

Building and Testing a Habitat Suitability Model for the American Marten (*Martes americana*) in Northeastern California

T. A. KIRK

Environmental and Natural Resource Sciences
Humboldt State University, Arcata, CA 95521 USA.
P.O. Box 4425, Arcata, CA 95518
Phone: (707) 825-2990 Email: tkirk@fs.fed.us

I used Geographic Information Systems (GIS) and survey data to develop a regional-scale habitat suitability model for the American marten (*Martes americana*), a forest-dwelling carnivore species. The model was developed in northeastern California where martens have experienced an apparent loss of occupied range. Landscape-scale habitat associations were assessed at three landscape-scale extents following previous research which indicates marten habitat selection is influenced by landscape conditions. Measures of landscape pattern, landownership, elevation, stream density, road density, and nearby marten detections were applied to resource selection functions to predict marten occurrence. Candidate model sets were created and then ranked using Akaike's Information Criteria (AIC) for each spatial scale. The top model at the 5 km radius scale outperformed those developed at smaller spatial extents and included the following predictor variables: total amount of habitat, the number of habitat patches, and land ownership. I used a spatial analysis program to prepare the input grids and GIS to apply the regression equation to create a predictive map of marten habitat suitability. I then evaluated the model using an independent data set provided by the Lassen National Forest. The model performed well with data collected during the same seasons as the developmental data set (Summer-Fall), but performed poorly with test data obtained during the winter and early spring. The results of this modeling effort may assist resource managers in conservation planning by identifying potential source-sink habitats, marten population centers, and target areas for future surveys.

Keywords: GIS, habitat modeling, American marten, model evaluation, landscape pattern

1. Introduction

The American marten is a housecat-sized, forest-dwelling weasel in the mustelidae family. They are among the most habitat-specific mammals in North America and prefer late-successional, closed-canopy stands of mesic conifers (Harris 1984, Buskirk and Powell 1994). The marten is arguably the best candidate for a forest carnivore indicator species based upon its close association with late-successional forests and its sensitivity to habitat fragmentation (Buskirk and Powell 1994, Bissonette and Broekhuizen 1995). They are commonly regarded as indicators of

ecosystem integrity and their decline in western states has increased conservation concerns among wildlife biologists and resource managers (Buskirk and Ruggiero, 1994). The marten has experienced an apparent loss of occupied range over the last 75 years in northeastern California, a region that has seen several top mammalian predators extirpated (Zielinski et al. 2005). Extinction selectivity, or relative vulnerability, is non-random and individual traits make some species more extinction-prone than others (McKinney 1997). Martens possess many of the life history traits that promote species risk and make them vulnerable to extinction including: specialized habitat preference, restricted distribution, low fecundity, high trophic level, and less adaptable behavior patterns (Buskirk and Powell 1994). Forest carnivores have been a focal point of many conservation efforts because of their association with late-successional forest habitats and their large home range sizes (Noss et al. 1994, Buskirk and Powell 1994).

Studies conducted elsewhere in North America have documented that martens are sensitive to forest fragmentation and to thresholds in landscape-scale characteristics (Bissonette et al. 1997, Hargis et al. 1999, Chapin et al. 1998). For the purposes of this study a landscape is defined as a region from several to hundreds of square kilometers. Hargis et al. (1999) found that in 18 nine km² landscapes with varying amounts of fragmentation that landscape-level habitat loss was negatively correlated with marten abundance. At the landscape scale, martens selected forests with more uncut stands and larger core areas (Potvin et al. 2000). Landscape-scale fragmentation effects were not detectable at smaller spatial scales; illustrating the advantage of a multiple-scale research design that includes greater than home-range-size spatial extents. Individual martens may be the most selective at the micro-habitat scale and the landscape scale (Minta et al. 1999). Buskirk and Powell (1994) suggested the choice of where martens establish their territories may be made at the landscape scale. The landscape-scale is also where the effects of forest fragmentation appear to influence marten habitat selection (Bissonette et al. 1997, Hargis et al. 1999, Potvin et al. 1999). This underscores the need to increase habitat modeling efforts at landscape-scale and regional scales. The rapid development of landscape ecology in North America coincides with the arrival of advanced GIS, increased computing power, and greater availability of remotely-sensed data (satellite imagery) necessary to model wildlife habitats at larger spatial scales.

My research focused on larger spatial extents because factors operating at various spatial scales, especially those at the landscape or regional scales may exert the most influence on marten population distributions. The study region included four national forests (Shasta-Trinity, Lassen, Plumas, Tahoe) and Lassen Volcanic National Park; an area encompassing over 28 000 km² (see figure 1). Large spatial extents (assessment areas) were used to detect scale-sensitive patterns associated with fragmentation at scales larger than the response range of individual martens (Bissonette et al. 1997). This paper describes the building of an empirical statistical model in GIS using landscape-scale habitat associations and its evaluation with an independent data set. I used Receiver Operating Characteristic curve analysis, the Area Under Curve (AUC), and classification success to assess and compare model performance. Three sets of survey data were used in the evaluation: the developmental data set, the independent data set (all seasons), and a subset of the independent data set (summer-fall surveys only). Research into landscape-level habitat fragmentation and the impacts on the functional connectivity of the landscape to wildlife may assist future conservation planning efforts (Harris et al. 1996, Noss and Cooperrider 1994, Wiens 1989). This is especially true for wide-ranging forest carnivore species, such as the marten, who select preferred habitat types from those available in the larger landscape.

2. Regional-scale habitat modeling in GIS

I modeled the spatial arrangement of selected forest types, size classes, and canopy cover densities that characterize optimal marten reproductive habitat at the regional scale (1000s of ha). The California Wildlife-Habitat Relationships (CWHR) system was used to classify vegetation types and the wildlife species associated with them (Mayer and Laudenslayer 1988). Agency and private wildlife biologists routinely use this system to describe habitat types and determine habitat suitability for planning purposes. Vegetation is classified into six tree size classes, four canopy closure classes, and a variety of forest and non-forest floristic types. These are the primary descriptive measures of forest structure important to marten ecology (Buskirk and Powell 1994). I developed a model using the CWHR system similar to the marten reproductive habitat model available from the California Department of Fish and Game (CDFG), but it was modified based on regional knowledge of marten associations gained from four seasons of field work (see Appendix A). I focused on reproductive habitat because it may prove more useful in a regional conservation context than either foraging or cover habitat. American martens have a well documented association with late-successional forest ecosystems in western coniferous forests, which provide important natal and maternal den sites essential for reproduction (Simon 1980, Spencer et al. 1983, Buskirk and Ruggiero 1994, Bull et al. 2005).

