DISTRIBUTION AND HABITAT ASSOCIATIONS OF FOREST CARNIVORES AND AN EVALUATION OF THE CALIFORNIA WILDLIFE HABITAT RELATIONSHIPS MODEL FOR AMERICAN MARTEN IN SEQUOIA AND KINGS CANYON NATIONAL PARKS

by

Rebecca E. Green

A Thesis

Presented to

The Faculty of Humboldt State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

In Natural Resources: Wildlife

May, 2007

DISTRIBUTION AND HABITAT ASSOCIATIONS OF FOREST CARNIVORES AND AN EVALUATION OF THE CALIFORNIA WILDLIFE HABITAT RELATIONSHIPS MODEL FOR AMERICAN MARTEN IN SEQUOIA AND KINGS CANYON NATIONAL PARKS

by

Rebecca E. Green

Approved by the Master's Thesis Committee:

Dr. Matthew D. Johnson, Major Professor — Date

Dr. William J Zielinski, Committee Member — Date

Dr. Richard T. Golighlty, Committee Member — Date

Coordinator, Natural Resources Graduate Program — Date

07-WI-628-05/09

Natural Resources Graduate Program Number — Date

Chris A. Hopper, Interim Dean for Research and Graduate Studies — Date

ABSTRACT

Distribution and Habitat Associations of Forest Carnivores and an Evaluation of the CWHR Model for American Marten in Sequoia and Kings Canyon National Parks

Rebecca E. Green

Concern for the conservation of American marten (*Martes americana*) and fisher (*Martes pennanti*) in California has increased in recent years and was the impetus for surveys conducted in Sequoia and Kings Canyon National Parks between 2002 and 2004. Track plates and remote cameras were used to detect carnivores at sites (n = 79) ranging in elevations from 600 to 3,500 m. Distribution patterns for marten and fisher exhibited similarities to historic records. Martens were detected at 36.7% of sites between 1,800 and 3,340 m across a relatively broad geographic area. Habitat types at sites with martens included Sierran mixed conifer (28%), red fir (24%), lodgepole (21%), montane riparian (10%), subalpine conifer (10%), and barren (7%). Martens were detected most often at sites dominated by trees with ≥ 61.0 cm dbh (59%) and ≥ 40% canopy cover (72%), but a few detections occurred at high elevation sites with boulder cover. Fishers were detected at only 11.4% of sites from 1,000 to 2,870 m in the western half of the Parks. Fishers occurred at sites in Sierran mixed conifer (56%), foothill hardwood-conifer (11%), montane hardwood (11%), white fir (11%), and subalpine conifer (11%) habitat types, with most detections at sites dominated by trees of ≥ 61.0 cm dbh (67%) and ≥ 40% canopy cover (100%). Eight other species of carnivore were detected, but

wolverine (*Gulo gulo*) and Sierra Nevada red fox (*Vulpes vulpes necator*) were notably absent from surveys. Conservation plans for marten and fisher in the southern Sierra Nevada should include the Parks within a larger regional network of suitable habitat.

Habitat models have become increasingly popular as tools to assist wildlife biologists in predicting species occurrence and identifying habitat for conservation. Numerous models have been created, but few have been evaluated with independent data. Surveys for forest carnivores in Sequoia and Kings Canyon National Parks provided presence-absence data to evaluate the California Wildlife Habitat Relationships model for American marten. Martens were primarily detected in habitat types accurately identified by the model, with the exception of a few detections in barren habitats with boulder cover at high elevations not predicted as suitable. In general, probability of marten occurrence increased with increasing suitability values. Correct classification ranged from 37 to 63% depending on the cut-points and criteria used; it improved up to 71% when suitability of Sierran mixed conifer was increased and optimal cut-points were applied. Association between marten occurrence and suitability values from the model was positive ($r_s = 0.52$, $P = 0.06$), but again improved with increased suitability of Sierran mixed conifer ($r_s = 0.71$, $P = 0.01$). Raising the predicted suitability value of Sierran mixed conifer tree size class 6 (mature, multilayered forest) from medium (0.66) to high (1.0), making adjustments to the barren category, and further incorporating and quantifying habitat elements would likely enhance the accuracy and usefulness of the model for biologists involved in managing lands in this region.

ACKNOWLEDGEMENTS

This project could not have been completed without the generous contributions of time, knowledge, field experience, financial support, and physical stamina of many people. I would first like to thank R. Mazur and H. Werner, wildlife biologists at Sequoia-Kings Canyon National Parks, for proposing this project to learn more about forest carnivores in the Parks, finding the funding to make it a reality, and giving me the privilege of surveying some truly spectacular areas. I would like to extend a special appreciation to them and the many other National Park Service employees who helped with the logistical challenges of this project. Financial support was provided primarily by a grant through the National Park Service, with additional assistance from the Sequoia Natural History Association, Volunteer in Parks Program, Student Conservation Association, and a scholarship from the Stockton Sportsman's Club. Many thanks to my family for their support and visits during my graduate project, including my parents John and Donna Ruth, my sister Rachael and her husband Dave, and my husband Jim.

I am extremely grateful to all carnivore crew members from the three seasons of surveys who wore out the soles of their boots hiking over 10,500 km (6,500 miles) of trails, went weeks without showers, and handled maggot-ridden cat food and skunk-scented lure with smiles on their faces. This group of champions included A. Baltensperger, J. Brownlee, K. Brzeski, M. Comer, W. Crombie, J. Koontz, H. Langendorf, M. Oliver, D. Ruthrauff, S. Senft-Grupp, J. Tietz, and J. Tigner. At Humboldt State University, I have benefited from the friendship and support of my

fellow graduate students and the faculty of the Wildlife Department. In particular, I would like to thank Dr. Golightly for giving me my first opportunity to work with carnivores and for his advice as a professor and committee member on my thesis. Dr. Zielinski and his colleagues at PSW Research Station have been inspirational in collecting and circulating a wealth of information on martens and fishers in the Sierra Nevada. These resources were invaluable to me in the planning and implementation of this project. I am very appreciative of Dr. Zielinski for his input and assistance as a committee member, and of his colleagues K. Slauson, T. Kirk, C. Ogan, J. Werren and R. Schlexer at Redwood Sciences Lab for sharing their expertise during this study. I would also like to thank the creators and administrators of the California Wildlife Habitat Relationships model, and hope that my evaluation of its performance will be viewed in the spirit of adding to rather than detracting from the huge amount of effort that has gone into making this multi-species model.

I am especially indebted to my graduate advisor, Dr. Johnson, for the enthusiasm, support, and thoughtful comments he has offered during all stages of my thesis. I am fortunate to have had such an inspiring mentor, and hope to apply what he has taught me about habitat and conservation in my future endeavors. Finally, I want to acknowledge the foresight of early conservationists such as John Muir and George Stewart who helped muster protection for the land within Sequoia and Kings Canyon National Parks, land which not only contains forests and mountains of unsurpassed beauty for humans to visit, but also a wide diversity of habitats used by the infrequently seen yet exceptionally intriguing carnivores mentioned in this thesis.

TABLE OF CONTENTS

Page

ABSTRACT iii

ACKNOWLEDGEMENTS v

TABLE OF CONTENTS vii

LIST OF TABLES ix

LIST OF FIGURES xi

LIST OF APPENDICES xii

CHAPTER 1 1

Introduction 1

Methods 4

Study area 4

Detection of carnivores 4

Vegetation classification and statistical analyses 9

Results 11

Discussion 15

Distribution and habitat associations of American marten 15

Distribution and habitat associations of fisher 17

Occurrence of other carnivores 20

Management implications and research needs 23

Literature cited 25

Tables and Figures 31

CHAPTER 2 37

Introduction 37

Methods 40

Study area 40

Detection of American marten 40

California Wildlife Habitat Relationships model 45

Statistical and Geographic Information System analyses 47

Results 51

Discussion 56

California Wildlife Habitat Relationships model performance 56

Model evaluation process 62

Recommendations, management implications and future research 63

Literature cited 65

Tables and Figures 70

APPENDICES 76

LIST OF TABLES

Table Page

1 Number of sites (n = 79) and associated habitat types where carnivores were detected in Sequoia and Kings Canyon National Parks, California between 2002 and 2004. Habitat types were classified according to the California Wildlife Habitat Relationships (CWHR) system and are ordered as they generally occurred by elevation, with foothill habitats at the bottom and alpine habitats at the top of the table. Percent of sites occurring in each habitat type relative to all sites surveyed is noted after each habitat type. 32

2 Similarity (%) of species composition across eight habitat categories at sites surveyed in Sequoia and Kings Canyon National Parks, California was compared using a Jaccard's coefficient. The total number of carnivore and marsupial species detected in each habitat group is shown at the top of each column. Habitat types which occurred at ≤ 2 survey sites were added to either the mixed conifer or hardwood categories as was appropriate. 33

3 Number of sites (n = 79) and associated canopy cover classifications where carnivores were detected in Sequoia and Kings Canyon National Parks, California between 2002 and 2004 . Canopy cover categories are based on California Wildlife Habitat Relationships system guidelines. Percentage of sites in each canopy cover category relative to all sites surveyed is noted after each category. 34

4 Number of sites (n = 79) and associated tree size classes where carnivores were detected in Sequoia and Kings Canyon National Parks, California between 2002 and 2004. Tree size classes are based on the California Wildlife Habitat Relationship system guidelines. Percentage of sites occurring in each tree size class relative to all sites surveyed is noted after each size class. 35

5 Confusion matrices from logistic regression analyses showing predicted and observed presence or absence of American marten and corresponding percent correct classification at five cut-points. Predicted values were based on habitat suitability values from the California Wildlife Habitat Relationships (CWHR) model and observed values are from surveys conducted in Sequoia and Kings Canyon National Parks, California between 2002 and 2004. The geometric mean was used to calculate suitability values in this example; arithmetic mean calculations were nearly identical................... 71

Table		Page

6 Measures of model performance calculated from confusion matrices using suitability values from the California Wildlife Habitat Relationships (CWHR) model and presence-absence data for American marten collected in Sequoia and Kings Canyon National Parks, California between 2002 and 2004. Values shown are for the original CWHR model, a model with increased values for Sierran mixed conifer (SMC), and the CWHR ArcInfo model. A cut-point of 0.5 was used. 72

7 Measures of performance for the California Wildlife Habitat Relationships (CWHR) model for American marten and confusion matrices associated with two approaches to calculating optimal cut-points. Predicted values are based on CHWR habitat suitability classifications and observed presences or absences are from surveys conducted in Sequoia and Kings Canyon National Parks, California between 2002 and 2004.. 73

LIST OF FIGURES

Figure		Page
1	Distribution of sites with detections of American marten (29) and fisher (9) in Sequoia and Kings Canyon National Parks, California. Sites (n = 79) were surveyed using track plates and remote cameras during summer and fall of 2002, 2003, and 2004. Forest and shrub dominated habitats are shown in gray and rock dominated areas are white..	31
2	Distribution of sites with detections of gray fox (5), raccoon (1), ringtail (3), Virginia opossum (1), western spotted skunk (9), and weasel (long- or short-tailed, 11) in Sequoia and Kings Canyon National Parks, California. Sites (n = 79) were surveyed using track plates and remote cameras during summer and fall of 2002, 2003, and 2004. Forest and shrub dominated habitats are shown in gray and rock dominated areas are white.....	36
3	Distribution of sites with detections of American marten in Sequoia and Kings Canyon National Parks, California. Martens were detected by track or photo at 29 (36.7%) of 79 sites surveyed during summer and fall of 2002, 2003 and 2004. Sites have been grouped to show whether martens were detected at ≤ 2 or ≥ 3 of the 5 stations at the site. Forest and shrub dominated habitats are shown in gray and rock dominated areas are white......................	70
4	Relationship between ranked area-adjusted frequency of American marten detections and ranked bins of habitat suitability values based on the California Wildlife Habitat Relationships (CWHR) system. Spearman rank correlations were calculated using original suitability values in graph a (P = 0.06) and increased values for Sierran mixed conifer tree size class 6 in graph b (P = 0.01). The arithmetic mean calculation was used..................	74
5	Output grid from the California Wildlife Habitat Relationships (CWHR) ArcInfo model showing predicted habitat suitability for American marten in Sequoia and Kings Canyon National Parks. Suitability values ranged from unsuitable at 0 to highly suitable at 1.0. Sites with and without detections of martens from surveys conducted between 2002 and 2004 are displayed.	75

LIST OF APPENDICES

Appendix Page

A Vegetation categories available to forest carnivores and sites surveyed in Sequoia and Kings Canyon National Parks, California between 2002 and 2004. Digital National Park Service (NPS) vegetation categories were reassigned to the closest California Wildlife Habitat Relationship (CWHR) classification for use in the ArcInfo model for American marten. 76

