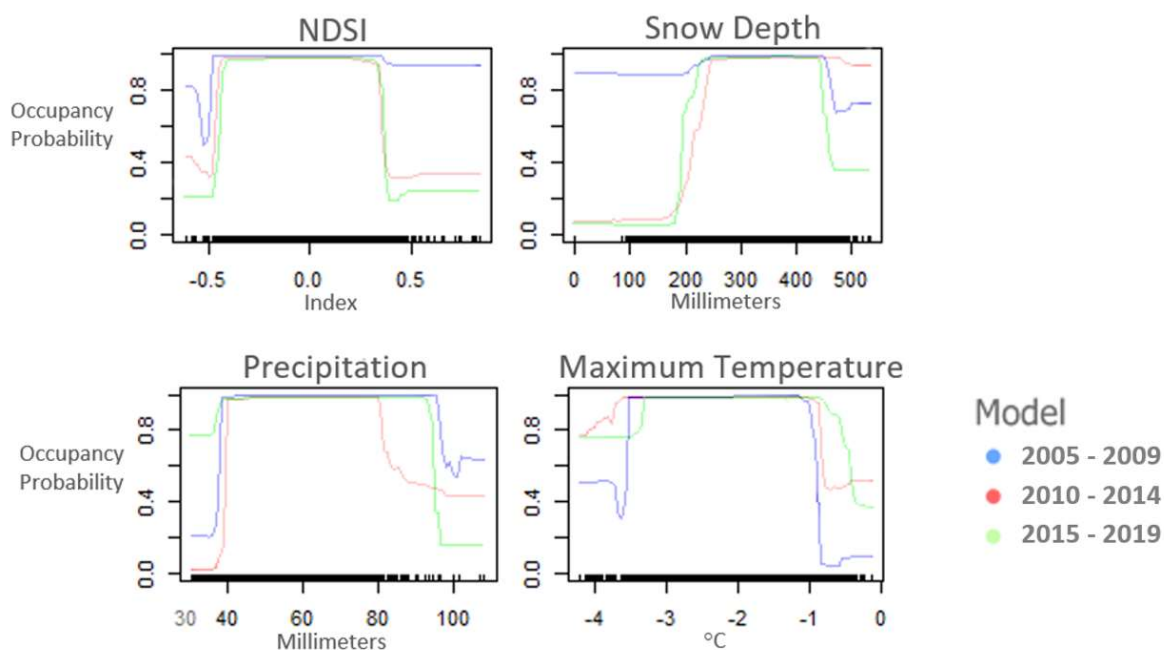


Figure 3. Response curves of American Marten occupancy probability for variation in abiotic and biotic environmental covariates. Black bars below plots illustrate data range and data density at each metric level. Max temperature indicates the mean winter maximum temperature. Snow depth indicates the mean winter snow depth. Precipitation indicates the mean winter total precipitation (snow & rain). NDSI indicates the mean winter snow cover index. Each metric was aggregated across 5 consecutive years of winters for each model output.

3.3 Model Projections

The 2005-2009 model had the largest projected distribution, whereas the 2015-2019 model had the smallest projected distribution (Figure 4). This indicates that the spatial occurrence of marten has shrunk over time. This contraction is most evident along the southern border of the study area. The section of the study area east of the Mackinac Bridge has experienced a decrease in occupancy of probability across time periods (Figure 1). The Keweenaw Peninsula has experienced a slight decrease in occupancy of probability across time periods, specifically the 2010-2014 model and the 2015-2019 model. Additionally, mean occurrence probability decreased over time across the study area.