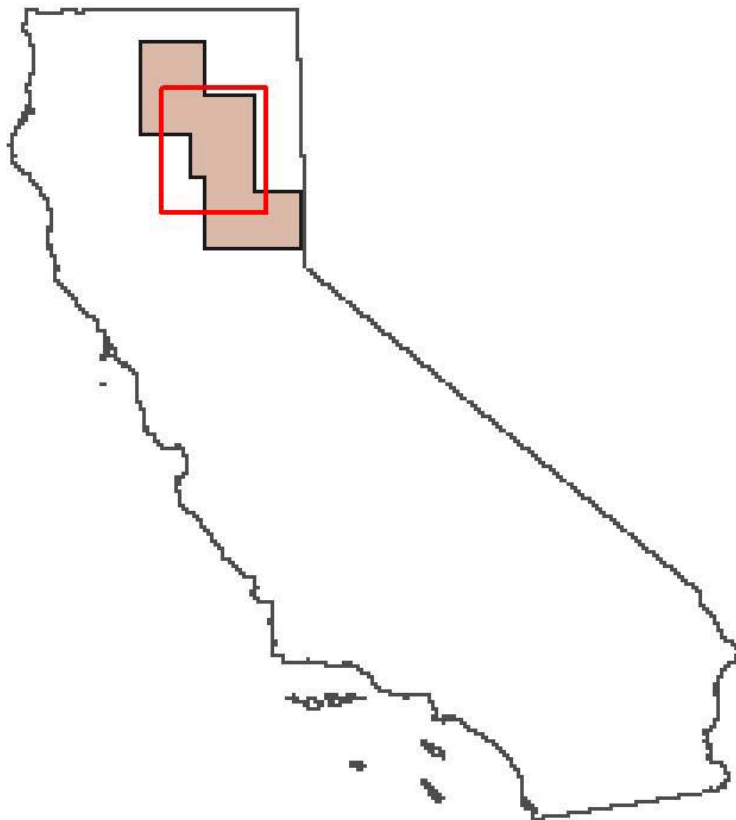


Figure 1. Map of the study region in northeastern California (brown polygon) where the marten habitat suitability model was developed and the evaluation region (red square) where the model was implemented spatially in GIS and tested using an independent data set.

The modified marten habitat model was implemented across the region in GIS using the California Department of Forestry's Fire and Resource Assessment Program (FRAP) vegetation data (FRAP 2002). In this study, the suitable forest patches were aggregated to represent habitat in a binary model: reproductive habitat and non-reproductive habitat. The FRAP data were compiled from a variety of sources that include remotely sensed satellite imagery (LANDSAT) and fine scale field inventories of vegetation attributes. Data of this type have several advantages for describing landscape pattern: seamless coverage across multiple land ownerships in northeastern California, relatively fine scale resolution (100 m cell size), and the vegetation types and structural components are classified using the CWHR system. Regional-scale habitat models, such as this, provide the basis for combining natural resource management planning and conservation efforts that may benefit martens.

3. Landscape pattern analysis and landscape metrics

I used landscape pattern analysis to quantify the composition and spatial arrangement of forest patches surrounding each survey location using the regional-scale habitat model. Landscape pattern is characterized using measures (landscape metrics) which describe the geometric and spatial properties of patterns represented as patches or aggregations of patches. The spatial analysis software program FRAGSTATS™ was used to calculate all landscape metrics (raster version 3.3; McGarigal and Marks 1995).

The criteria I used for selecting landscape metrics appropriate for use in correlation analyses followed the suggestions of Li and Wu (2004). They suggest simple, area-based metrics which have ecological meaning for the study organism. Complex landscape indices, such as contagion, evenness, and fractal dimension are not recommended for use in correlation analyses because of their non-linear formulation and multiple inputs make them prone to mixed responses to changes in landscape pattern (Li and Reynolds 1994, Hargis et al. 1998). Ecological relevance of the landscape pattern was ensured by incorporating attributes of marten habitat (forest structure) into the categorical map data used in the spatial pattern analyses (Li and Wu 2004). Landscape metrics were carefully selected based on the spatial ecology of martens derived from the literature (Bissonette and Broekhuizen 1995, Hargis et al. 1998, Hargis et al. 1999, Potvin et al. 2000). I selected simple metrics measured directly from maps, such as patch size, proportion, and core area, because they are more likely to produce meaningful results when used in regression analyses (Li and Wu 2004).

4. Multiple scale analysis

A multiple scale research approach has been recommended for the American marten because influences at various spatial scales, especially those at the landscape-scale, affect their habitat selection and distributions (Bissonette and Broekhuizen 1995). In this study, the grain size remained fixed and I varied the extent of the circular 'landscapes' to focus the analysis on the landscape-scale. I selected three spatial extents or assessment areas and used forest carnivore survey locations as the origin for buffer distances of 1, 2.5, and 5 km radii, yielding landscapes of 314, 1960, 7850 ha, respectively. I defined the smallest extent to approximate the size of a female marten's home range because they appear to be more selective than males, due to their need for natal and maternal den sites when rearing kits (Buskirk and Powell 1994). I defined a median extent of sufficient size to encompass several home ranges. A third extent was defined

to investigate possible upper-level constraints imposed by landscape-level fragmentation effects which may affect the distribution of marten populations.

Forest habitat composition, configuration, fragmentation, and several other GIS-derived variables were evaluated at 184 sample units, where circular ‘landscapes’ were created at three spatial extents using an Arc Macro Language (AML) script. Systematic grid-based surveys were conducted on public and private lands from 1999 – 2002 by the U.S. Forest Service, Pacific Southwest Research Station. Martens were detected using sample units comprised of six track plates and one remotely-triggered camera station. Marten prevalence was low; they were detected at only 10.8% of sample units (20/184), with detections clustered in three distinct areas of the study region.

5. Statistical analysis and model implementation

I used the Information-Theoretic approach to data analysis (Burnham and Anderson 1998). I created a series of 89 *a priori* conceptual models of habitat selection using published research on marten ecology and landscape ecology, expert-opinion, and my field experience. Carefully selected landscape metrics were combined with other GIS-derived variables to develop multiple working hypotheses that include a broad range of factors potentially influencing marten habitat selection (Burnham and Anderson 1998). Conceptual models were represented by resource selection probability functions (logistical regression models) using a set of variables thought to influence marten habitat selection and included measures of land cover, land ownership, landscape pattern, elevation, stream density, road density, and nearby marten detection data.