B Recent and historic fire history (1920-2006) patterns in Sequoia and Kings Canyon National Park displayed by decade. This map reflects extent but not severity of the fires and includes prescribed, natural and accidental sources of ignition. Sites surveyed for forest carnivores between 2002 and 2004 are shown with corresponding detections of American marten and fisher. Forest and shrub dominated habitats without associated fire history are shown in gray and rock dominated habitats are in white............... 77

C Diagrams for the Coroplast track plate box and open plate used in this project: (a) pattern to cut Coroplast, (b) folded box secured by binder clips, (c) pattern for "backdoor" to seal off baited end of box, and (d) open plate configuration using two 20.3 x 76.2 cm aluminum plates, flat wooden sticks, and binder clips. Box design attributed to Gomper et al. 2006 with help from Chet Ogan of PSW Research Station. Open plate developed from ideas in Fowler and Golightly 1994 and Zielinski 1995................................. 78

D Map of Sequoia and Kings Canyon National Parks with place names of base camps and other locations used in describing the distribution of carnivores detected during surveys in 2002, 2003, and 2004. Forest and shrub dominated habitats are shown in gray, while rock dominated habitats are shown in white... 79

E Habitat types, as classified by the California Wildlife Habitat Relationships (CWHR) system, at 395 stations surveyed for forest carnivores in Sequoia and Kings Canyon National Parks between 2002 and 2004. Habitat types are ordered by elevation, with foothill habitats at the bottom and alpine habitats at the top of the figure. The number of stations in each habitat type is noted at the end of the bar. 80

Appendix		Page
F	Detections of carnivores and one marsupial from surveys conducted in Sequoia and Kings Canyon National Parks, California using track plates and remote cameras. Sites (*n* = 79) were surveyed during summer the and fall of 2002, 2003, and 2004. Each site consisted of five stations and sites were checked every three days for fifteen days.	81
G	Distribution of sites with detections of carnivore and marsupial species by elevation from surveys conducted in Sequoia and Kings Canyon National Parks between 2002 and 2004. Elevations of the five stations at each site were averaged to represent the site, and elevations ranged from 614 to 3,536 m across sites (*n* = 79) surveyed. Vertical lines illustrate the range of detections for each species, gray bars signify ± 1 SD from the mean, and horizontal bars denote single detections.	82
H	Distribution of sites with detections of black bear (58), coyote (6), and mountain lion (1) in Sequoia and Kings Canyon National Parks, California. Sites (*n* = 79) were surveyed using track plates and remote cameras during 2002, 2003, and 2004. Forest and shrub dominated habitats are shown in gray and rock dominated areas are white.	83
I	Density of a subset of habitat elements for American marten from the California Wildlife Habitat Relationships model and boulder cover measured at survey stations in Sequoia and Kings Canyon National Parks. Characteristics were determined by tallies from two 50 x 10 m vegetation transects. Numbers presented are the mean density of five stations at each site where martens were identified as present (*n* = 29) or absent (*n* = 50).	84
J	Suitability grid created for use in the ArcInfo application of the California Wildlife Habitat Relationships system model for American marten. This input grid was created using digital vegetation data for habitat type, canopy cover, and a surrogate for tree size class in Sequoia and Kings Canyon National Parks. Numerical values represent habitat suitability for marten and range from 0 (unsuitable) to 1.0 (highly suitable). Sites surveyed during 2002, 2003 and 2004 and associated marten detections are also shown.	85
K	Description of habitat at sites in or adjacent to rock cover with detections of American marten in Sequoia and Kings Canyon National Parks.	86
L	California Wildlife Habitat Relationships (CWHR) system classifications of vegetation at 67 stations with detections of American marten from surveys in Sequoia and Kings Canyon National Parks between 2002 and 2004.	90

Chapter 1: Distribution and Habitat Associations of Forest Carnivores in Sequoia and Kings Canyon National Parks

Introduction

Many wildlife species in North America have declined as a direct result of excessive harvesting for commercial products such as feathers or fur (Mitchell 1994, Roland and Gots 2003) or indirectly through habitat loss and alteration (Nelson 1997, Jackson 2002). Some species, such as American marten (*Martes americana*) and fisher (*M. pennanti*), have been confronted with both overexploitation by fur trappers and ongoing reduction of suitable habitat (Grinnell et al. 1937, Gibilisco 1994). Concern for these forest carnivores in western North America has prompted recent efforts to identify their current distribution (Aubry and Houston 1992, Zielinski et al. 2005) and habitat requirements (Bull and Heater 2000, Zielinski et al. 2004a). As the structure and continuity of North American forests have changed considerably over the last century (Hemstrom 2003), a comparison of historic and current occurrence of these species may assist future conservation efforts (Aubry and Houston 1992, Zielinski et al. 2005).

Most historic records of marten and fisher in California come from the Sierra Nevada and northwestern coastal forests (Grinnell et al. 1937). Reports of martens were typically from higher elevations than fishers, but some overlap in geographic distribution and habitat use was noted (Grinnell et al 1937, Schempf and White 1974). Martens continue to occur throughout much of their former range in California (Kucera et al. 1995), with the exception of northwestern forests where only a small population remains

(Slauson 2003). Recent evidence also suggests that the distribution of marten in the southern Cascades and northern Sierra Nevada has become fragmented (Zielinski et al. 2005). Fishers persist in northwestern forests (Carroll et al. 1999) and the southern Sierra Nevada (Boroski et al. 2002, Zielinski et al. 1995), but a large distributional gap in the northern half of the Sierra Nevada now separates these populations (Zielinski et al. 2005).

The legacy of historic trapping combined with a reliance on habitat characteristics typically found in older forests has led to conservation challenges for marten and fisher. In western North America, both species are generally associated with late-successional forests with extensive canopy closure (Buskirk and Ruggiero 1994, Powell and Zielinski 1994) and they use large woody structures (e.g., snags, live trees with cavities) for resting (Spencer 1987, Seglund 1995) and denning (Powell et al. 2003). Martens and fishers also have large home ranges for their body size and occur at low densities (Buskirk and Ruggiero 1994, Powell and Zielinski 1994). These ecological traits have the potential to put habitat conservation for these species in conflict with timber harvest.

Marten and fisher have received limited protection in California. Trapping of either species has been illegal for over 50 years (except on tribal lands, M. Higley, Hoopa Tribal Forestry, personal communication), but historic trapping has had lasting impacts in some areas (Buskirk and Ruggiero 1994, Powell and Zielinski 1994). Both species are classified as sensitive by National Forests in the west, a designation which stipulates that viable populations be maintained on those lands (Buskirk and Ruggiero 1994, Powell and Zielinski 1994). In 2004, a petition to protect the west coast fisher population (*M. p. pacifica*) under the Endangered Species Act of 1973 yielded a decision that listing was

justified but not granted due to priority status of other species (Fish and Wildlife Service 2004). National Parks which encompass areas historically used by marten and fisher (Grinnell et al. 1937, Schempf and White 1974) provide some protected forest reserves.

As much of the research on marten and fisher in California has taken place on lands where timber harvest is a management objective (Slauson 2003, Zielinski et al. 2004a, Yaeger 2005, Zielinski et al. 2005), new studies in protected forests could complement previous work. Compared to historic conditions, the greatest relative concentrations of high-quality late-successional forests in the Sierra Nevada are in Sequoia, Kings Canyon, Yosemite and Lassen Volcanic National Parks (Franklin and Fites-Kauffman 1996). Sequoia and Kings Canyon also have: historic records of marten and fisher (Schempf and White 1974), forests largely untouched by timber harvest, a high proportion of designated wilderness, and ongoing efforts to retain fire as an ecosystem process (National Park Service 1996).

The primary objective of this study was to determine the distribution and habitat associations of American marten and fisher in Sequoia and Kings Canyon National Parks (hereafter, Parks). A secondary objective was to document occurrence of other mesocarnivores in the area. Particular species of concern were wolverine (*Gulo gulo*) and Sierra Nevada red fox (*Vulpes vulpes necator*), both of which occurred in the Parks historically but have become extremely rare (Schempf and White 1974). Records of other small carnivores were of interest to better understand the ecology of these species and the carnivore community in which martens and fishers occur (Buskirk and Zielinski 2003, Campbell 2004).

Methods

Study area

Sequoia and Kings Canyon National Parks are located in the southern Sierra Nevada of California. The Parks are managed as one unit, contain just over 350,160 ha, include elevations from approximately 500 to 4,400 m, and are surrounded by lands managed by the Inyo, Sequoia, and Sierra National Forests (National Park Service 1996). Sequoia National Park and General Grant National Park (precursor to Kings Canyon National Park) were established in 1890, with substantial additions in 1926 and 1940 (National Park Service 1996). A wide variety of habitats occur across the elevation gradient, including chaparral- and oak-dominated communities in the foothills, mixed conifer forest and giant sequoia groves (*Sequoiadendron giganteum*) at mid-elevations, red fir (*Abies magnifica*) and lodgepole pine (*Pinus contorta*) forests in the subalpine zone, and alpine lakes surrounded by peaks of granite at the highest elevations (Appendix A). Over 84% of the land is designated wilderness (National Park Service 1996). Road access is confined to the western half of the Parks and prescribed and naturally ignited fires are the primary disturbance factors in forested areas (Appendix B).

Detection of carnivores

I conducted field work between late May and mid-October in 2002, 2003 and 2004. Sample units (hereafter, sites) were selected using a 5 km sampling grid created in a Geographic Information System (GIS) in ArcView (Version 3.3, Environmental Systems Research Institute Inc., Redlands, CA). The 5 km distance was based on marten home range size, such that detection of an individual at one location should be

independent of one 5 km away (Zielinski and Stauffer 1996). Fisher detections ≥10 km apart should represent different individuals based on home range size (Zielinski and Stauffer 1996). Each site contained five detection devices (hereafter, stations) which were arranged in the shape of a cross: three enclosed track plates, one open plate, and one remote camera. An enclosed track plate was placed at the center of the cross as close to the 5 km grid-based Universal Transverse Mercator (UTM) coordinates as possible using a global positioning system (e-trex model, Garmin International Inc., Olathe, KS, mean accuracy <10 m). The four remaining stations were randomly assigned to cardinal directions and placed 150 m from the center, a distance which could be extended up to 250 m as needed (e.g., to find a suitable tree for a camera).

If a site occurred in a narrow canyon or next to a water barrier, outer stations were either rotated 90 degrees or one outer station was moved ≥150 m away from another outer station (changing the site's shape from a "+" to a "T"). These adjustments allowed the site to fit in the terrain but still cover the same area. Due to the rugged topography in the Parks, central coordinates were moved slightly if possible or omitted to maintain safe conditions for surveyors. Of 150 grid points that fell within or on the boundary of the Parks, only about half could be surveyed, so efforts were prioritized using the following criteria: represent different geographic areas of the Parks, focus on forests but include other available habitat types, and narrow final selection of grid points to areas with safe access for surveyors. A comparison of possible survey sites to overall habitat availability prior to field work suggested that barren would be the main habitat underrepresented, as rocky high elevation peaks and basins made up nearly 40% of the landscape. Martens

and fishers are generally associated with dense forest (Powell et al. 2003), so I surveyed only a small proportion of the available barren habitat.

Track plate boxes were constructed from pieces (81 x 112 cm) of lightweight black plastic (Coroplast, Towers Marketing, Eugene, OR) folded into boxes with 25 x 25 cm openings and closed at the baited end (Gompper et al. 2006, Appendix C). In the field, boxes were placed against logs, trees, or rocks and natural materials were used to stabilize and shade devices from the sun. Aluminum track plates (0.15 x 20.3 x 76.2 cm) were covered with soot from an acetylene torch. White shelving paper (23 x 28 cm pieces, Con-tact, Kittrich Corp., La Mirada, CA) was attached 10 cm from the baited end with the adhesive side up (Fowler and Golightly 1994, Zielinski 1995).

Open plates and remote cameras were included to provide a means of detecting wolverine (Kucera et al. 1995, Zielinski 1995). Open plates consisted of two aluminum track plates arranged side by side and held in place by three flat sticks (2.5 x 40.5 cm) secured underneath and perpendicular to the plates by binder clips (Appendix C). Unlike other open plate designs, the same size aluminum plates as described for enclosed stations (complete with shelving paper) were used, which simplified plate replacement and improved track quality. When possible, open plates were placed in areas where natural materials (e.g., trees, logs, rocks) provided some cover from rain, channeled animals towards the sooted ends of the plates, and hindered them from getting the bait without leaving tracks. Natural materials were used to block the sides and baited end of open plates.