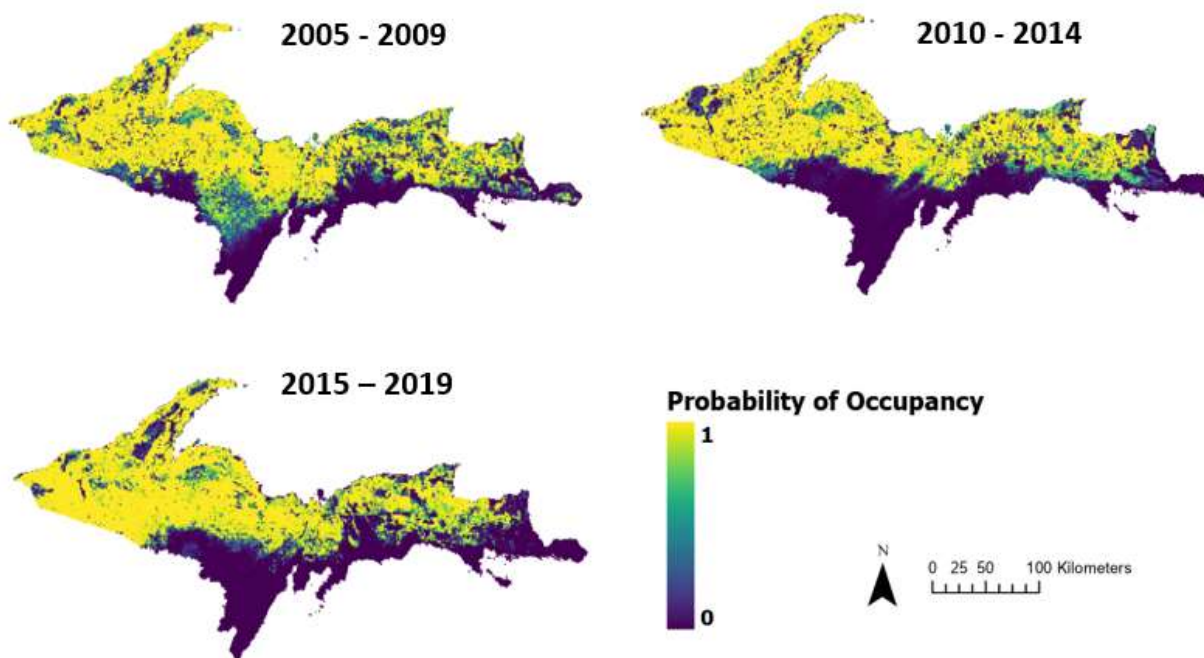


Figure 4. Probability of American Marten occupancy projections across the study area for each model: 2005-2009, 2010-2014, 2015-2019. Yellow indicates high probability, while dark blue indicates low probability. The ensemble models had mean occurrence probabilities of 60%, 55%, and 52% respectively across the entire study area.

3.4 Stability Scores

The southern border of the study area had highly unstable abiotic conditions for marten across time-periods (Figure 5). Snow depth values along this southern border was unsuitable for martens across model runs, with unsuitable conditions encroaching upon the south-central area of the Upper Peninsula increasingly from 2010 to 2019.

Additionally, snow depth values along the southeastern border of the study area were unstable across model runs, with a small pocket of instability in the Keweenaw peninsula (Figure 1). We see similar instability in average maximum winter temperatures along this southern border, with some instability also present along the southeastern border.

Average monthly winter precipitation primarily was unstable in the southwest of the study area, with small pockets of unstable areas along the northern border as well. NDSI stability was highly variable, with pockets of stable and sub-stable areas littered across the study area.