These hypotheses (models) were ranked from best to worst using Akaike’s Information Criteria (AIC) and scaled using Akaike weights to reflect the strength of evidence given the data and the models in the set (Burnham and Anderson 1998). The AIC approach is based on information theory and emphasizes the principle of parsimony, which balances model fit with the number of model parameters. I used AIC_c to select the best model from the candidate model set due to the low ratio of sample size to model parameters (Burnham and Anderson 1998). The AIC_c has an additional bias correction term, and is recommended for situations when the ratio of sample size to the number of estimable parameters is <40 (Burnham and Anderson 1998). The model with the lowest AIC_c value is considered the best model. The model with the lowest AIC_c value was model 21; this model included two habitat-based measures of landscape pattern, PLAND, the percent of habitat in the landscape, and NP, the number of habitat patches. A landuse variable, PUBLIC, the amount of public land in the landscape was also in the top model (see equation 1).

$$(1) y = -2.2786 + \text{PLAND}(0.0622) + \text{NP}(0.0261) + \text{PUBLIC}(-0.0549)$$

I calculated Cohen’s Kappa statistic using the full dataset and a cross-validated dataset (10-fold) as well as the classification success for the top model from each assessment area (Manel et al. 2001). The top model at the 5 km radius assessment area had the highest Kappa value of all the spatial scales, Kappa = 0.61. This indicates substantial support and somewhat stronger agreement of the model to the data at larger spatial scales. Consistent with the results from the smaller assessment areas, the top model correctly classified more non marten sites than marten sites, 98.1% and 55% respectively. Model performance was only slightly lower using the cross-validation dataset, Kappa = 0.60. I also calculated the marten detection probability during

the 16-day survey period by creating detection profiles and using a SAS program (Zielinski and Baldwin unpublished data). The probability of detecting a marten was 99% (95% C.I. = 97-100%).

This habitat suitability model was implemented spatially in GIS within the evaluation region using moving window functions in the FRAGSTATSTM software to prepare the input grids. Grids representing the marten habitat model and land in public ownership were derived from the FRAP data in ArcMapTM (ESRI, 2000). I used map algebra to apply the regression equation of the top model and created a predictive map of marten habitat suitability within the evaluation region using ArcInfoTM (ESRI, 1999). This spatially explicit regional habitat model was evaluated using an independent data set of forest carnivore surveys provided by the wildlife biologists of the Lassen National Forest for the central portion of the study region.

6. Model evaluation using independent data

I created point coverages from the developmental and the independent data sets to derive the predicted probabilities for each site from the spatial habitat suitability model in ArcInfoTM. Three data sets were used to evaluate model performance: the developmental data, the full independent dataset, and a subset of the independent data which included only data from June through November (Summer-Fall), the seasons when the data used to develop the model were collected. The present/absent results from each data set were displayed on the habitat suitability map and used to make histograms of their relative classification success which were binned by their predicted probability values. Receiver Operator Characteristic (ROC) curves and AUC scores were also calculated to assess model performance (see figures 2-10).

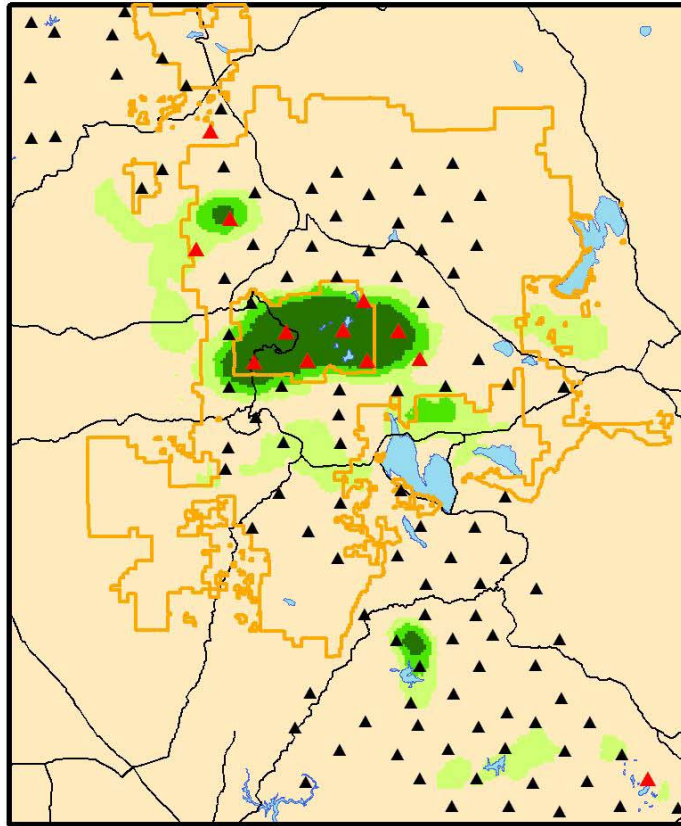


Figure 2. Map of the evaluation region where the top AIC selected model was implemented spatially in GIS. Dark green indicates probabilities between 0.6-1.0, light green 0.3-0.6, pale green 0.1-0.3, and tan 0-0.1. Triangles represent the developmental data set, marten detections (red) and non-detection sites (black), which show good agreement with the model. The orange line is the Lassen National Forest border. The black lines are major highways. Blue areas are major lakes. The large dark green area of high probability corresponds with Lassen Volcanic National Park. Note the high marten density within this region.

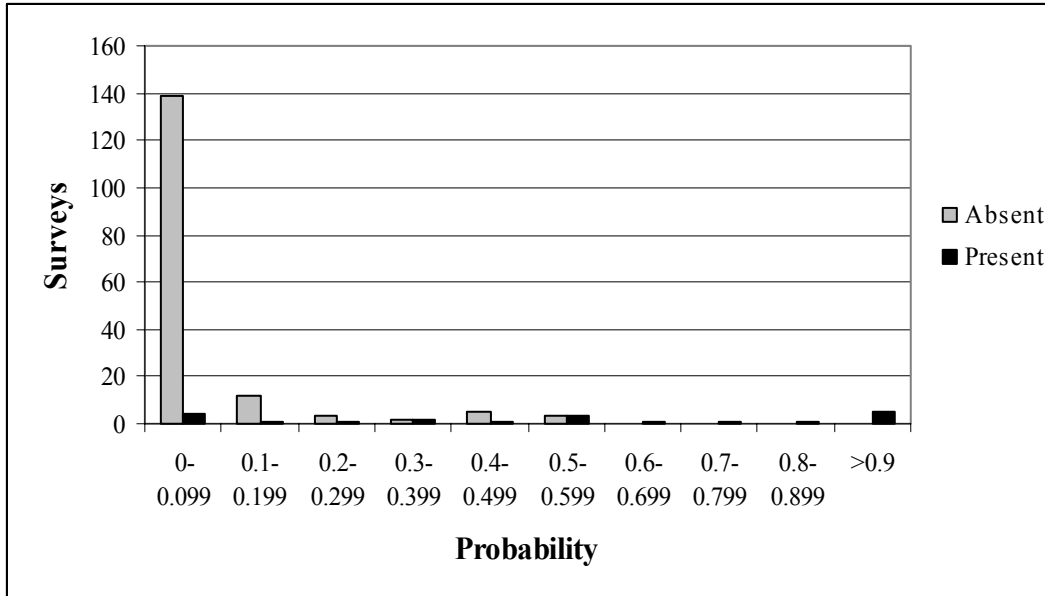


Figure 3. Histogram of the classification success for the developmental data. The model works better at classifying sites without marten detections, but performs reasonably well for sites with marten detections. These data were collected over a two year period in 2000 and 2001. Present (n=20) Absent (n=164).