A single passive infrared sensor and a 35 mm camera (TM35-1 Olympic camera, TrailMaster, Goodson and Associates, Inc., Lenexa, KS) were deployed at each site and attached to a tree or rock with webbing and duct tape (Scotch duct tape, 3M Canada, London, Ontario, Canada). Sensors exposed to direct sun and wind could be falsely activated to take pictures, so protected areas were selected where available. If numerous false activations occurred during the day at sites with little cover, sensors were adjusted to take pictures only between dusk and dawn.

A survey consisted of the initial establishment of the site followed by monitoring and re-baiting every three days for a total of fifteen days. This survey duration was shorter than recommended by some studies (Fowler and Golightly 1994), but reflected a reasonable compromise to optimize detection probability (Zielinski 1995) and minimize costs of working in remote areas. Track plates were baited with half a can (81.3 ml) of chicken-flavored canned cat food (9-Lives brand Chicken Dinner) mixed with 5 ml of lard to delay desiccation. A small amount of Gusto™ (2.5 ml), a commercial skunk-scented lure (Minnesota Trapline Products, Pennock, MN), mixed with lanolin was placed next to the bait on a flat piece of bark or rock inside the enclosed track plate or at the back of the open plate. Camera stations were baited with a punctured can of cat food attached to a tree or rock using an elastic cord, with the Gusto mixture applied a few centimeters above the bait. Stations were re-baited on each visit and dry or maggot-infested cat food was removed from the site. The Gusto mixture was agitated with a stick on each visit and additional lure was applied as needed to maintain an odor perceptible to surveyors.

During each visit, all carnivore tracks on the contact paper were collected. Tracks in soot were burnished using clear packing tape and placed on paper (Zielinski 1995). At sites where black bears (*Ursus americanus*) repeatedly destroyed more than three devices, reducing the chances of detecting other species, stations were not re-baited for one visit and Gusto was used as the only attractant. This technique was used infrequently (33 or 1.7% of all trap nights at 7 of 79 sites), but Gusto alone was still able to attract marten and fisher. Mean latency to first detection (the length of time before a species was first detected at a site) was calculated using both number of days (based on a visit every third day for 15 days) and number of visits (based on 5 visits).

Sampling design and survey methods were derived from a protocol used by the Pacific Southwest Research Station (Zielinski et al. 2000), with adjustments made to accommodate the logistic challenges associated with remote roadless areas. Alterations to the original protocol included a decrease in size of the sampling grid from 10 to 5 km, a reduction in the number of detection devices at each sample unit from six to five, and an increase in proximity of devices from 500 to 150 m from a central point at the site.

I identified carnivore tracks with the assistance of example tracks (Zielinski 1995), tracking manuals (Elbroch 2003), and reference measurements (Taylor and Raphael 1988, Zielinski and Truex 1995). Researchers from Pacific Southwest Research Station (B. Zielinski, K. Slauson, T. Kirk, R. Schlexer) and Humboldt State University (R. Golightly) reviewed a representative sample of tracks for further verification. Weasel tracks could not be identified to species, so *Mustela* spp. was used to represent long- and short-tailed weasels (*M. frenata* and *M. erminia*), both of which occur in the Parks.

Stations with no identifiable tracks or photos, but a considerable amount of disturbance (e.g., box smashed, camera torn from tree), were classified as black bear detections. Detections of Virginia opossum (*Didelphis virginiana*), a non-native marsupial, were included as this species plays a similar role to carnivores in the ecosystem and has been reported in similar surveys (Zielinski et al. 2005).

Vegetation classification and statistical analyses

Classifications of habitat type, tree size class, and canopy cover were based on descriptions in the California Wildlife Habitat Relationships (CWHR) system vegetation manual (Mayer and Laudenslayer 1988). Habitat type, tree size class, and canopy cover were visually estimated by one individual based on vegetation within a 25 m-radius of each station. CWHR tree size class categories, names, and diameter at breast height (dbh) measurements were as follows: class 1 (seedling tree, <2.5 cm), class 2 (sapling tree, 2.5-15.0 cm), class 3 (pole tree, 15.2-27.7 cm), class 4 (small tree, 27.9-60.7 cm), class 5 (medium/large tree, ≥61.0 cm), class 6 (multilayered tree, a distinct layer of class 5 trees over distinct layer of class 4 or 3, and total canopy cover ≥60%). A dbh tape was used periodically to calibrate the observer's estimates. CWHR canopy cover categories used were sparse (10.0-24.9%), open (25.0-39.9%), moderate (40.0-59.9%), and dense (>60.0%). Areas of <10% tree cover qualified as barren, meadow or shrub as was fitting.

The designation of a CWHR category to represent a site was based on the most common habitat type, tree size class, and canopy cover category present at the five survey stations. Assigning a dominant classification was straightforward in most cases, but a few sites with greater heterogeneity across stations (e.g., river canyons, forest-alpine

edges) were more difficult. As an example, 54% of sites had all 5 stations in one habitat type, 25% had 4 stations in the same habitat, 19% had 3 stations in a single habitat, and 1% had only 2 stations in the same habitat. Therefore, habitat classifications are reported by site, with additional information on stations where appropriate. Assessment of use compared with availability of habitat type was not feasible due to small sample sizes, but comparison of habitat types surveyed relative to species detected in them was possible using a Jaccard's similarity coefficient

$$S_j = \frac{a}{a + b + c}$$

where S_j is the similarity coefficient, a is the number of joint occurrences in habitats A and B, b is the number of species in habitat B but not in habitat A, and c is the number of species in habitat A but not in habitat B (Krebs 1989).

Chi-squared tests of independence or two-tailed Fisher's exact tests were calculated for tree size class and canopy cover categories where appropriate for species detected at ≥10% of all sites. For canopy cover, expected values for species were compared between sites with dense and moderate cover (≥40%) and those with open, sparse or no cover (<40%). Expected values for species at sites in tree size classes 5 and 6 were compared with those of tree size classes 3 and 4.

Statistical analyses were conducted using NCSS (NCSS 2004) and Microsoft Office Excel (Microsoft Corporation, Redmond, WA). Protocols for survey methods were approved by the Institutional Animal Care and Use Committee (Humboldt State University, #01/02.W.121.0).

Results

Surveys were conducted at 79 sites from 2002 to 2004 (Figure 1, Appendix D). Thirteen habitat types were dominant at ≥1 site (Table 1), with 17 habitat types represented at ≥1 station (Appendix E). Mean elevation at sites ranged from 610 to 3,540 m. American marten, fisher, ringtail (*Bassariscus astutus*), Western spotted skunk (*Spilogale gracilis*), gray fox (*Urocyon cinereoargenteus*), weasel spp., raccoon (*Procyon lotor*), black bear, mountain lion (*Felis concolor*), coyote (*Canis latrans*), Virginia opossum and domestic dog (*Canis familiaris*) were detected (Appendix F). No detections of wolverine or Sierra Nevada red fox occurred. Habitat types distributed at adjacent elevations were more similar to each other in carnivore species composition than those separated by elevation. Species composition was most similar in red fir and montane riparian forest (80%) and least similar in hardwood forest and barren areas (0%, Table 2). Sites surveyed included habitat patches within or bordering areas with recent and historic documentation of fire (Appendix B).

American martens were detected at 36.7% of sites in elevations from 1,800 to 3,340 m (Appendices F and G). Mean latency to first detection at a site was 6.1 days (SD = 4.6) or 2.0 visits (SD = 1.6). Martens occurred across the nearly continuous forests of the western slope and in the matrix of riparian forest and boulder cover in eastern Sequoia and northern Kings Canyon National Parks (Figure 1). Martens were present at sites dominated by Sierran mixed conifer (28%), red fir (24%), lodgepole pine (21%), subalpine conifer (10%), montane riparian (10%), and barren habitat types (7%, Table 1).

In two cases, martens were detected at stations in habitat types not represented by the dominant classifications: a site denoted as red fir had detections only at stations in subalpine forest and a site classified as lodgepole had detections at stations in barren and aspen habitats. A high proportion (72%) of marten detections were at sites with ≥40% canopy cover, but not more than expected compared to those in <40% cover ($\chi^2 = 2.10$, $P = 0.15$, Table 3). Notably, all sites with detections in barren habitat and those with <40% canopy cover were above 2,800 m in areas with boulder or shrub cover. Martens were found more often than expected at sites in tree size classes 5 and 6 compared to classes 3 and 4 ($\chi^2 = 4.96$, $P = 0.03$, Table 4). Other species detected at sites with martens were black bear (25), coyote (1), fisher (2), mountain lion (1), weasel sp. (2), and western spotted skunk (5).

Fishers were detected at 11.4% of sites in elevations from 1,000 to 2,870 m (Appendices F and G). Mean latency to first detection at a site was 9.0 days (SD = 5.0) or 3.0 visits (SD = 1.7). The majority of fisher detections occurred in the western half of the Parks in areas of relatively continuous forest (Figure 1). Fishers were detected at sites dominated by Sierran mixed conifer (56%), montane hardwood (22%), subalpine conifer (11%), and white fir habitat types (11%, Table 1). Most stations with detections were in the dominant habitat type, but at one site classified as montane hardwood the two stations with detections were in montane hardwood-conifer. Fishers were found at sites with ≥40% canopy cover more often than expected compared to sites with <40% cover (Fisher's $P = 0.01$, Table 3), but they were not detected at sites in tree size classes 5 and 6 more than expected compared to sites in classes 3 and 4 (Fisher's $P = 0.29$, Table 4).

Fishers were present at sites with detections of black bear (9), marten (2), ringtail (1), and western spotted skunk (1).

Five other small carnivores were detected during the surveys and are described as they occurred from low to high elevations (Figure 2, Appendices F and G). Ringtails were detected at 3.8% of sites at elevations from 840 to 1,320 m. Ringtails occurred at forested sites with hardwoods, dense canopy and size class 4 trees (Tables 1, 3, 4). All three sites with ringtail detections contained rocky outcrops and either encompassed or bordered a stream or river. Gray foxes were detected at 6.3% of sites at elevations from 600 to 2,170 m. Gray foxes occurred at sites in hardwood and conifer forests with dense or open canopy cover and small to large size trees (Tables 1, 3, 4). Western spotted skunks were detected at 11.4% of sites in elevations from 1,900 to 2,830 m. Spotted skunks were found at sites in conifer dominated habitat types, predominantly in dense canopy cover with small to large size trees (Tables 1, 3, 4), but they were not found at sites in different tree size classes or canopy cover categories more often than expected (Fisher's $P = 0.14$). Weasels were detected at 13.9% of sites in subalpine conifer, lodgepole, montane riparian and red fir forests between 2,000 to 3,420 m (Table 1). Weasels occurred at sites with sparse to moderate canopy cover, small to large size trees (Tables 3 and 4), and nearly all (91%) sites also contained a stream or river. Weasels did not occur at sites in different tree size classes or canopy cover categories more often than expected (Fisher's $P = 0.09$). A raccoon was detected by camera in lodgepole forest near a stream and trail at 3,400 m (over 30 km from a trailhead), and a Virginia opossum was detected by camera at a site in blue oak woodland along a stream at 710 m (Figure 2).

Although techniques were not targeted for large carnivores, black bears, coyotes, and mountain lions were all detected during the surveys (Appendices F, G, H). Bears occurred at more sites (73.4%), in more habitat types (11), and across a wider range of elevations (600 to 3,200 m) than any other carnivore (Tables 1, 3, 4). Bears were detected at sites with >40% canopy cover ($\chi^2 = 17.7$, $P < 0.001$) and at sites in tree size classes 5 and 6 (Fisher's $P = 0.022$) more often than expected. Generally the only sites without bear detections were at high elevations with little canopy cover. Coyotes were detected at 7.6% of sites at elevations from 2,610 to 3,430 m in subalpine and lodgepole forests (Table 1). Coyote pups were detected at enclosed and open track plates (verified by camera post-surveys) at one site and by camera only at a second site; both sites were in forests bordering meadows above 3,100 m. Coyote and domestic dog tracks can be hard to differentiate, but five of six sites with detections had photo verification of coyotes. A mountain lion with two kittens was photographed at a site in red fir on the Hockett Plateau at 2,670 m.

Discussion

Distribution and habitat associations of American marten

American martens were detected in two different geographic areas of the Parks: the nearly continuous mid- to high elevation forests on the western slope and the riparian forest-boulder matrix found in the higher elevations of eastern Sequoia National Park and the northern half of Kings Canyon National Park. This distribution was within Grinnell's range for the Sierran subspecies (Grinnell et al. 1937) and was comparable to historic locations from the region (Schempf and White 1974). Detections with no corresponding historic records occurred in the Grant and Sugarbowl sequoia groves on the western boundary and Volcanic and Glacier Lakes in central Kings Canyon National Park.