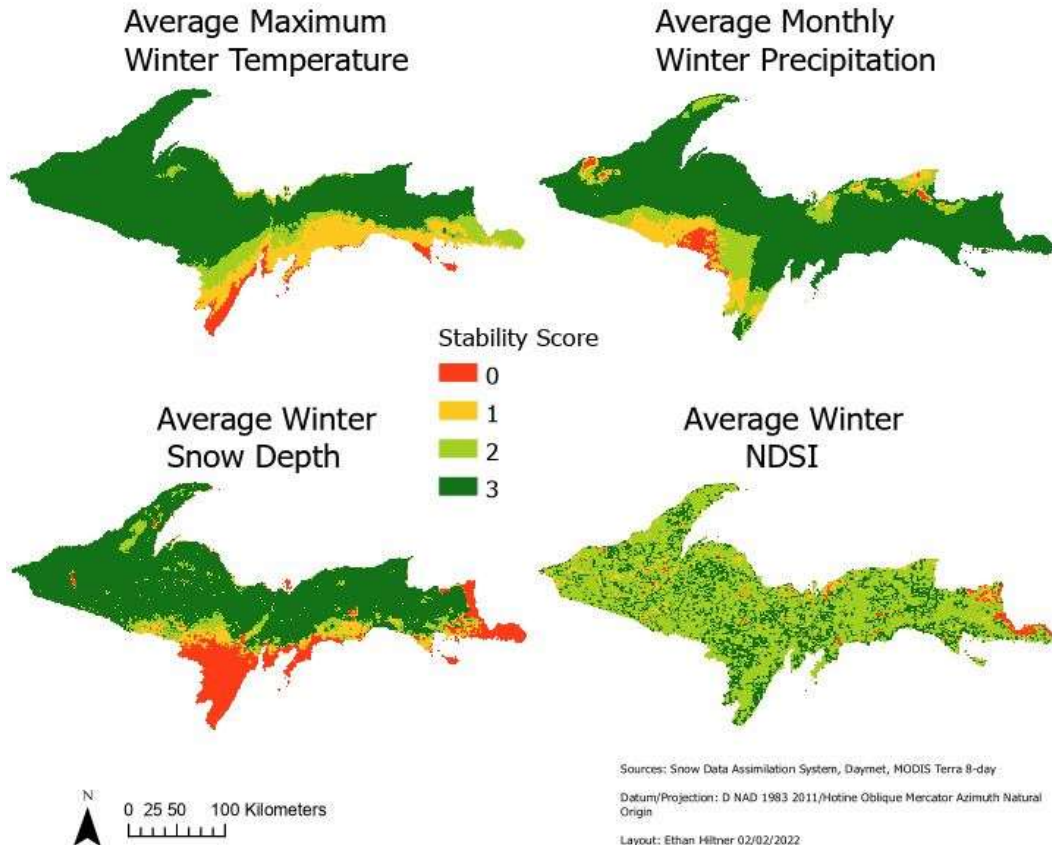


Figure 5. Stability score of abiotic environmental covariates across ensemble model runs. Stability score was determined using the suitable range of each abiotic environmental covariate for high probability of marten occupancy for each model. Each 1-kilometer grid cell is assigned a 0 or a 1 depending on if the environmental covariate contains suitable conditions for marten occupancy in each model. These values are then combined to provide a measure of spatial stability across time.

Discussion

4.1 Changes to Marten Occurrence Probability

Our results indicate marten populations in the Upper Peninsula are experiencing a shift in occurrence persistence in response to winter abiotic conditions. This pattern corresponds to findings in Lawler et al., 2012, which concludes that populations of marten occurring at more southerly latitudes will likely experience distributional and numerical declines and increased isolation over the next century. Marten occupancy in the southern Lower Peninsula shifted through time, with winter temperature and snow depth driving those changes from 2005 to 2019 (Figure 5). We additionally observed a decrease in the mean occurrence probability across the study area over time, indicating that occupancy in the Upper Peninsula may be more limited in the future (Figure 4). This temporal change is further explained by a reduction in high and low occurrence probability areas and an increase in very low occurrence probability areas across model runs (Figure 6). This shift is likely associated with the increasingly unstable and unsuitable abiotic conditions present along the southern border of the study area (Figure 5).