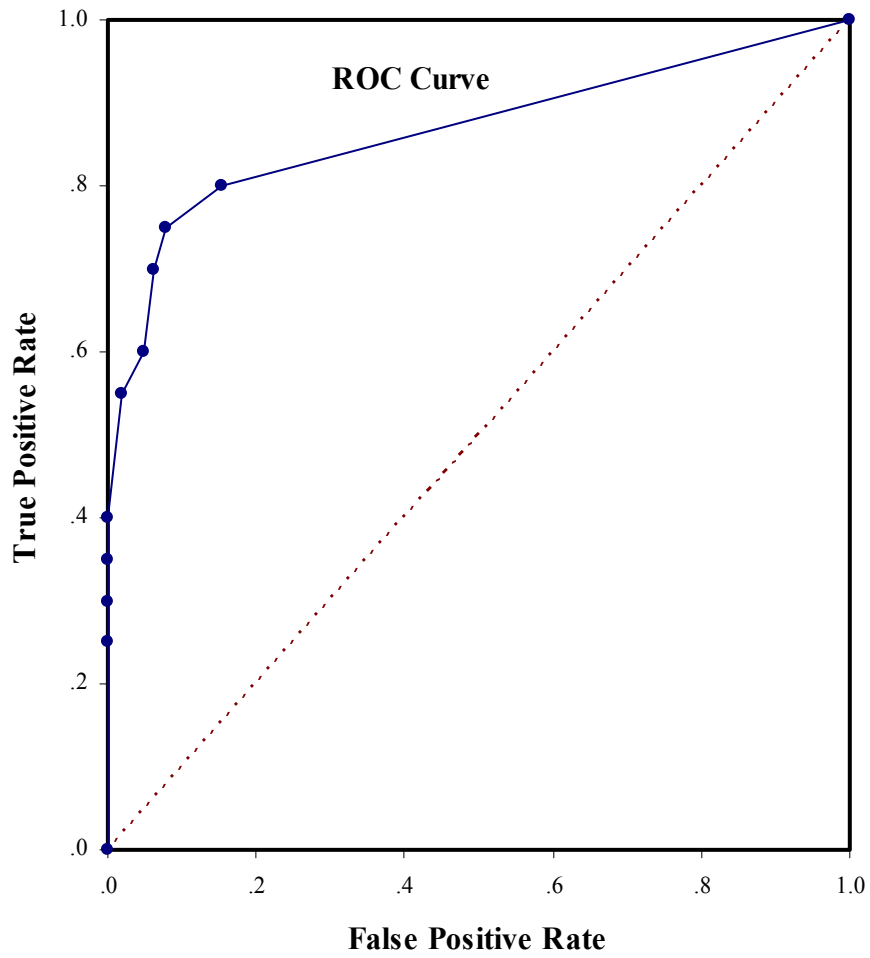


Figure 4. Receiver Operating Characteristic curve for the developmental data set. The Area Under Curve (AUC) is equal to 0.8669. The SE_{AUC} equals 0.0527. A larger AUC indicates better agreement with the data. AUC scale: 0.7-0.8 acceptable, 0.8-0.9 excellent, 0.9-1.0 outstanding (Hosmer and Lemeshow 2000).

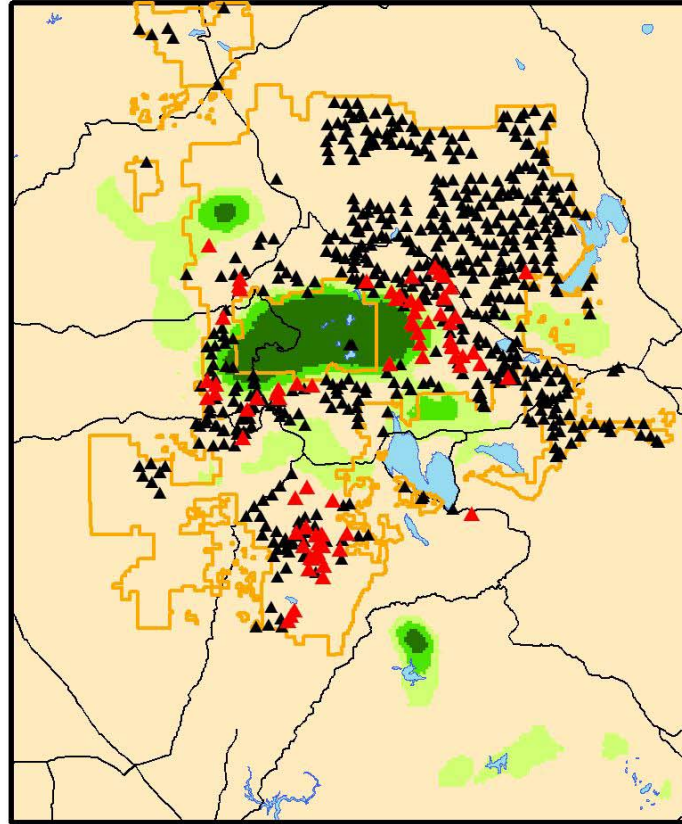


Figure 5. Map of the evaluation region where the top AIC selected model was implemented spatially in GIS. Dark green indicates probabilities between 0.6-1.0, light green 0.3-0.6, pale green 0.1-0.3, and tan 0-0.1. Triangles represent the entire independent data set, marten detections (red) and non-detection sites (black), which show poor agreement with the model. The model does not appear to work well in geographic subregions to the south and east of Lassen Volcanic National Park. The orange line is the Lassen National Forest border. The black lines are major highways. Blue areas are major lakes. The large dark green area of high probability corresponds with Lassen Volcanic National Park.