Although there was much agreement between the current and historic distribution of martens, several differences occurred. Grinnell et al. (1937) presented photos of subalpine forest near Wallace Creek and the Chagoopa Plateau in eastern Sequoia National Park as examples of good marten habitat, however, martens were not detected at those sites. In both cases martens were detected at sites 5 to 10 km away, but in riparian rather than subalpine forest. Sites in Sugarloaf Valley and Roaring River of southwestern Kings Canyon National Park also yielded no marten detections, though Shorty Lovelace trapped martens in that area up until 1940 (Tweed 1976). Potential explanations for lack of detections in previously used locations are that sites did not fall in the most suitable marten habitat in those areas or populations have not recovered from historic trapping.

Martens occurred in two somewhat distinct cover types found in geographically different areas of the Parks. At sites in the west and southwest (n = 16, mean elevation =

2,300 m), martens were detected in the nearly continuous band of Sierran mixed conifer, red fir and subalpine forest dominated by large tree size classes (5 and 6) and dense canopy cover. These western sites resembled the old-growth forest structure described elsewhere as typical marten habitat (Buskirk and Zielinski 2003). In northern and eastern portions of the Parks (n = 13, mean elevation = 2,900 m), martens occurred at sites in a matrix of lodgepole, montane riparian, subalpine, and red fir forests interspersed with boulder cover. In contrast with the western half of the Parks, most sites in the eastern and northern areas had smaller diameter trees (mean tree size class 4) and less canopy cover (range from <10 % to dense). In these areas, the small diameter trees reflected forest structure representative of high elevations (Hemstrom 2003) as opposed to regeneration from timber harvest. Forest cover in these higher elevations was less continuous, often occurring in linear patches along streams or around edges of lakes. In high elevation forest patches, martens may compensate for reduced canopy cover by using boulder fields and shrubs as alternate cover (Buskirk and Zielinski 2003). This idea is supported by reports of martens using rock slides and talus slopes during summer in the Sierra Nevada (Grinnell et al. 1937) and areas with abundant surface rocks in northwestern California (Slauson 2003).

Although my study was able to address some aspects of marten distribution, presence-absence data cannot identify the roles that different habitats and geographic areas play in regional population demographics. Sites with marten detections in continuous forest on the western slope tended to have a higher proportion of detections at stations (west, n = 16, 2.7 ± 1.6 SD; north-east, n = 13, 1.8 ± 1.3 SD) and site visits (west,

n = 16, 2.7 ± 1.6 SD; north-east, n = 13, 1.9 ± 1.4 SD) compared to sites in the north and east. Whether this reflects actual differences in population density, home range size, habitat quality, or seasonal movements of individuals in these two geographic areas is unclear. Based on track size (Slauson et al., in prep.), male and female martens were present in both geographic areas, but this too does not necessarily mean both areas are equally suitable for reproduction. Surveys were conducted only in summer and early fall, so I do not know whether martens using high elevations in the summer remain there or move elsewhere during the winter. However, radio-collared martens in the southern Cascades showed some evidence of seasonal differences in their use of habitat and a few individuals shifted their location on the landscape over time (Ellis 1998). From a management perspective, martens occurring in late-successional forests of the western slope may warrant the most attention because their habitat has a greater chance of being altered by human activities. However, marten use of habitats at high elevations raises interesting ecological questions regarding seasonal movements and alternative cover which also deserve investigation.

Distribution and habitat associations of fisher

Based on results of this study and historic records, fishers appear to have a more restricted distribution in the Parks compared to martens and were primarily associated with the continuous band of low to mid-elevation forest on the western slope. Current fisher detections fell within the historic range described for California (Grinnell et al. 1937) and overlapped with historic records in some areas (Schempf and White 1974). Grinnell et al. (1937) included two photographs as examples of fisher habitat from the

southwest portion of the Parks, one of hardwood-conifer forest near the Kaweah River northeast of Ash Mountain and another of mixed conifer forest in Giant Forest. I detected fishers at two sites near the section of the Kaweah River in Grinnell's photo. Although no fishers were detected in Giant Forest, they occurred at sites in similar mixed conifer habitat 10 km northwest of that area. Finally, nearly all fishers detected occurred near boundaries with National Forests, underscoring the need for regional cooperation in developing fisher conservation plans in this area.

The distribution of fisher detections in the Parks generally corresponded to historic records, with a few exceptions. A lack of detections around Giant Forest may have been the result of recurrent damage to detection devices by bears during surveys, as fishers were recorded in the area historically (Schempf and White 1974), the habitat was comparable to other sites with detections (Sierran mixed conifer, tree size class 6, dense canopy), and a fisher was found dead on the road near Giant Forest in 2003 (pers. obs.). A fisher detected at Coyote Creek west of the Kern River had no corresponding historic records in southeastern Sequoia National Park (Schempf and White 1974). Historic and recent records suggest that low to mid-elevation hardwood-conifer and mixed conifer forests in southwestern Sequoia National Park are also likely suitable for fishers (Werner 1998, Zielinski et al. 2000). Unfortunately, sites in that area were omitted from my study as illegal cultivation of marijuana created safety concerns for surveyors.

All sites with fisher detections occurred in areas with moderate or dense canopy cover, consistent with previous studies (Carroll et al. 1999). Fishers were detected at sites (67%) in middle elevation coniferous forests and sites (67%) in the largest tree size

classes (5 and 6), although this later result was not different than expected based on availability within sites surveyed. Historic records (Schempf and White 1974) and radio telemetry studies from the region (Mazzoni 2002, Zielinksi et al. 2004a) suggested that Sierran mixed conifer forest with extensive canopy closure and large trees may be important for fisher in the southern Sierra Nevada, findings which are consistent with my investigation. Although this habitat type is dominated by conifers, it also contains California black oak (*Quercus kelloggii*) which may be of value to fishers as a source of cavities and food for prey (Zielinksi et al. 2004a). Detections at sites in montane hardwood forest are also noteworthy because only a small percentage of sites (6%) occurred in that habitat and the site most frequently visited by fishers (4 of 5 visits) was in a mix of montane hardwood and hardwood-conifer forest. Notably, all of the montane hardwood sites either bordered mixed chaparral or had extensive shrub cover within the site. A large proportion of sites with detections had a hardwood component (78%) and bordered a stream (78%); this is similar to results found in other studies (Seglund 1995, Carroll et al. 1999, Zielinski et al. 2004b). The highest elevation fisher detection was in subalpine forest at 2,870 m (a male based on track size, Slauson et al., in prep.). Across the three survey seasons, twelve sites (15%) were surveyed in subalpine forest and only one had a fisher detection, suggesting that subalpine forest may be used infrequently.

As with martens, presence-absence data cannot answer many questions related to why fishers occur in some areas but not others, or why they select certain habitats. Although fishers may hunt in the same habitat patches where they find rest sites (Dark 1997), they have also been known to forage in areas that are different from where they

rest or den (Powell et al. 2003). Thus, habitat classifications from sites with detections in this study may represent a combination of foraging and resting habitat used by fishers in the Parks. Radio-telemetry studies conducted on neighboring lands in the southern Sierra Nevada suggested that fishers need forest patches with large diameter trees and dense canopy cover for resting and denning (Mazzoni 2002). However, their home ranges may also contain areas with smaller trees (size classes 3 and 4) and moderate canopy cover (Zielinski et al. 2004a) used for foraging or travel. The low number of detections in this study did not allow for a detailed habitat analysis, but the habitat types, canopy cover categories, and tree size classes used are similar to those used by radio-collared fishers in the region (Mazzoni 2002, Zielinski et al. 2004a).

Occurrence of other carnivores

Habitat associations and distribution of other small carnivores were generally comparable to other studies from western North America, with a few detections at higher elevations than have been reported elsewhere. Ringtails were not widespread and occurred only in low elevation forests with a hardwood component, riparian area, and rocky outcrops, as noted previously (Buskirk and Zielinski 2003, Gehrt 2003). Gray foxes were not widely distributed in the Parks compared to surveys conducted further north, but they were associated with similar habitat types including hardwood, pine, and mixed conifer forest (Zielinski et al. 2000). In my study, gray fox and fisher were not ever detected at the same sites (fisher, $n = 9$ sites, gray fox, $n = 5$ sites), potentially supporting Campbell's (2004) suggestion that fisher may displace gray fox in some areas. Western spotted skunks were detected in mixed conifer forests as seen elsewhere (Carroll

1997, Zielinski et al. 2000, Campbell 2004), but also occurred in montane riparian, montane chapparal, and red fir habitats. Western spotted skunks have typically been found at low to mid-elevations (Orr 1943, Carey and Kershner 1996, Carroll 1997), but in the Parks they occurred in elevations up to 2,830 m, a potential new elevation record (Rosatte and Lariviere 2003). Weasels were detected in mid- to high elevation forests and near streams or small meadows, as described elsewhere (Svendsen 2003). The raccoon detection at a remote high elevation site had no associated historic records, but was near the Pacific Crest Trail with much human activity.

Detections of black bears were numerous, wide-spread, and occurred throughout the survey period, a pattern which supports current regulations requiring proper food storage in all areas of the Parks. Coyotes have been known to use high elevation forests in recent and historic times (Grinnell et al. 1937, Buskirk and Zielinski 2003), but little documentation exists regarding pup-rearing in these areas. Although coyotes were not detected in the low and middle elevations on the west side of the Parks, they were heard, seen, and identified by tracks in these areas during the survey period (pers. obs.). Thus, detections from this project do not reflect the full distribution of coyotes in the Parks. Coyotes, potential predators of martens (Bull and Heater 2001), were detected at a few high elevation sites near historic records of martens, but the two species both occurred at only one site. Little can be said about mountain lions in the Parks from a single detection except to verify their presence and acknowledge that the methods used were inadequate to detect lions or coyotes reliably. Anecdotally, one lion was observed and tracks were

seen in low to middle elevation forests during this project, including tracks on trails near twelve of the sites (pers. obs.).

The Virginia opossum was introduced west of Sequoia National Park around 1920 and has gradually moved east (Grinnell et al. 1937). Evidence from other presence-absence surveys suggests that this non-native marsupial has expanded its range in the northern Sierra Nevada (Zielinski et al. 2005), but only one was detected in this study near the western boundary of Sequoia National Park.

Geographic areas and habitat types historically occupied by Sierra Nevada red fox and wolverine were included in the scope of this project (Grinnell et al. 1937, Schempf and White 1974), but neither species was detected. This lack of evidence does not verify their absence in the Sierra Nevada, but adds to a growing number of surveys in which they were not detected (B. Hudgens, Institute for Wildlife Studies, unpubl. data, Kucera and Barrett 1993, Zielinski et al. 2005). Sierra Nevada red foxes were reportedly not common in the Parks even in historic times (Grinnell et al. 1937), however, Schempf and White (1974) documented nearly as many records for wolverine as for marten and fisher. Wolverines were reportedly seen, shot, or trapped in the vicinity of the Parks every few years in the early 1900s, but since the 1940s reports have been infrequent and often inconclusive (Grinnell et al. 1937, Schempf and White 1974). Given the lore and mixed emotions that humans associate with wolverines, it can be hard to separate fact from fiction in old records and unverified sightings today. The Parks still keep reports of red fox and wolverine on file, but the lack of verifiable evidence (e.g., scat, track, photo) in recent years leaves the question of their fate unanswered but not promising in this area.

Management implications and research needs

Although surveys from my project do not translate directly to population parameters, the widespread pattern of detections suggests that martens may be faring better in the Parks than in northern coastal forests or the northern Sierra Nevada (Zielinski et al. 2001, Zielinski et al. 2005). As martens were found in both late-successional forests and the forest-boulder matrix at high elevations, they appear to have more suitable habitat available to them in the Parks than do fishers. If fishers are really restricted to a smaller geographic area of the Parks than martens and have larger home ranges (Powell et al. 2003), maintaining a fisher population in the Parks may depend on a network of continuous suitable habitat across several land ownerships in the region.