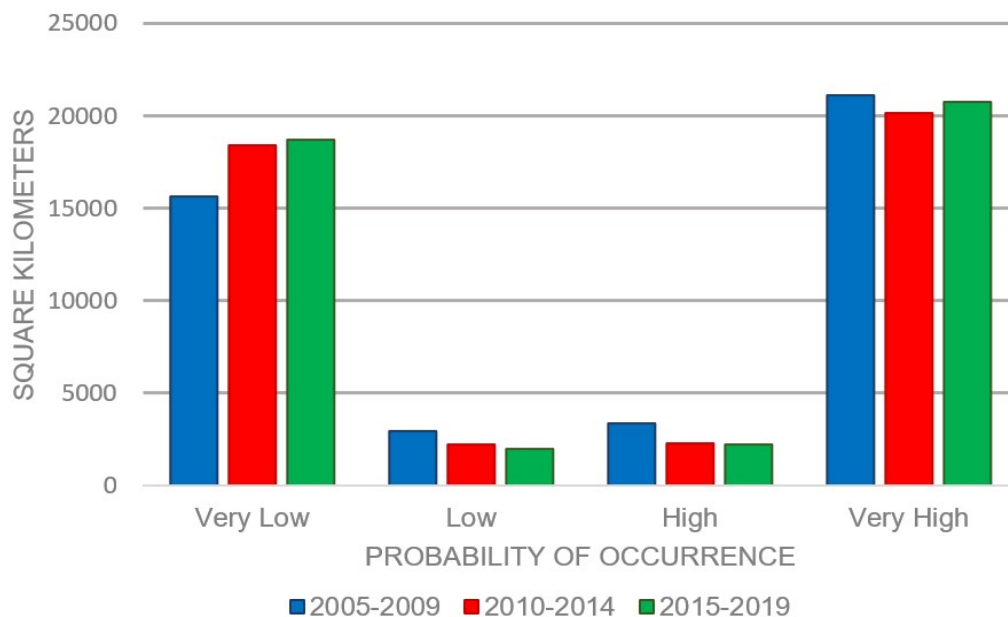


Figure 6. Area of unique levels of marten probability of occurrence determined by BIOMOD2 marten distribution projections. Each bar represents the total square kilometers each occurrence level contains across ensemble models. Very Low = 0-25%, Low = 26-50%, High = 51-75%, Very High = 76-100%.

Occurrence probability is being increasingly limited by these unsuitable abiotic conditions in the south and central Upper Peninsula, with the presence of Lake Superior along the northern border of the study area restricting any increase in occurrence probability northward over time (Figure 1). Abiotic conditions will likely increasingly impact marten occupancy in the Upper Peninsula as climate change intensifies. This contraction in climatically suitable range has the potential to impact marten population persistence in the Upper Peninsula in the future, as conditions will be increasingly favorable in regions further north such as Minnesota and Southern Ontario (Lawler et al., 2012). The extent to which marten will be able successfully shift their distribution northward in response to these changes in the future is dependent on many factors. Individual species vary greatly in their rates of distribution change, which could be attributed to multiple internal species traits and external abiotic and biotic drivers (Chen

et al., 2011). Both physical landscape features and the co-occurrence of species likely facilitate marten distribution, with functional connectivity limiting their ability to expand their range (Leibold et al., 2004; Pauli et al., 2022). However, it has been found that martens are slow to expand their range, as is the case with many species occupying heterogeneous landscapes where range shifts can be heavily dependent on habitat configuration (Årevall et al., 2018; Williams et al., 2007). The ability for marten to shift their range in the Upper Peninsula will likely depend on landscape scale habitat connectivity, species interactions, and the speed at which climate conditions change.

4.2 Winter Abiotic Conditions and Marten Occupancy

Our results indicate an increase in the effect of average winter snow depth on marten occupancy at the landscape-scale across the study area from 2005 to 2019, with greater snow depth having a positive effect on occupancy. This is likely due to the decrease in suitable snow depth levels across their southern UP distribution over time (Figure 5). Wiebe et al., 2014 concluded that martens prefer areas with intermediate snow depth between the deepest and shallowest in Ontario which may explain why martens often avoided areas of high (500mm+) snow depth present on the Keweenaw Peninsula (Figure 1) and were increasingly affected by low snow depth along their southern UP distribution (Figure 5). Additionally, as mid-winter snowpack across a landscape decrease, so does subnivean access, a consistently important marten winter refuge (Pauli et al., 2022; Wiebe et al., 2014). Martens have been found to move more efficiently than fishers and coyotes in deep snow (Raine, 1983; Suffice et al., 2020; Thibault & Ouellet, 2016). Although martens still experience higher locomotive cost in deep snow, the benefits gained from deep snow areas such as predator avoidance and subnivean access must outweigh the energetic costs since they often select for such areas at fine and landscape-level scales (Pauli et al., 2013; Suffice et al., 2020). Our findings additionally suggest that average maximum winter temperature influences marten occupancy at the landscape scale. Thompson et al., 2021 indicates that a consistently cold winter paired with deep snowpack produces a high-quality subnivium as opposed to a freeze-thaw cycle throughout the winter which disrupts overall subnivium stability and formation. It

is likely that snowpack and snow depth both effect marten landscape scale habitat suitability with consistently low winter temperatures and frequent snowfall aiding in the formation of high-quality subnivium and restriction of predator access. Decreases in average snow depth, and snow season length coupled with increasing average winter temperatures in the Upper Peninsula expressed in climate projections (Notaro et al., 2010) indicate snow depth and winter maximum temperature might become increasingly important to marten occupancy across their southern distribution.