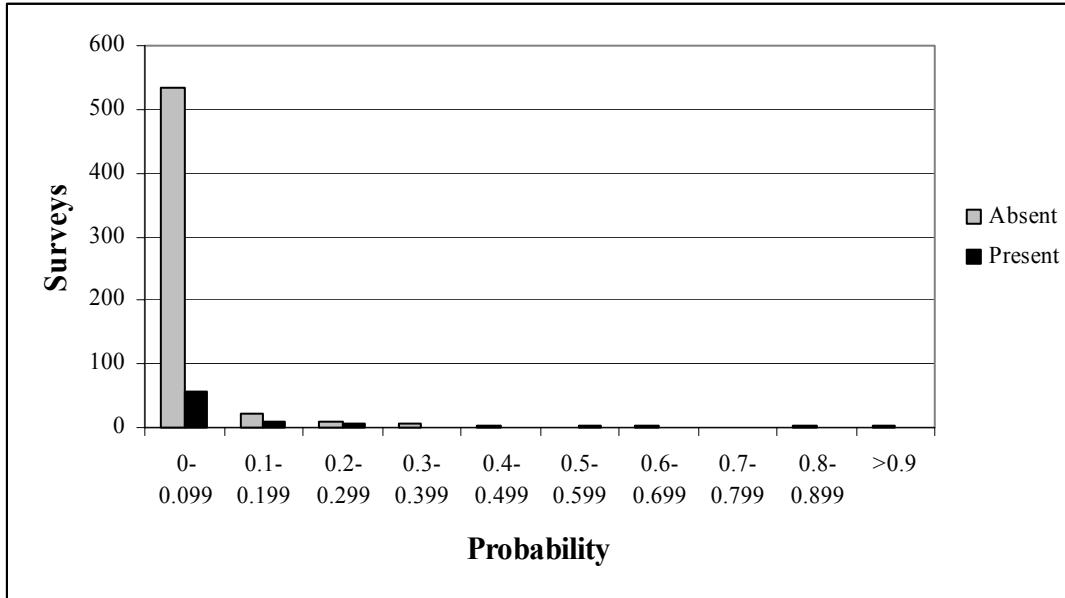


Figure 6. Histogram of the classification success for the full independent data set. The model performs poorly when classifying sites with or without marten detections and shows little agreement with the data. This data set contains surveys from both summer and winter over an eight year period beginning five years prior to the surveys used to develop the model. Present (n=76) Absent (n=582).

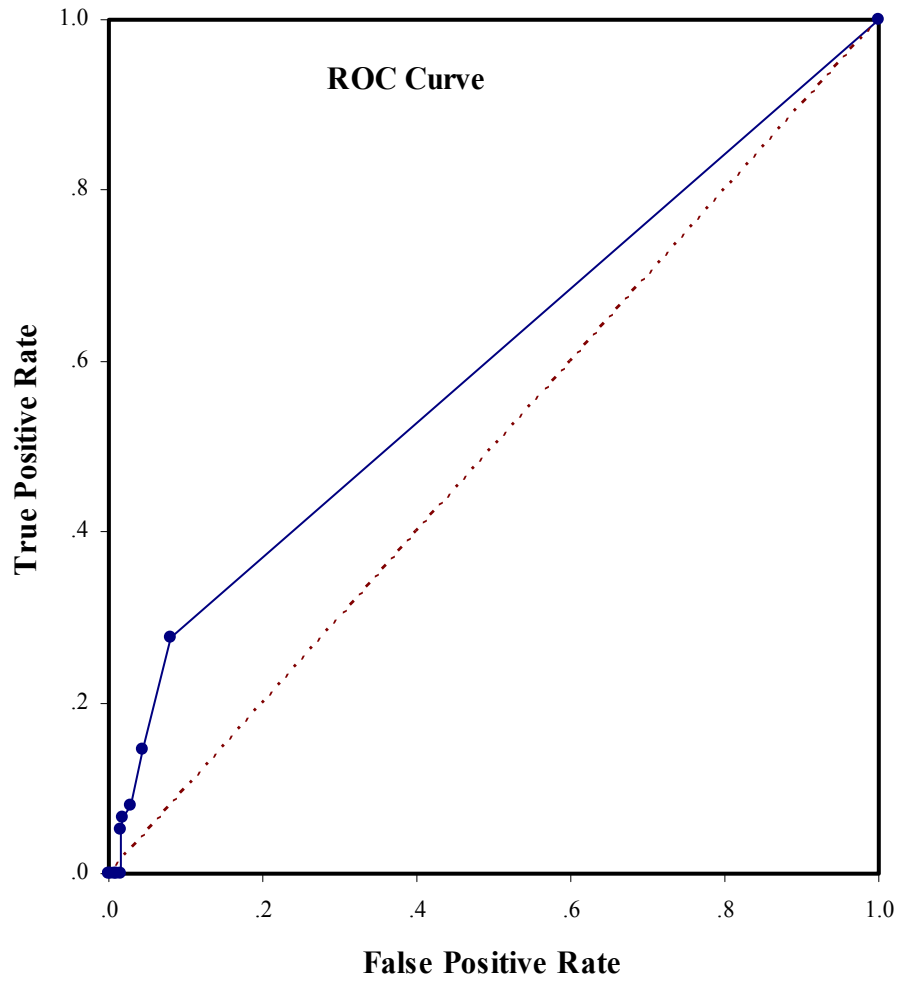


Figure 7. Receiver Operating Characteristic curve for the full independent data set. The Area Under Curve (AUC) is equal to 0.5971. The SE_{AUC} equals 0.0361. The small AUC indicates poor agreement with the data. AUC scale: 0.7-0.8 acceptable, 0.8-0.9 excellent, 0.9-1.0 outstanding (Hosmer and Lemeshow 2000).

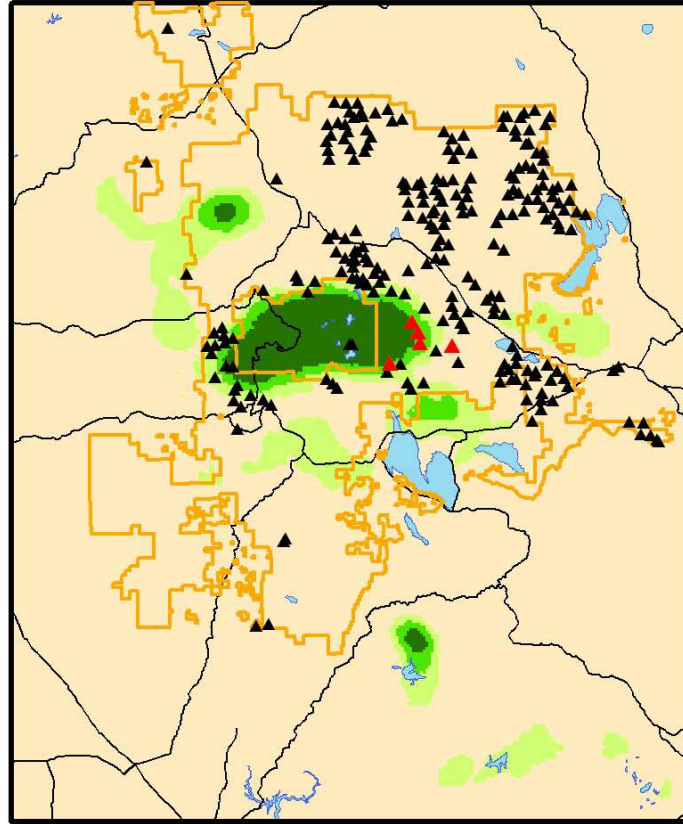


Figure 8. Map of the evaluation region where the top AIC selected model was implemented spatially in GIS. Dark green indicates probabilities between 0.6-1.0, light green 0.3-0.6, pale green 0.1-0.3, and tan 0-0.1. Triangles represent the Summer-Fall independent data set, marten detections (red) and non-detection sites (black), which show good agreement with the model. The model works well in geographic subregions to the south and east of Lassen Volcanic National Park. The orange line is the Lassen National Forest border. The black lines are major highways. Blue areas are major lakes. The large dark green area of high probability corresponds with Lassen Volcanic National Park.