The habitat within Sequoia and Kings Canyon National Parks is protected to a great extent, however, there are still potential threats to martens and fishers. Even sizeable national parks may not be able to maintain viable populations of carnivores with large home ranges in the long term if they can only rely on habitat available within their boundaries (Newmark 1985). Timber harvest and catastrophic fires in forest types used by marten and fisher outside of Park boundaries may decrease habitat suitability within the Parks and cause fragmentation. The Parks' active fire program includes annual low to moderate intensity prescribed and natural fires (Appendix B). However, the risks and benefits associated with prescribed and natural fires for marten and fisher are poorly understood. Potential benefits include creation of new snags, reduced chance of catastrophic wildfire, and a temporary increase in prey. Risks may include displacement, loss of live trees and snags, and potential death of kits if fires occur in the spring (Shaffer

and Laudenslayer 2006). Both martens and fishers have been killed by cars in the Parks (pers. obs., Rachel Mazur, National Park Service, pers. com.), including during the survey period. Although the Parks contain few roads, those that exist run through habitat types and geographic areas with detections of both species. While these issues may impact martens, they may be of special concern for fishers which occur almost entirely in habitat types regionally harvested for timber, in elevations at risk from wildfires, and near Park boundaries (Sierra Nevada Ecosystem Project 1996).

To improve our ability to create effective conservation plans for forest carnivores in Sequoia and Kings Canyon National Parks and the southern Sierra Nevada in general, further research is needed in several areas. First, data from my project could be combined with other spatial data from the region to identify habitat characteristics associated with these species at broader spatial scales. Periodic monitoring should be conducted to ensure that martens and especially fishers persist in areas where they currently occur. If resources are limited, priority should be given to surveying hardwood, hardwood-conifer, Sierran mixed conifer, and red fir forests between 1,000 to 2,500 m in the western half of the Parks. As the technique improves, hair snares may provide a means to determine population parameters (Zielinski et al. 2006). More information is needed on habitat used by female martens and fishers during reproduction, juvenile dispersal, effects of fire on habitat suitability and survival of fishers, and marten ecology at high elevations. Finally, questions still exist regarding the ecology of the lesser studied small carnivores and the status of wolverine and Sierra Nevada red fox in the region.

Literature cited

Aubry, K. B. and D. B. Houston. 1992. Distribution and status of the fisher (*Martes pennanti*) in Washington. Northwestern Naturalist 73:69-79.

Borowski, B. B., R. T. Golightly, A. K. Mazzoni, and K. A. Sager. 2002. Fisher research and the Kings River sustainable forest ecosystems project: current results and future efforts. Pages 143-154 *in* J. Verner, editor. Proceedings of the Symposium on the Kings River Sustainable Forest Ecosystems Project: Progress and Current Status. United States Forest Service, Pacific Southwest Research Station, General technical report PSW-GTR-183. Albany, California, USA.

Bull, E. L., and T. W. Heater. 2000. Resting and denning sites of American martens in Northeastern Oregon. Northwest Science 74:179-185.

Bull, E. L., and T. W. Heater. 2001. Survival, causes of mortality, and reproduction in the American marten in northeastern Oregon. Northwestern Naturalist 82:1-6.

Buskirk, S. W., and L. F. Ruggiero. 1994. American 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. United States Forest Service, General technical report RM-254, Rocky Mountain Forest and Range Experimental Station, Fort Collins, Colorado, USA.

Buskirk, S. W., and W. J. Zielinski. 2003. Small and mid-sized carnivores. Pages 207-249 *in* C. J. Zabel and R. G. Anthony, editors. Mammal community dynamics: Management and conservation in the coniferous forests of western North America. Cambridge University Press, Cambridge, United Kingdom.

Campbell, L. A. 2004. Distribution and habitat associations of mammalian carnivores in the central and southern Sierra Nevada. Dissertation, University of California, Davis, California, USA.

Carey, A. B., and J. E. Kershner. 1996. *Spilogale gracilis* in western Washington and Oregon. Northwestern Naturalist. 77:29-34.

Carroll, K. N. 1997. Maco-and microhabitat characteristics of the western spotted skunk, *Spilogale gracilis*, in the Sierra Nevada of Northern California. Thesis, California State University, Sacramento, California, USA.

Carroll, C., W. J. Zielinski, and R. F. Noss. 1999. Using presence-absence data to build and test spatial habitat models for the fisher in the Klamath Region, USA. Conservation Biology 13:1344-1359.

Dark, S. 1997. A landscape scale analysis of mammalian carnivore distribution and habitat use by fisher. Thesis, Humboldt State University, Arcata, California, USA.

Elbroch, M. 2003. Mammal tracks and sign: a guide to North American species. Stackpole Books, Mechanicsburg, Pennsylvania, USA.

Ellis, L. M. 1998. Habitat-use patterns of the american marten in the southern Cascade Mountains of California, 1992-1994. Thesis, Humboldt State University, Arcata, California, USA.

Fish and Wildlife Service. 2004. Endangered and threatened wildlife and plants; 12-month finding for a petition to list the west coast distinct population segment of the fisher (*Martes pennanti*); proposed rule. Federal Register, 69 (68), Sacramento, California, USA.

Fowler, C. H., and R. T. Golightly. 1994. Fisher and marten survey techniques on the Tahoe National Forest. State of California Department of Fish and Game, Nongame bird and mammal section report 94-9, Arcata, California, USA.

Franklin, J. F., and J. A. Fites-Kaufmann. 1996. Assessment of late-successional forests of the Sierra Nevada. Sierra Nevada Ecosystem Project: Final report to congress, vol. II, assessments and scientific basis for management options. University of California, Davis, California, USA.

Gehrt, S. 2003. Raccoon: *Procyon lotor* and Allies. Pages 611-634 *in* G. A. Feldhamer, B. C. Thompson and J. A. Chapman, editors. Wild Mammals of North America: biology, management and conservation. Johns Hopkins University Press, Baltimore, Maryland, USA.

Gibilisco, C. J. 1994. Distributional dynamics of modern *Martes* in North America. Pages 59-71 *in* S. W. Buskirk, A. S. Harestad, M. G. Raphael, and R. A. Powell, editors. Martens, sables, and fishers: biology and conservation. Cornell University Press, Ithaca, New York, USA.

Gompper, M. E., R. W. Kays, J. C. Ray, S. D LaPoint, D. A. Bogan, and J. R. Cryan. 2006. A comparison of noninvasive techniques to survey carnivore communities in Northeastern North America. Wildlife Society Bulletin 34:1142-1151.

Grinnell, J., J. S. Dixon, and J. M. Linsdale. 1937. Fur-bearing mammals of California: their natural history, systematic status, and relations to man. Volume 1, 2. University of California, Berkeley, California, USA.

Hemstrom, M. A. 2003. Forests and woodlands of western North America. Pages 9-40 *in* C. J. Zabel and R. G. Anthony, editors. Mammal community dynamics: Management and conservation in the coniferous forests of western North America. Cambridge University Press, Cambridge, United Kingdom.

Jackson, J. A. 2002. Ivory-billed woodpecker (*Campephilus principalis*). Number 711 *in* A. Poole, editor. The Birds of North America. American Ornithologists' Union, Washington, D. C., USA.

Krebs, C. J. 1989. Ecological methodology. Harper and Row, New York, New York, USA.

Kucera, T. E. and R. H. Barrett. 1993. The California cooperative wolverine survey: a progress report. Transactions of the Western Section of the Wildlife Society 29:49-53.

Kucera, T. E., W. J. Zielinski, and R. H. Barrett. 1995. Current distribution of the American marten, *Marten americana*, in California. California Fish and Game 81: 96-103.

Mayer, K. E., and W. F. Laudenslayer. 1988. A guide to wildlife habitats of California. California Department of Forestry and Fire Protection, Sacramento, California, USA.

Mazzoni, A. K. 2002. Habitat use by fishers (*Martes pennanti*) in the southern Sierra Nevada, California. Thesis, California State University, Fresno, California, USA.

Mitchell, C. D. 1994. Trumpeter swan (*Cygnus buccinator*). Number 105 *in* A. Poole, editor. The Birds of North America. American Ornithologists' Union, Washington, D. C., USA.

National Park Service. 1996. Sequoia National Park: Official National Park Handbook. Division of Publications, National Park Service, Washington, D.C., USA.

NCSS. 2004. Number Cruncher Statistical Systems, Kaysville, Utah, USA.

Nelson, S. K. 1997. Marbled murrelet (*Brachyramphus marmoratus*). Number 276 *in* A. Poole, editor. The Birds of North America. American Ornithologists' Union, Washington, D. C., USA.

Newmark, W. D. 1985. Legal and biotic boundaries of western North American National Parks: a problem of congruence. Biological Conservation 33:197-208.

Orr, R. T. 1943. Altitudinal record for the spotted skunk in California. Journal of Mammalogy 24:270.

Powell, R. A., S. W. Buskirk, and W. J. Zielinski. 2003. Fisher and marten. Pages 635-649 *in* G. A. Feldhamer, B. C. Thompson and J. A. Chapman, editors. Wild Mammals of North America: biology, management and conservation. Johns Hopkins University Press, Baltimore, Maryland, USA.

Powell, R. A., and W. J. Zielinski. 1994. Fisher. Pages 38-73 *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. United States Forest Service, General technical report RM-254, Rocky Mountain Forest and Range Experimental Station, Fort Collins, Colorado, USA.

Roland, K. and B. L. Gots. 2003. Seals. Pages 789-854 *in* G. A. Feldhamer, B. C. Thompson and J. A. Chapman, editors. Wild Mammals of North America: biology, management and conservation. Johns Hopkins University Press, Baltimore, Maryland, USA.

Rosatte, R., and S. Lariviere. 2003. Skunks. Pages 692-707 *in* G. A. Feldhamer, B. C. Thompson and J. A. Chapman, editors. Wild Mammals of North America: biology, management and conservation. Johns Hopkins University Press, Baltimore, Maryland, USA.

Schempf, P. F., and M. White. 1974. A survey of the status of seven species of carnivores on National Park Service lands in California. Wildlife-Fisheries Unit, Department of Forestry and Conservation, University of California, Berkeley, Califorina, USA.

Seglund, A. E. 1995. The use of resting sites by the Pacific fisher. Thesis, Humboldt State University, Arcata, California, USA.

Shaffer, K. E., and W. F. Laudenslayer. 2006. Fire and animal interactions. Pages 118-144 *in* E. G. Sugihara, J. W. van Wagtendonk, K. E. Shaffer, J. A. Fites-Kaufman, and A. E. Thode, editors. Fire in California ecosystems. University of California Press, Berkeley, California, USA.

Sierra Nevada Ecosystem Project. 1996. Final Report to congress. Centers for Water and Wildland Resources, University of California, Davis, California, USA.

Slauson, K. M. 2003. Habitat selection by American martens (*Martes americana*) in coastal northwestern California. Thesis, Oregon State University, Corvallis, Oregon, USA.

Slauson, K. M., R. L. Truex, and W. J. Zielinski. In Preparation. Distinguishing the sexes of American marten and fisher tracks at track plate stations.

Spencer, W. D. 1987. Seasonal rest-site preferences of pine martens in the northern Sierra Nevada. Journal of Wildlife Management 51:616-621.

Svendsen, G. E. 2003. Weasels and black-footed ferret. Pages 650-661 *in* G. A. Feldhamer, B. C. Thompson and J. A. Chapman, editors. Wild Mammals of North America: biology, management and conservation. Johns Hopkins University Press, Baltimore, Maryland, USA.

Taylor, C. A., and M. G. Raphael. 1988. Identification of mammal tracks from sooted track stations in the Pacific Northwest. California Fish and Game 74:4-15.

Tweed, W. C. 1976. Shorty Lovelace: Kings Canyon Fur Trapper. National Park Service, Western Regional Office, Division of Cultural Resource Management.

Werner, H. 1998. Mineral King Risk Reduction Project, 1998 Annual Report: Wildlife Monitoring. National Park Service, Sequoia-Kings Canyon National Parks, Three Rivers, California, USA.

Yaeger 2005. Habitat at fisher resting sites in the Klamath Province of Northern California. Thesis, Humboldt State University, Arcata, California, USA.

Zielinski, W. J. 1995. Track plates. Pages 67-89 *in* W. J. Zielinski and T. E. Kucera, editors. American marten, fisher, lynx, and wolverine: survey methods for their detection. United States Forest Service, Pacific Southwest Research Station, General technical report, PSW-GTR-157, Albany, California, USA.

Zielinski, W. J., T. E. Kucera, and R. H. Barrett. 1995. Current distribution of the fisher, *Martes pennanti*, in California. California Fish and Game 81:104-112.

Zielinski, W. J., F. V. Schlexer, K. L. Pilgrim, and M. K. Schwartz. 2006. The efficacy of wire and glue hair snares in identifying mesocarnivores. Wildlife Society Bulletin 34: 1152-1161.

Zielinski, W. J., K. M. Slauson, C. R. Carroll, C. J. Kent, and D. G. Kudrna. 2001. Status of American martens in coastal forests of the Pacific states. Journal of Mammalogy 82:478-490.

Zielinski, W. J., and H. B. Stauffer. 1996. Monitoring *Martes* populations in California: survey design and power analysis. Ecological Applications 6:1254-1267.