4.3 Land Cover and Marten Occupancy

Land cover covariates had minimal influence on marten occupancy at the landscape-scale with the proportion of mixed forest on a landscape having the highest influence among land cover covariates. Marten often prefer mixed woods stands, and conifer and deciduous stands to a lesser extent (Thompson et al., 2017). This may be why we see selection for proportion of mixed forest across models, while selection for other forest types, wetlands, and developed areas remains minimal. Additionally, pockets of mature conifers within deciduous forests are often classified as mixed forest by NLCD datasets, which are often sought out by marten (McCann et al., 2014; Dewitz, 2019;). These heterogeneous forests often contain complex horizontal cover, and house many different prey species for marten. Conifer pockets within these mixed stands additionally provide martens with many large snags, downed woody debris and intricate above-ground root systems for predator avoidance and den formation (McCann et al., 2014; Roloff et al., 2020). However, documented selection of habitat attributes by martens such as coarse-woody-debris, subnivean access and canopy cover can vary within a single land cover type, lessening the influence of land cover on broad scale marten occupancy (McCann et al., 2014; Payer & Harrison, 2005). Furthermore, Godbout & Ouellett, 2010 found that many fine-scale variables are not significantly different between habitat types in Maine, which could further explain why land cover variables in our study had minimal influence on occupancy. Utilizing ground measured data known to influence marten occupancy such as average basal area, coarse woody debris density, and snag density in

addition to abiotic data when conducting marten distribution modeling at broad scales will likely yield optimal results.

4.4 Management Implications

Climate change challenges our ability as scientists to manage and sustain populations of many species, especially in areas experiencing a high rate of abiotic change (Chen et al., 2011; Lawler et al., 2012). Traditional methods of marten population management employ strategies to increase habitat suitability in response to altered forest conditions and often look to increase of coarse woody debris, basal area, and subnivean access (Carroll, 2007; Godbout & Ouellet, 2010). However, with increasing climate uncertainty, abiotic conditions should be considered in addition to biotic conditions before proposing management solutions at large spatial scales. Areas with suitable biotic conditions within a broader area of unsuitable abiotic conditions are likely to have little influence on marten occupancy, and benefits from management conducted in such areas will likely be temporary or localized to fine scale (Suffice et al., 2020). Conservation managers establishing core habitat areas for marten would benefit from considering where such habitats exist within the broader Upper Peninsula marten distribution, the connectedness of the habitat with others across the landscape, barriers to dispersal, and how winter climate in the area is expected to change. Areas with minimal projected changes to snow depth and winter temperatures will continue to be of high importance for habitat restoration of degraded areas across the Upper Peninsula. This entails an emphasis on connecting temporally persistent high-quality habitat to provide marten populations with means to persist in such areas and disperse when abiotic conditions are no longer optimal.

Appendices

Appendix A – Environmental Covariate Metadata

Environmental Covariate	Description	Spatial Resolution	Temporal Resolution	Hypothesized Relationship to occurrence	Source
Mixed Forest	Proportion of mixed forest within a grid cell	1 kilometer	N/A	Provides access to coarse woody debris, snags, and canopy cover from ariel predators. Additionally provides a complex forest structure with high diversity of prey and cover types.	(Dewitz, 2019; U.S. Geological Survey, 2011, 2014)
Evergreen Forest	Proportion of evergreen forest within a grid cell	1 kilometer	N/A	Provides access to coarse woody debris, snags, and canopy cover from ariel predators	(Dewitz, 2019; U.S. Geological Survey, 2011, 2014)
Deciduous Forest	Proportion of deciduous forest within a grid cell	1 kilometer	N/A	Provides access to coarse woody debris, snags, and canopy cover from ariel predators	(Dewitz, 2019; U.S. Geological Survey, 2011, 2014)
Woody Wetlands	Proportion of woody wetlands within a grid cell	1 kilometer	N/A	Provides access to coarse woody debris, snags, and canopy cover from ariel predators. Additionally, is more easily traversed by marten when compared to	(Dewitz, 2019; U.S. Geological Survey, 2011, 2014)