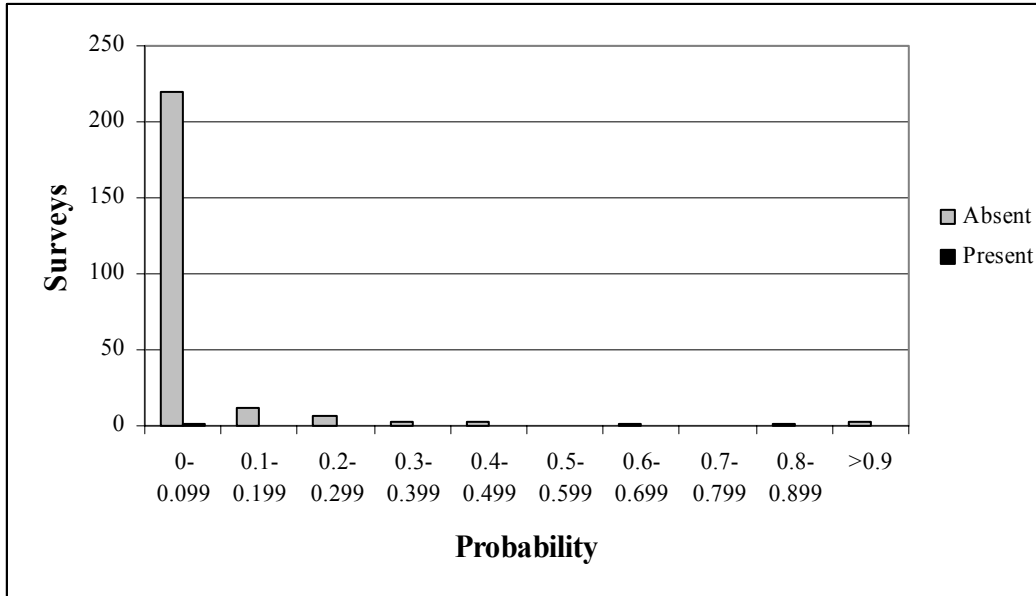


Figure 9. Histogram of the classification success for the Summer-Fall independent data set. The model performs well when classifying sites with or without marten detections and shows good agreement with the data with the majority of marten detections > 0.6. This data set contains surveys from June-November over an eight year period beginning five years prior to the surveys used to develop the model. These data were collected during the same seasons as the developmental data set. Present (n=5) Absent (n=248). Note the lower number of detections during this time of year.

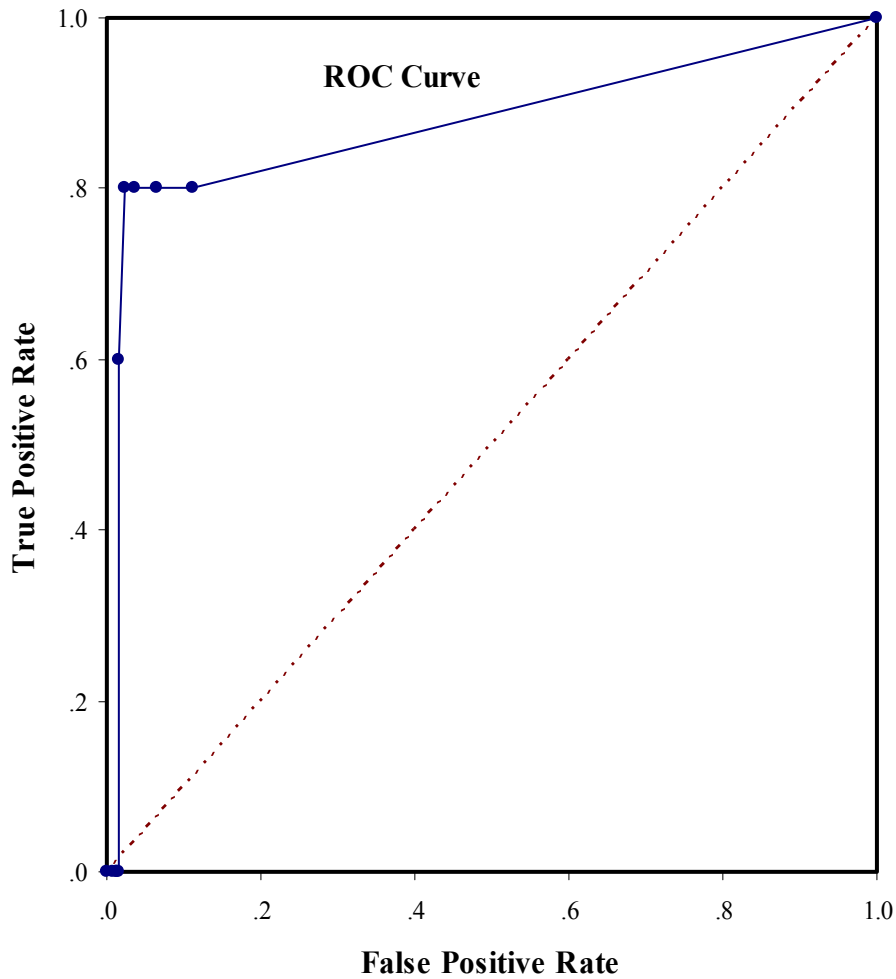


Figure 10. Receiver Operating Characteristic curve for the Summer-Fall data set. The Area Under Curve (AUC) is equal to 0.8750. The SE_{AUC} equals 0.115. A larger AUC indicates better agreement with the data. The AUC is slightly larger than the developmental indicating the model works well at predicting marten occurrence in the months between June and November. AUC scale: 0.7-0.8 acceptable, 0.8-0.9 excellent, 0.9-1.0 outstanding (Hosmer and Lemeshow 2000).