Zielinski, W. J., and R. L. Truex. 1995. Distinguishing tracks of marten and fisher at track-plate stations. Journal of Wildlife Management 59:571-579.

Zielinski, W. J., R. L. Truex, L. A. Campbell, C. R. Carroll, and F. V. Schlexer. 2000. Systematic surveys as a basis for the conservation of carnivores in California forests, Progress Report II: 1996-1999. United States Forest Service, Pacific Southwest Research Station, Arcata, California, USA.

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.

Zielinski, W. J., R. L. Truex, G. A. Schmidt, F. V. Schlexer, K. N. Schmidt, and R. H. Barrett. 2004a. Home range characteristics of fishers in California. Journal of Mammalogy 85: 649-657.

Zielinski, W. J., R. L. Truex, G. A. Schmidt, F. V. Schlexer, K. N. Schmidt, and R. H. Barrett. 2004b. Resting habitat selection by fishers in California. Journal of Wildlife Management 68: 475-492.

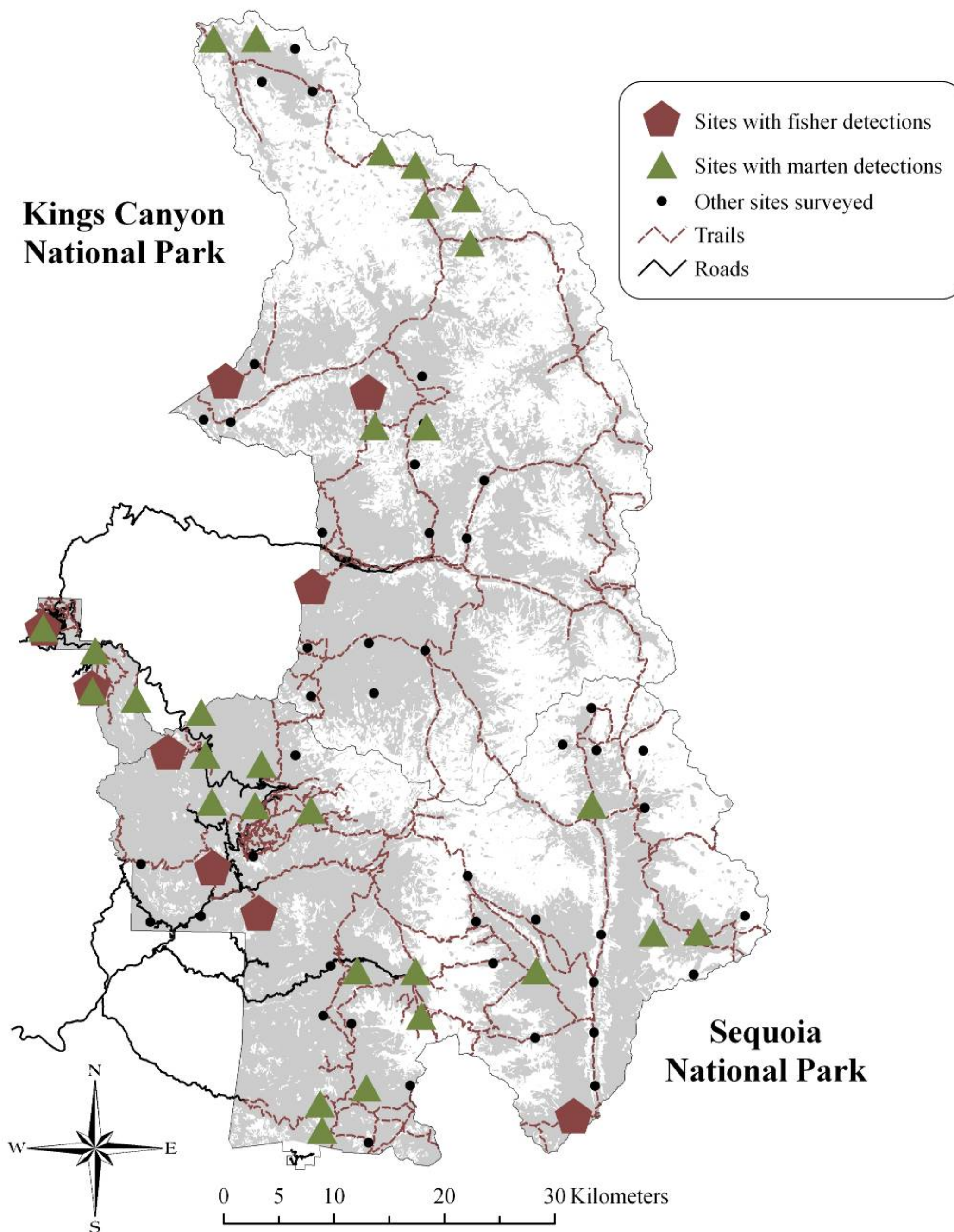


Figure 1. Distribution of sites with detections of American marten (29) and fisher (9) in Sequoia and Kings Canyon National Parks, California. Sites (*n* = 79) were surveyed using track plates and remote cameras during summer and fall of 2002, 2003, and 2004. Forest and shrub dominated habitats are shown in gray and rock dominated areas are white.

Table 1. Number of sites (n = 79) and associated habitat types where carnivores were detected in Sequoia and Kings Canyon National Parks, California between 2002 and 2004. Habitat types were classified according to the California Wildlife Habitat Relationships (CWHR) system and are ordered as they generally occur by elevation, with foothill habitats at the bottom and alpine habitats at the top of the table. Percentage of sites occurring in each habitat type relative to all sites surveyed is noted after each habitat type.

CWHR habitat type	Species							
	American marten (n = 29)	Black bear (n = 58)	Coyote (n = 6)	Fisher (n = 9)	Gray fox (n = 5)	Ringtail (n = 3)	Weasel spp. (n = 11)	W. spotted skunk (n = 9)
Barren (6%)	2	0	1	0	0	0	0	0
Subalpine conifer (15%)	3	6	2	1	0	0	4	0
Lodgepole pine (19%)	6	9	3	0	0	0	4	1
Red fir (16%)	7	11	0	0	0	0	1	2
Montane riparian (9%)	3	6	0	0	0	0	2	2
Jeffrey pine (1%)	0	1	0	0	0	0	0	0
White fir (1%)	0	1	0	1	0	0	0	0
Sierran mixed conifer (22%)	8	17	0	5	2	0	0	4
Ponderosa pine (1%)	0	0	0	0	1	0	0	0
Montane hardwood-conifer (1%)	0	1	0	0	1	1	0	0
Montane hardwood (6%)	0	5	0	2	1	2	0	0
Blue oak woodland (1%)	0	1	0	0	0	0	0	0

Table 2. Similarity (%) of species composition across eight habitat categories at sites surveyed in Sequoia and Kings Canyon National Parks, California was compared using a Jaccard's coefficient. The total number of carnivore and marsupial species detected in each habitat group is shown at the top of each column. Habitat types which occurred at ≤ 2 survey sites were added to either the mixed conifer or hardwood categories as was appropriate.

Habitat categories	Barren (2 species)	Subalpine (5 species)	Lodgepole (6 species)	Red fir (5 species)	Montane riparian (4 species)	Mixed conifer (5 species)	Hardwood (5 species)
Barren	—						
Subalpine	40	—					
Lodgepole	33	57	—				
Red fir	17	43	57	—			
Montane riparian	20	50	67	80	—		
Mixed conifer	17	43	38	43	50	—	
Hardwood	0	25	10	11	13	43	—

Table 3. Number of sites (n = 79) and associated canopy cover classifications where carnivores were detected in Sequoia and Kings Canyon National Parks, California between 2002 and 2004. Canopy cover categories are based on California Wildlife Habitat Relationships system guidelines. Percentage of sites in each canopy cover category relative to all sites surveyed is noted after each category.

	Species							
Canopy cover[a]	American marten (n = 29)	Black bear (n = 58)	Coyote (n = 6)	Fisher (n = 9)	Gray fox (n = 5)	Ringtail (n = 3)	Weasel spp. (n = 11)	W. spotted skunk (n = 9)
Dense (33%)	13	25	0	6	4	3	0	6
Moderate (29%)	8	19	1	3	0	0	4	2
Open (19%)	4	11	2	0	1	0	4	1
Sparse (13%)	2	3	2	0	0	0	3	0
<10% (6%)	2	0	1	0	0	0	0	0

[a]Dense = 60-100%, Moderate = 40-59%, Open = 25-39%, Sparse = 10-24%

Table 4. Number of sites (n = 79) and associated tree size classes where carnivores were detected in Sequoia and Kings Canyon National Parks, California between 2002 and 2004. Tree size classes are based on the California Wildlife Habitat Relationship system guidelines. Percentage of sites occurring in each tree size class relative to all sites surveyed is noted after each size class.

	Species							
Tree size class [a]	American marten (n = 29)	Black bear (n = 58)	Coyote (n = 6)	Fisher (n = 9)	Gray fox (n = 5)	Ringtail (n = 3)	Weasel spp. (n = 11)	W. spotted skunk (n = 9)
6 (15%)	9	12	0	3	1	0	0	3
5 (28%)	8	19	1	3	1	0	4	2
4 (43%)	9	23	4	2	2	3	6	4
3 (8%)	1	4	0	1	1	0	1	0
2 (0%)	0	0	0	0	0	0	0	0
1 (0%)	0	0	0	0	0	0	0	0
No size class (6%)	2	0	1	0	0	0	0	0

[a]Class 1 = seedling tree, <2.5 cm; Class 2 = sapling tree, 2.5-15.0 cm; Class 3 = Pole tree, 15.2-27.7 cm; Class 4 = small tree, 27.9-60.7 cm dbh; Class 5 = medium/large tree, ≥61.0 cm dbh; Class 6 = multilayered tree, class 5 trees over layer of class 3 or 4 with dense canopy cover.

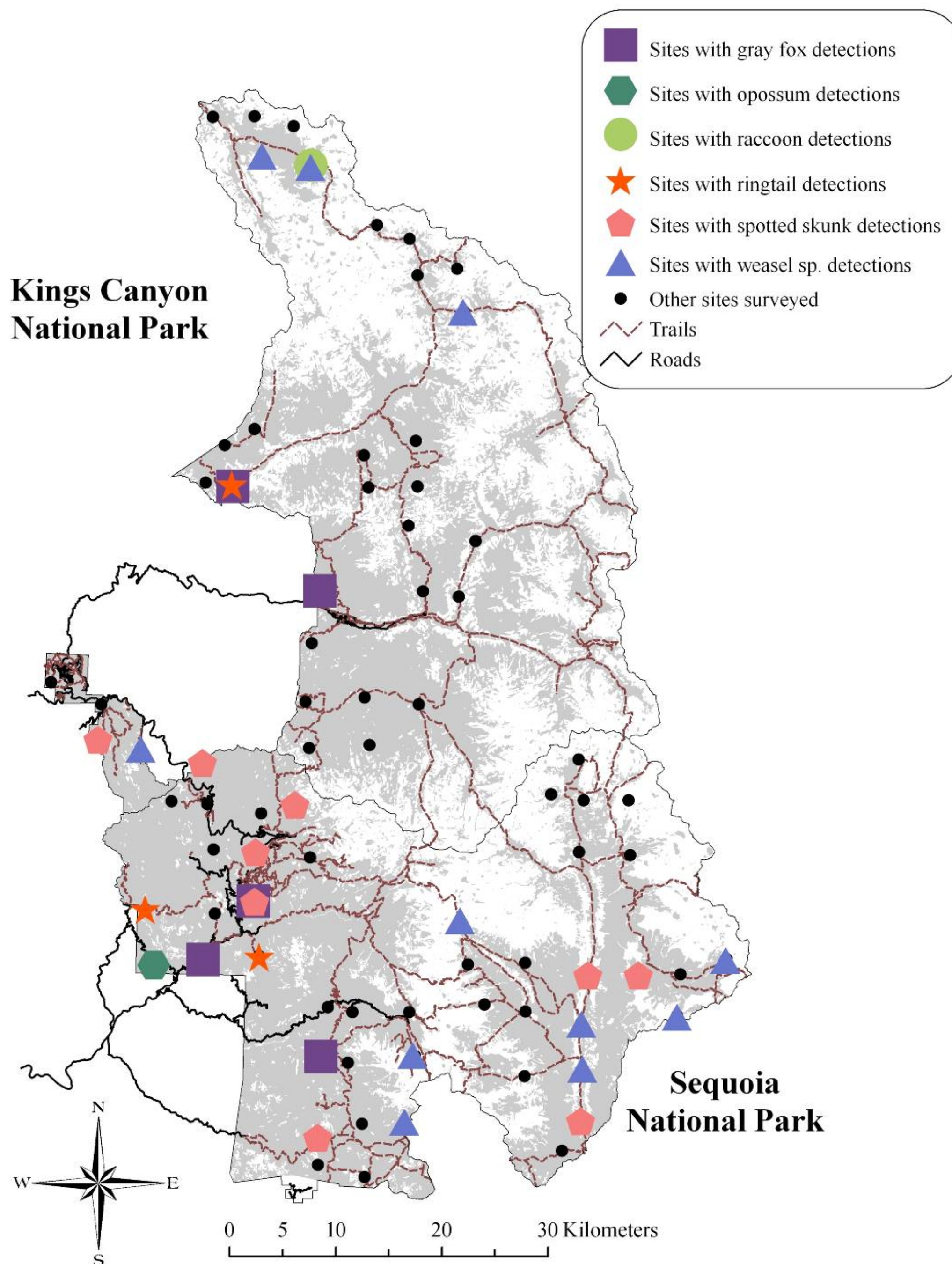


Figure 2. Distribution of sites with detections of gray fox (5), raccoon (1), ringtail (3), Virginia opossum (1), western spotted skunk (9), and weasel (long- or short-tailed, 11) in Sequoia and Kings Canyon National Parks, California. Sites (*n* = 79) were surveyed using track plates and remote cameras during summer and fall of 2002, 2003, and 2004. Forest and shrub dominated habitats are shown in gray and rock dominated areas are white.