				fishers and coyotes.	
Herbaceous Wetlands	Proportion of herbaceous wetlands within a grid cell	1 kilometer	N/A	Provides access to coarse woody debris and shrub cover. Additionally, is more easily traversed by marten when compared to fishers and coyotes.	(Dewitz, 2019; U.S. Geological Survey, 2011, 2014)
Developed Land	Proportion of developed land within a grid cell	1 kilometer	N/A	Avoided by marten due to noise and light pollution and lack of adequate cover.	(Dewitz, 2019; U.S. Geological Survey, 2011, 2014)
Snow Depth	Snow depth in millimeters	1 kilometer	5 winters (November-February)	Selection of high snow depth areas for subnivean access and competitive advantage in locomotion.	(National Operational Hydrologic Remote Sensing Center, 2004)
Snow Cover Index	An index indicating the extent of snow-covered land	1 kilometer	5 winters (November-February)	Selection of snow-covered land which provides subnivean access and competitive advantage in locomotion when snow depth is high enough.	(Hall & Riggs, 2016)
Maximum Temperature	Maximum monthly winter temperature	1 kilometer	5 winters (November-February)	Selection of low maximum temperatures which facilitates formation of consistent winter snowpack.	(Oak Ridge National Laboratory Distributed Active Archive Center, n.d.)

Winter Precipitation	Total monthly precipitation	1 kilometer	5 winters (November-February)	Selection for high winter precipitation in areas with low maximum winter temperatures.	(Oak Ridge National Laboratory Distributed Active Archive Center, n.d.)
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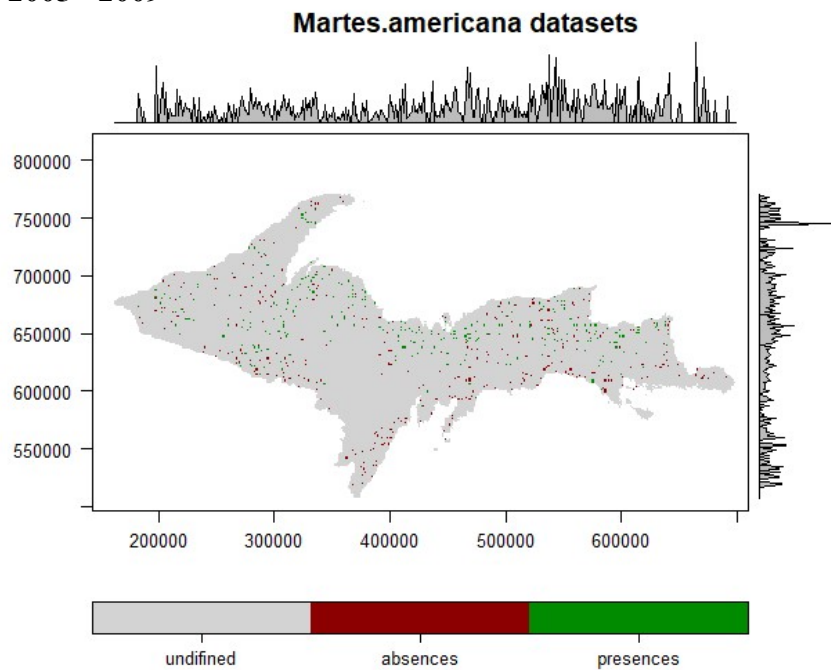
Appendix B – Correlation Matrix

Pearson's correlation matrix testing the correlation between biotic and abiotic environmental covariates. This table is an average across the 3-covariate time-periods. Dec = proportion of deciduous forest, Dev = proportion of developed land, Ev = proportion of evergreen forest, Mix = proportion of mixed forest, Weth = proportion of herbaceous wetland. Swamp = proportion of forested wetland, NDSI = mean winter snow cover index, Depth = mean winter snow depth, Precip = mean winter total precipitation, Max = mean winter maximum temperature.