7. Discussion and conclusions

7.1 Developmental data

This is the first landscape-level research on American martens conducted in California. The results from the habitat suitability model built using the developmental data support the hypothesis that martens respond to landscape-scale conditions and that late-successional forest landscape patterns are correlated with marten occurrence. The model that was developed at largest spatial scale outperformed those from smaller scales based on model performance diagnostics, suggesting that habitat availability within the surrounding landscape may be an important factor for determining marten population distributions and likely influences their metapopulation dynamics.

The top models in each of the three assessment areas used in this study contained measures of forest habitat-related variables; this indicates that the late-successional forests I modeled are important to martens. The marten's spatial population dynamics and late-successional forest habitat requirements suggest that their distributions are likely related to the distribution of suitable forest habitat; however their population densities may vary widely. These results indicate that late-successional forests located at higher elevations appear to be crucial for marten population persistence. Descriptive statistics indicate that marten detection sites had on average three times the amount of reproductive habitat and core area habitat as non-detection sites. Maintenance of large, better connected forest patches may also benefit martens.

Land use data was also substantially different between sites where martens were and were not detected. The importance of land use in the model is underscored by the individual importance weight calculations that indicate, across the region where the developmental data was collected, it was the most important predictor variable. There are several possible reasons for this: land use affects forest structure and landscape pattern, the location of different land ownerships may simply be correlated with specific forest types, some land use areas (wilderness) may be less impacted by timber harvesting activities and provide more 'natural conditions' with which martens have evolved, and some land ownerships may occur at higher elevations where martens have a competitive advantage of other sympatric carnivores. It was not possible to determine the exact cause and effect or mechanistic linkages to animal fitness and survival from this study, but the largest density of martens were detected within designated wilderness areas.

The habitat suitability model I developed using landscape-scale habitat associations shows substantial agreement with the data after using a 10-fold cross-validation procedure to assess model stability. Model stability alone, however is not sufficient for wildlife biologists to assume good performance. The prevalence or relative scarcity of martens within northeastern California should be expected to influence the accuracy of presence-absence modeling because of the difficulty in correctly calibrating models where occupied sites are few (Manel et al. 2001). Testing or evaluating a model with independent data provides a means to overcome these problems and avoid misleading inferences.

7.2 Independent data

The differences in model performance, when tested using independent data, point to the complexities of ecological systems. Habitat modeling is a simplification of these systems that

allows us to predict where a species is likely to occur in specific locations. Due to variability in environmental conditions over time and space some models will perform better than others.

There are numerous reasons why the model performed poorly when tested with the full independent data set. They include, but are not limited to: detection of dispersing juvenile martens, low population densities, sink habitats where martens are detected but do not survive, unequal detection probabilities between summer and winter, potential seasonal changes in habitat use, and the mismatch between the scale of the region where the developmental data was collected and the scale of the evaluation region. Juvenile dispersal may explain some of the differences in the geographic subregions where martens were detected. Several detections within the same month may be the result of only a few wide-ranging martens if the spatial independence of the survey locations is not assured, as is the case with the test data. However, detections in the same area over longer time periods may indicate either low population densities, which were not detected in the relatively coarse scale sampling grid (10 km) or the presence of sink habitat. Martens may be more willing to visit detection stations in the harsh winter months than in summer when prey is more abundant, however this remains speculative. While changes in seasonal habitat use are not well documented in American marten, this may be a target of future research given the results of this study. Model generality may also limit the precision of specific predictions, such as when a model is applied to smaller geographic subregions. However, it is encouraging that the results of the Summer-Fall data fit the model very well; this suggests the data used to develop the model is from resident martens. During the Summer-Fall months juvenile martens would not be expected to be dispersing to new areas as they would be in the winter months (Buskirk and Powell, 1994).

7.3 Uses for the model

Conservation biologists have suggested a focus on preserving the remaining late-successional forests and maintaining adequate habitat connectivity to ensure forest carnivore population viability (Noss et al. 1997). This model may prove useful for identifying source-sink habitats and marten population centers, as well as generating hypotheses about the marten's spatial population dynamics in this region. Land managers are presented with many challenges when managing for wide-ranging carnivore species such as the marten. Their specialized habitat requirements, need for canopy cover, complex structure at ground level, juvenile dispersal characteristics, and metapopulation dynamics strongly suggest that regional planning may be more effective for successful species conservation.

Martens persist in landscapes that contain larger amounts, core areas, patches, and core area patches of late-successional forests. Spatially explicit habitat modeling identifies the landscape context within which a given timber sale or fuels reduction project may happen to fall. Further, the relative importance of a specific project area to regional forest connectivity may be considered and therefore provide better conservation decisions. The results of this study suggest that resource managers and wildlife biologists may need to consider much larger spatial extents to provide effective conservation planning for marten populations. Managers must adopt a landscape-scale perspective and begin planning future management actions at scales far larger than the forest stand-scale (project area) they are accustomed to.

GIS-based regional habitat modeling will likely increase in importance as a conservation tool as the influence of the surrounding landscapes structural condition (forest cover and old forest) on smaller scale phenomena (wildlife) become better understood through landscape-scale research projects such as this. There are many new hypotheses to explore regarding the possible

reasons for the discrepancies between the results of the full data set and the Summer-Fall only data set. Many of which may involve future research focused on marten dispersal, survivorship, and metapopulation dynamics. Refinement of the model, by incorporating other detection data, may also be possible in the future. Trends in the distribution of martens in this region indicate proactive conservation actions are needed and the results of this GIS modeling effort may address this need by producing statistically valid regional-scale habitat models useful in resource management and conservation planning.

Acknowledgements

This study was made possible through the efforts and assistance of many people. I wish to thank Dr. William Zielinski of USFS Redwood Sciences Laboratory, Arcata, California, who provided guidance and direction throughout the course of my research. Dr. Zielinski was the lead scientist who secured funding and was responsible for the implementation of the systematic forest carnivore surveys conducted throughout California which provided the data on which this research was based. I wish to thank the members of my committee, my advisor, Dr. Steven Steinberg and Dr. Roland Lambertson of Humboldt State University for their enthusiastic support of this research. The biologists and staff of Redwood Sciences Laboratory also provided significant analytical and technical support for this research. The biologists and staff of the Lassen, Plumas, Tahoe, Shasta-Trinity, and Klamath National Forests provided facilities and invaluable assistance with field survey logistics. Many long, often difficult hours were spent collecting the carnivore distribution data essential to developing the habitat model. I wish to thank all the hard working field crews of Redwood Sciences Laboratory for their help during the four years of data collection. I am extremely grateful to the biologists of the Lassen National Forest for sharing their data, providing funding, and assistance for the model evaluation.

Appendix A: Modifications to the CDFG marten reproductive habitat model.