Chapter 2: An Evaluation of the California Wildlife Habitat Relationships Model for American marten in Sequoia and Kings Canyon National Parks

Introduction

Predicting species occurrence with the aid of habitat models can improve our human understanding of the habitat requirements and distribution of wildlife species (Morrison et al. 1998, Carroll et al. 1999, Knapp et al. 2003). Habitat models can help biologists expedite wildlife related land management decisions and offer a standardized approach to classifying habitat across land ownerships (Garrison et al. 1999, Mladenoff et al. 1999, Lauver et al. 2002). However, habitat models oversimplify relationships that exist in the natural environment and biologists should not expect them to be flawless in predicting species occurrence (Garshelis 2000, Van Horne 2002, Barry and Elith 2006). At the same time, models need to exhibit a reasonable level of accuracy to justify their use in management and conservation planning (Morrison et al. 1998). Evaluation is frequently proposed and encouraged as part of the model creation process, but few models have been assessed with independent data (Thomasma et al. 1991, Brooks 1997, Carroll et al. 1999, Rowland et al. 2003). Testing an existing habitat model with new data may help establish confidence levels for its application in management and may provide an opportunity to improve model performance (Block et al. 1994, Brooks 1997, Garrison et al. 2000).

Geographic extent, complexity and specificity of individual habitat models varies from simple but broadly applicable wildlife-habitat relationship models to intricate

mathematical equations tailored for discrete areas (Allen 1982, Van Horne 2002, Knapp et al. 2003). The California Wildlife Habitat Relationships (CWHR) system is a collection of relatively simple community level matrix models for 675 wildlife species and 59 habitat types (Garrison et al. 1999, California Department of Fish and Game 2002). This compilation of models was created in an effort to provide biologists with a resource capable of identifying habitat conditions associated with wildlife species in California and has been used in timber harvest plans and environmental impact statements (e.g., Final Environmental Impact Statement, Kings River Project, Sierra National Forest, 2006). The model's computer interface allows users to select an individual species and display its predicted habitat classifications, or specify a habitat type and receive a list of species predicted to occur within it (Garrison et al. 1999). Previously conducted tests of the CWHR model have focused on the latter approach, comparing lists of species predicted to occur with those detected under certain habitat conditions (Hejl and Verner 1988, Block et al. 1994, Howell and Barrett 1998). In contrast, the goal of my evaluation was to examine predicted suitability values for one species, the American marten (*Martes americana*), in the southern part of its range in California.

The American marten is a small, arboreal carnivore in the family Mustelidae that occurs only in North America and is associated with mature forests (Buskirk and Ruggiero 1994). Along with fisher (*Martes pennanti*) and wolverine (*Gulo gulo*), marten populations in California were heavily impacted by fur trapping in the 1800s and early 1900s (Grinnell et al. 1937, Kucera et al. 1995). Trapping for marten has been illegal in

California since 1952, but populations of the Sierran subspecies (*M. a. sierrae*) and a recently re-discovered population within the range of the Humboldt subspecies (*M. a. humboldtensis*) continue to be impacted by loss, alteration, and discontinuity of mature forest habitat (Kucera et al. 1995, Slauson 2003, Zielinski et al. 2005). Martens are classified as a sensitive species in National Forests of California, charging the United States Forest Service with maintaining broadly distributed populations on their lands (Buskirk and Ruggiero 1994). As concern for marten and particularly fisher has increased in recent years, surveys have been initiated to determine the status of these species and consider management options (e.g., Slauson et al. 2003, Zielinski et al. 2005). CWHR provides one of the only models available for marten in California to help biologists identify suitable habitat for monitoring, management, and conservation plans.

Performance of the CWHR model for American marten was evaluated using presence-absence data and CWHR habitat suitability values from field surveys conducted in Sequoia and Kings Canyon National Parks, California. Model performance was evaluated in two ways: 1) correct classification was assessed by comparing marten presence-absence with CWHR suitability values, and 2) degree of association was measured between marten detections and CWHR suitability values. I tested the predictions that probability of marten occurrence would increase with increasing suitability values and that frequency of marten detections would be positively correlated with suitability. A spatial application of the CWHR model for marten (Timossi et al. 1995) was also investigated using marten presence-absence data from surveys and available digital vegetation data.

Methods

Study area and procedures

Sequoia and Kings Canyon National Parks (hereafter, Parks) are located in the southern Sierra Nevada of California. The Parks are managed as one unit, contain just over 350,160 ha, include elevations from approximately 500 to 4,400 m, and are surrounded by lands managed by the Inyo, Sequoia, and Sierra National Forests (National Park Service 1996). Sequoia National Park and General Grant National Park (precursor to Kings Canyon National Park) were established in 1890, with substantial additions in 1926 and 1940 (National Park Service 1996). A wide variety of habitats occur across the elevation gradient, including chaparral- and oak-dominated communities in the foothills, mixed conifer forest and giant sequoia groves (*Sequoiadendron giganteum*) at mid-elevations, red fir (*Abies magnifica*) and lodgepole pine (*Pinus contorta*) forests in the subalpine zone, and alpine lakes surrounded by peaks of granite at the highest elevations (National Park Service 1996, Appendix A). Over 84% of the land is designated wilderness. Road access is confined to the western half of the Parks and prescribed and naturally ignited wildland fires are the major disturbance factors in forested areas (Appendix B).

Detection of American marten

Surveys for presence-absence of marten were conducted between late May and mid-October in 2002, 2003, and 2004. Sample units (hereafter, sites) were selected using a 5 km sampling grid created in a Geographic Information System (GIS) in ArcView (Version 3.3, Environmental Systems Research Institute Inc., Redlands, CA). The 5 km

distance was based on marten home range size, such that detection of an individual at one location should be independent of one 5 km away (Zielinski and Stauffer 1996). Each site contained five detection devices (hereafter, stations) and was arranged in the shape of a cross: three enclosed track plates, one open plate, and one remote camera. An enclosed track plate was placed at the center of the cross as close to the 5 km grid-based Universal Transverse Mercator (UTM) coordinates as possible using a global positioning device (e-trex model, Garmin International Inc., Olathe, KS, mean accuracy <10 m). The four remaining stations were randomly assigned to cardinal directions and placed 150 m from the center, a distance which could be extended up to 250 m as needed (e.g., to find a tree for the camera).

If a site occurred in a narrow canyon or next to a water barrier, outer stations were either rotated 90 degrees or one outer station was moved ≥150 m away from another outer station (changing the site's shape from a "+" to a "T"). These adjustments allowed the site to fit in the terrain but still cover the same area. Due to the rugged topography in the study area, central coordinates were moved slightly if possible or omitted to maintain safe conditions for surveyors. If a site occurred in a narrow canyon or next to a water barrier, outer stations were either rotated 90 degrees or an outer station was moved ≥150 m away from another outer station (changing the site's shape from a "+" to a "T"). These adjustments allowed the site to fit in the terrain but still cover the same area. Due to the rugged topography in the Parks, central coordinates were moved slightly if possible or omitted to maintain safe conditions for surveyors. Of 150 grid points that fell within or on the boundary of the Parks, only about half could be surveyed, so efforts were

prioritized using the following criteria: represent different geographic areas of the Parks, focus on forests but include other available habitat types, and narrow final selection of grid points to areas that could be safely accessed. A comparison of possible survey sites to overall habitat availability prior to field work suggested that barren areas were the primary habitat underrepresented, as rocky high elevation peaks and basins made up nearly 40% of the landscape. However, the primary focus of this project was to identify areas where martens occurred. Because they are generally associated with densely forested areas (Powell et al. 2003), I surveyed a smaller proportion of barren habitat.

Track plate boxes were constructed from pieces (81 x 112 cm) of lightweight black plastic (Coroplast, Towers Marketing, Eugene, OR) folded into boxes with 25 x 25 cm openings and closed at the baited end (Gompper et al. 2006, Appendix C). In the field, boxes were placed against logs, trees, or rocks and natural materials were used to stabilize and shade devices from the sun. Aluminum track plates (0.15 x 20.3 x 76.2 cm) were covered with soot from an acetylene torch and white shelving paper (23 x 28 cm pieces, Con-tact, Kittrich Corp., La Mirada, CA) was attached 10 cm from the baited end with the adhesive side up (Fowler and Golightly 1994, Zielinski 1995).

Open plates consisted of two aluminum track plates arranged side by side and held in place by three flat sticks (2.5 x 40.5 cm) secured underneath and perpendicular to the plates by binder clips (Appendix C). Unlike other open plate designs, the same size aluminum plates as described for enclosed stations (complete with shelving paper) were used, which simplified plate replacement and improved track quality. When possible, open plates were placed in areas where natural materials (e.g., trees, logs, rocks) provided

some cover from rain, channeled animals towards the sooted ends of the plates, and hindered them from getting the bait without leaving tracks. Natural materials were used to block the sides and baited end of open plates.

A single passive infrared sensor and a 35 mm camera (TM35-1 Olympic camera, TrailMaster, Goodson and Associates, Inc., Lenexa, KS) were deployed at each site and attached to a tree or rock with webbing and duct tape (Scotch duct tape, 3M Canada, London, Ontario, Canada). Sensors exposed to direct sun and wind could be falsely activated to take pictures, so protected areas were selected where available. If numerous false activations occurred during the day at sites with little cover, sensors were adjusted to take pictures only between dusk and dawn.

A survey consisted of the initial establishment of the site followed by monitoring and re-baiting every three days for a total of fifteen days. This survey duration was shorter than recommended by some studies (Fowler and Golightly 1994), but reflected a reasonable compromise to optimize detection probability (Zielinski 1995) and minimize costs of working in remote areas. Track plates were baited with half a can (81.3 ml) of chicken-flavored canned cat food (9-Lives brand Chicken Dinner) mixed with 5 ml of lard to delay desiccation. A small amount of Gusto™ (2.5 ml), a commercial skunk-scented lure (Minnesota Trapline Products, Pennock, MN), mixed with lanolin was placed next to the bait on a flat piece of bark or rock inside the enclosed track plate or at the back of the open plate. Camera stations were baited with a punctured can of cat food attached to a tree or rock using an elastic cord, with the Gusto mixture applied a few centimeters above the bait. Stations were re-baited on each visit and dry or maggot-

infested cat food was removed from the site. The Gusto mixture was agitated with a stick on each visit and additional lure was applied as needed to maintain an odor perceptible to surveyors.

During each visit, any suspected carnivore tracks on the contact paper were collected. Tracks in soot were burnished using clear packing tape and placed on paper (Zielinski 1995). At sites where black bears (*Ursus americanus*) repeatedly destroyed more than three devices, reducing the chances of detecting any other species, stations were not re-baited for one visit and Gusto was used as the only attractant. This technique was used infrequently (33 or 1.7% of all trap nights at 7 of 79 sites), but detection of a marten using only Gusto in the first season supported it as a viable option. Mean latency to first detection was calculated to indicate the length of time before a marten was initially detected at a site. This was calculated by number of days (based on a visit every third day for 15 days) and number of visits (based on 5 visits).