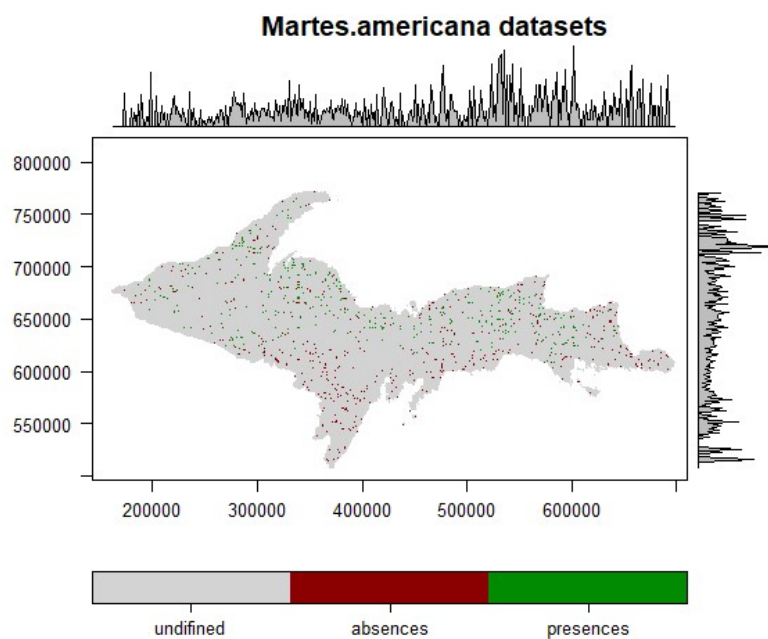
	Dec	Dev	Ev	Mix	Weth	Swamp	NDSI	Depth	Precip	Max
Dec	1	-0.07	-0.28	0.04	-0.23	-0.49	-0.43	0.22	-0.06	-0.39
Dev	-0.07	1	0.05	-0.06	-0.06	-0.19	0.16	-0.08	-0.09	0.04
Ev	-0.28	0.05	1	0.03	-0.08	-0.21	0.10	0.10	0.13	0.10
Mix	0.04	-0.06	0.03	1	-0.20	-0.42	-0.39	0.32	-0.14	-0.32
Weth	0.23	-0.06	-0.08	-0.20	1	0.15	0.21	-0.02	0.10	0.13
Swamp	-0.49	-0.19	-0.21	-0.42	0.15	1	0.12	-0.09	0.08	0.31
NDSI	-0.43	0.16	0.10	-0.39	0.21	0.12	1	-0.39	0.09	0.35
Depth	0.22	-0.08	0.10	0.32	-0.02	-0.09	-0.39	1	0.26	-0.45
Precip	-0.06	-0.09	0.13	-0.14	0.10	0.08	0.09	0.26	1	0.30
Max	-0.39	0.04	0.10	-0.32	0.13	0.31	0.35	-0.45	0.30	1

Appendix C – Marten Presence and Pseudoabsence Data

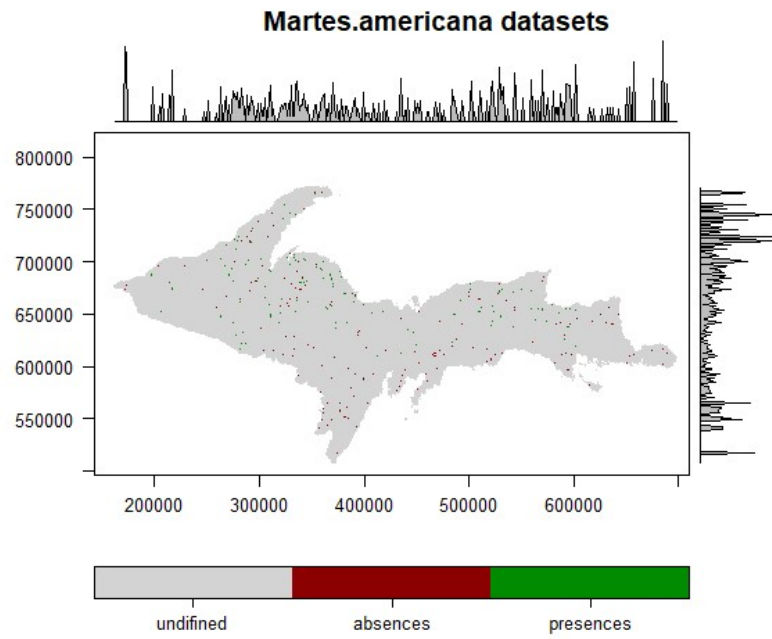
2005 - 2009



2010 - 2014



2015 - 2019



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