CWHR Forest Type (Acronym)	Size Class ^a	Canopy Closure ^b
CDFG High Suitability Reproductive Habitat:		
Montane Hardwood Conifer (MHC)	4, 5	M, D
Douglas-fir (DFR)	4, 5, 6	M, D
Lodgepole Pine (LPN)	4, 5	M, D
Red Fir (RFR)	4, 5	M, D
Subalpine Conifer (SCN)	4, 5	M, D
Montane Riparian (MRI)	5, 6	M, D
Modified High Suitability Reproductive Habitat:		
Lodgepole Pine (LPN)	4, 5	M, D
Red Fir (RFR)	4, 5	M, D
White Fir (WFR)	4, 5, 6	M, D
Subalpine Conifer (SCN)	4, 5	M, D
Montane Riparian (MRI)	5, 6	M, D

^a dbh 4 = (11 - 24 in), 5 = (> 24 in), 6 = (> 24 in multi-layered canopy)

^b M = moderate (40 - 60%), D = dense (>60%)

References

- BISSONETTE, J. A., and S. BROEKHUIZEN. 1995. *Martes* populations as indicators of habitat spatial patterns: the need for a multiscale approach. Pages 95-121 in W. Z. Lidicker, Jr., editor. *Landscape approaches in mammalian ecology and conservation*.
- BISSONETTE, J. A., D. J. HARRISON, C. D. HARGIS, and T. G. CHAPIN. 1997. The influence of spatial scale and scale-sensitive properties on habitat selection by American marten. Pages 368-385 in J. A. Bissonette, editor. *Wildlife and Landscape Ecology*. Springer-Verlag, New York.
- BULL, E. L., T. W. HEATER, AND J. F. SHEPHERD. 2005. Habitat selection by the American marten in northeastern Oregon. *Northwest Science* 79(1): 37-43.
- BUSKIRK, S. W., and R. A. POWELL. 1994. Habitat ecology of fishers and American martens. Pages 283-296 in S. W. Buskirk, A. S. Harestad, M. G. Raphael, and R. A. Powell, editors. *Martens, sables, and fisher: biology and conservation*. Cornell University Press, Ithaca, New York.
- BUSKIRK, S. W., and L. F. RUGGIERO. 1994. Marten. Pages 7-37 in L. F. Ruggiero, K. B. Aubry, S. W. Buskirk, L. J. Lyon, and W. J. Zielinski, editors. *The scientific basis for conserving forest carnivores: American marten, fisher, lynx and wolverine in the western United States*. USDA Forest Service General Technical Report RM-254.
- CHAPIN, T. G., D. J. HARRISON, and D. D. KATNIK. 1998. Influence of landscape pattern on habitat use by American marten in an industrial forest. *Conservation Biology* 12(6):96-227.
- ESRI. 1999. ArcINFO Version 8.3. Environmental Systems Research Institute, Inc. 380 New York Street, Redlands, California 92373-8100.
- ESRI. 2000. ArcGIS Version 8.3. Environmental systems Research Institute, Inc. 380 New York Street, Redlands, California 92373-8100.
- FRAP. 2002. Multi-source Land Cover Data Version 1.0. California Department of Forestry and Fire Protection. <http://frap.cdf.ca.gov/data.html>
- HARGIS, C. D., J. A. BISSONETTE, and D. L. TURNER. 1999. The influence of forest fragmentation and landscape pattern on American martens. *Journal of Applied Ecology* 36:157-172.
- HARGIS, C. D., J. A. BISSONETTE, and J. L. DAVID. 1998. The behavior of landscape metrics commonly used in the study of habitat fragmentation. *Landscape Ecology* 13: 167-186.

- HARRIS, L. D. 1984. The fragmented forest: island biogeography and the preservation of biotic diversity. University of Chicago Press, Chicago, Illinois.
- HARRIS, L. D., T. S. HOCTOR, and S. E. GERGEL. 1996. Landscape processes and Their significance to biodiversity conservation. Pages 319-347 in O. E. Rhodes, Jr., R. K. Chesser, and M. H. Smith, editors. *Population dynamics in ecological space and time*. University of Chicago Press, Chicago, Illinois.
- HOSMER, D.W. and S. LEMESHOW. 2000. Applied logistic regression, 2nd edition. John Wiley & Sons, Inc., New York, New York
- LI, H., and J. WU. 2004. Use and misuse of landscape indices. *Landscape Ecology* 19: 389-399.
- LI, H., and J. F. REYNOLDS. 1994. A simulation experiment to quantify spatial heterogeneity in categorical maps. *Ecology* 75: 2446-2455.
- MANEL, S., H.C. WILLIAMS, and S. J. ORMEROD. 2001. Evaluating presence-absence models in ecology: the need to account for prevalence. *Journal of Applied Ecology* 38:921-931.
- MCGARIGAL, K. and B. J. MARKS 1995. FRAGSTATS: spatial pattern analysis program for quantifying landscape structure. General technical report PNW 351. U. S. Forest Service, Pacific Northwest Research Station, Portland, Oregon.
- MAYER, K. E., and W. F. LAUDENSLAYER. 1988. A guide to wildlife habitats of California. California Department of Forestry and Fire Protection , Sacramento, California.
- MCKINNEY, M. L. 1997. Extinction vulnerability and selectivity: combining ecological and paleontological views. *Annual Reviews of Ecological Systems* 28: 495-516.
- MINTA, S. C., P. M. KAREIVA, and A. C. PEYTON. 1999. Carnivore research and conservation: learning from history and theory. Pages 323-404 in T. W. Clark, A. C. Peyton, S. C. Minta, and P. M. Kareiva. *Carnivores in ecosystems: the Yellowstone experience*. Yale University Press, New Haven, Connecticut.
- NOSS, R. F., M. A. O'CONNELL, and D. D. MURPHY. 1997. *The science of conservation planning: habitat conservation under the endangered species act*. Island Press, Washington, D. C.
- NOSS, R. F., and A. Y. COOPERRIDER. 1994. *Saving nature's legacy: protecting and restoring biodiversity*. Island Press, Washington, D.C.

- POTVIN, F., L. BELANGER, and K. LOWELL. 2000. Marten habitat selection in a clear-cut boreal landscape. *Conservation Biology* 14:844-857.
- SIMION, T. L. 1980. An ecological study of pine marten in the Tahoe National Forest. Master's thesis. California State University, Sacramento.
- SPENCER, W. D., R. H. BARRETT, and W. J. ZIELINSKI. 1983. Marten habitat preferences in the northern Sierra Nevada. *Journal of Wildlife Management* 47(4):1181-1186.
- WIENS, J. A. 1989. Spatial scaling in ecology. *Functional Ecology* 3:385-397.
- ZIELINSKI, W. J., R. L. TRUEX, F. V. SCHLEXER, L. A. CAMPBELL, and C. CARROLL. 2005. Historical and contemporary distributions of carnivores in forests of the Sierra Nevada, California, USA. *Journal of Biogeography* 32:1385-1407.