Sampling design and survey methods were derived from a protocol used by the Pacific Southwest Research Station (Zielinski et al. 2005), with adjustments made to accommodate the logistic challenges of working in remote roadless areas. The most notable alterations to the original protocol were a decrease in size of the sampling grid from 10 to 5 km, a reduction in the number of detection devices at each sample unit from six to five, and an increase in proximity of devices from 500 to 150 m from the center of the site. I identified carnivore tracks using several resources (Taylor and Raphael 1988, Zielinski 1995, Zielinski and Truex 1995). Researchers from Pacific Southwest Research

Station (B. Zielinski, K. Slauson, T. Kirk, R. Schlexer) and Humboldt State University (R. Golightly) reviewed a representative sample of tracks for further verification.

California Wildlife Habitat Relationships model

The CWHR model for American marten was created using expert opinion and relies primarily on three habitat components: habitat type, tree size class, and canopy cover (Garrison et al. 1999). Habitat suitability values range from 0 to 1.0, and are categorical such that 0 represents unsuitable habitat, 0.33 is low, 0.66 is medium, and 1.0 is high suitability (California Department of Fish and Game 2002). The model assigns suitability values to reproductive, cover, and feeding categories based on the habitat components, and these habitat categories can be used individually or combined using a geometric or arithmetic mean of the three categories. For example, lodgepole pine forest with pole sized trees (15.2-27.7 cm dbh) and open canopy cover (25-39%) is classified as unsuitable for reproduction (0) or cover (0), but is moderately suitable for feeding (0.66). Overall suitability in this case would be 0.22 using an arithmetic or 0 with a geometric mean. When using the CWHR model to identify suitable marten habitat, the presence of three essential habitat elements (small mammals, medium mammals, tree layer) is assumed. If one or more of these elements are designated as absent, martens will not be predicted to occur. Secondary habitat elements (e.g., logs, snags) must also be present, but they can be substituted with other secondary elements.

Habitat type, tree size class, and canopy cover were classified using the CWHR system vegetation manual (Mayer and Laudenslayer 1988). Classifications were visually estimated by one individual using vegetation within a 25 m-radius of each station.

CWHR tree size class categories, names, and diameter at breast height (dbh) measurements were as follows: class 1 (seedling tree, <2.5 cm), class 2 (sapling tree, 2.5-15.0 cm), class 3 (pole tree, 15.2-27.7 cm), class 4 (small tree, 27.9-60.7 cm), class 5 (medium/large tree, ≥61.0 cm), class 6 (multilayered tree, a distinct layer of class 5 trees over a layer of class 4 or 3, and total canopy cover ≥60%). A dbh tape was used periodically to calibrate the observer's estimates. CWHR canopy cover categories were sparse (10.0-24.9%), open (25.0-39.9%), moderate (40.0-59.9%), and dense (>60.0%). Areas of <10% tree cover qualified as barren, meadow or shrub as was appropriate.

Seven of the habitat elements (e.g., logs, snags) listed for marten by the CWHR model as well as spaces in rock cover >15 cm in diameter were counted in two 50 x 10 m perpendicular transects which crossed at the station and ran north to south and east to west. These data have been summarized (Appendix I). Nine other elements (e.g., shrub layer, open water, talus) were noted as present or absent within 25 m of the station. In this evaluation, absence of essential elements was not used to rule out any sites as unsuitable because martens were detected at a few sites with no tree layer and trapping small and medium mammals was not logistically feasible during this project. However, evidence of rodents in the form of tracks, photos or observations occurred at 97% of sites, adding validity to the assumption of presence.

A few of the species models in the CWHR system, including marten, have applications available for use in GIS. The CWHR ArcInfo (Environmental Systems Research Institute Inc., Redlands, CA) model for marten is based on components in the original model, but also incorporates parameters such as home range size, core habitat

(medium to high suitability areas greater than two home ranges), colony habitat (medium to high quality areas greater than one home range and within dispersal distance of other suitable habitat that is not necessarily always occupied), and estimated dispersal distance (Timossi et al. 1995). The model includes an Arc Macro Language (AML) script for use in ArcInfo with digital habitat type, tree size class, and canopy cover data. Output from the model contains grid cells classified by suitability value across the study area.

Statistical and Geographic Information System analyses

Detection of marten at any or all stations at a site was considered a detection for the site. Probability of detecting a marten in the surveys was determined using program PRESENCE version 2 (J. E. Hines, United States Geological Survey, Laurel, MD), which generated a single visit detection probability (p) using detection history from all sites. This single visit detection probability was used to calculate probability of detection for the whole survey period using the equation: $1-[(1-p)^5]$. As detection probability was high (94.7%, see Results), logistic regression was suitable to relate observed presence or absence to CWHR suitability values rather than maximum-likelihood models that distinguish probability of detection from probability of occurrence.

CWHR suitability values were determined for each site based on habitat at stations using three approaches: 1) suitability values from the five stations were averaged, 2) the station with the highest suitability value represented the site, and 3) the station with the lowest suitability value represented the site. Initial analyses used these designations of site suitability (average, maximum, and minimum respectively) in combination with presence or absence of marten at a site in logistic regression to investigate the model's

correct classification abilities (Hosmer and Lemeshow 2000). Confusion matrices were generated for reproductive, cover, feeding, arithmetic and geometric means. I calculated prevalence and seven measures of model performance (correct classification, sensitivity, specificity, positive predictive value, negative predictive value, misclassification rate, and Kappa, Fielding and Bell 1997) at five cut-points (0.1, 0.3, 0.5, 0.7, 0.9). In conjunction with receiver operator characteristic (ROC) plots, area under the curve (AUC) was calculated as a measure of performance independent of cut-point.

Akaike's Information Criteria (AIC_c) values corrected for small sample size (Burnham and Anderson 2002) were calculated for logistic regressions of presence-absence data on all combinations of site suitability designations (average, maximum, minimum) and CWHR categories (reproductive, cover, feeding, arithmetic and geometric means). Models were ranked from highest to lowest by proportion of assigned AIC_c weights, and results determined the site suitability designation to use in further analyses.

ROC plots were also used to identify optimal cut-points that balanced sensitivity and specificity with the equation:

$$m = \frac{CC}{OC} x \frac{(1-p)}{p},$$

where m is the slope of the line used to identify the cut-point on the ROC curve, CC is commission cost, OC is omission cost, and p is prevalence (Zweig and Campbell 1993). Cut points were calculated for both the neutral case in which cost of commission errors (false positives) and omission errors (false negatives) were equal and a scenario in which omission errors were twice as costly. As martens are relatively rare, omission errors

would typically be more problematic in habitat conservation planning (Fielding 2002).

Spearman rank correlations were used to assess strength of association between marten occurrence and CWHR suitability values. Suitability values were classified into ten ranked bin categories and compared with ranked area-adjusted frequency of marten detections (Boyce et al. 2002).

A grid with suitability values was created from digital vegetation data of habitat type, tree size class, and canopy cover for use in the CWHR ArcInfo model. Vegetation data with direct compatibility to CWHR classifications were not available for the Parks, however, data layers that could be reasonably interpreted to CWHR habitat types (Appendix A) and canopy cover categories were available from the National Park Service. A surrogate data layer for tree size class was created from a Sierra Nevada Ecosystem Project polygon layer which ranked forested areas by late-successional characteristics across the Sierra Nevada (Franklin and Fites-Kaufman 1996). These three layers did not crosswalk perfectly with CWHR (e.g., National Park Service dense canopy cover = 70-100% and CWHR dense canopy cover = 60-100%, Sierra Nevada Ecosystem Project categories 4 and 5 roughly equate to CWHR tree size classes 5 and 6). However, the Parks are dominated by large tree size classes and CWHR assigns suitability categorically to groups within habitat types (e.g., red fir size classes 4 and 5 with moderate or dense canopy cover all have high suitability), so inconsistencies were not as problematic as they might have been on lands where tree size and canopy cover are more variable due to timber harvest.

The Geoprocessing wizard in ArcMap (ArcGIS 7.0, Environmental Systems Research Institute Inc., Redlands, CA) was used to combine digital vegetation data for use in the ArcInfo model. Suitability values (using a geometric mean) were assigned in tables and the output was converted to 30 x 30 m grid cells (Appendix J). The AML was implemented in ArcInfo and the resulting grid imported into ArcView 3.3 to compare with observed marten detections. To decrease potential bias from GIS and UTM error, the grid cell value at a station was averaged with the surrounding eight cells to estimate suitability for a 90 x 90 m area at each station. These values were used in logistic regression and measures of model performance as described previously.

CWHR version 8.0 was used to identify habitat suitability values (California Department of Fish and Game 2002) and SPSS 12.0 was used for analyses (SPSS Inc. 2003). Field techniques were approved by the Humboldt State University Institutional Animal Care and Use Committee (#01/02.W.121.0).

Results

Surveys were conducted between late May and mid-October at 79 sites during 2002, 2003 and 2004. Thirteen habitat types were dominant at ≥1 site and 17 habitat types were represented at ≥ 1 station (Appendix E). Mean elevation at sites ranged from 610 to 3,540 m (Appendix G). American martens were detected by track or photo at 29 (36.7%) sites and 67 (17.0%) stations in elevations ranging from 1,800 to 3,340 m. Mean latency to first detection was 6.1 days (SD = 4.6) or 2.0 visits (SD = 1.6), and probability of detecting a marten at a site where one occurred was 94.7% (95% C.I. = 90.1 to 99.2%). Martens occurred in three geographic areas: the largely continuous late-successional forests on the western slope, forested riparian corridors in eastern Sequoia National Park, and the matrix of riparian forest adjacent to alpine boulder cover in central and northern Kings Canyon National Park (Figure 3, Appendix K).

Martens were detected at sites in six dominant habitat types: Sierran mixed conifer (n = 8, 28%), red fir (n = 7, 24%), lodgepole pine (n = 6, 21%), subalpine conifer (n = 3, 10%), montane riparian (n = 3, 10%), and barren (n = 2, 7%). Within the Sierran mixed conifer category, 5 sites with detections fell at least partially within a giant sequoia grove. Martens were detected at sites with dense (n = 13, 45%), moderate (n = 8, 28%), open (n = 4, 14%), sparse (n = 2, 7%), and <10% (n = 2, 7%) canopy cover. However, detections at sites in the last three canopy cover categories occurred above 2,800 m in areas where boulders or shrubs provided alternate forms of cover. Martens were found at sites dominated by tree size class 6 (n = 9, 31%), class 5 (n = 8, 28%), class 4 (n = 9, 31%), class 3 (n = 1, 3%) and sites with little or no tree cover (n = 2, 7%). CWHR

habitat classifications at individual stations differed in some cases from the dominant site classification, so habitat at stations with detections were also summarized (Appendix L).

Initial analyses to evaluate CWHR model performance using logistic regression incorporated all three site suitability designations (average, maximum, minimum) and associated presence or absence of marten. The resulting confusion matrices and measures of model performance generally supported use of the average calculation. Although the minimum approach tended to have slightly higher rates of correct classification than the average designation, it achieved this by predicting more absences rather than accurately predicting presences. Additionally, the average site designation yielded the highest AUC values and occurred in four of the top five models in an AIC_c comparison (total AIC w_i: average = 0.53, maximum = 0.32, minimum = 0.15). Consequently, only the average site designation was used in subsequent analyses.

Further logistic regression analyses combined selected cut-points (0.1, 0.3, 0.5, 0.7, 0.9) and CWHR habitat categories (arithmetic and geometric mean, reproductive, cover, feeding) and revealed trade-offs between correct classification rates and accurate prediction of marten presence. Values for the geometric mean have been displayed as an example (Table 5), but the trend was similar for arithmetic mean, reproductive, cover, and feeding categories. A cut-point of 0.1 caused the model to predict only presences (high commission error) with low percentage correct classification, while a threshold of 0.7 or higher yielded predictions of all absences (high omission error) but a higher rate of correct classification. A cut-point of 0.3 improved the balance between predicted presence and absence, but over-predicted presences and had relatively low correct

classification (58%). In comparison, a cut-point of 0.5 raised correct classification to 62%, but predicted fewer presences correctly.

As with confusion matrices, measures of model performance varied by cut-point, with the five habitat categories yielding similar values. Prevalence, the proportion of sites with detections, was relatively high at 36.7%. Correct classification rate, the accurate classification of observed presences and absences, ranged from 37 to 65% across all cut-points and categories. Sensitivity, ability to classify presences correctly, ranged from 0 to 100% across cut-points and categories. Sensitivity was highest at cut-points of 0.1 to 0.3 and low at cut-points of 0.5 and above. Specificity, correct classification of absences, also ranged from 0 to 100% across cut-points and categories, but was highest at cut-points of 0.5 and above. Positive predictive power ranged from 37 to 54%. Negative predictive power ranged from 63 to 84%. Misclassification rate was 35 to 63%. Kappa, ability to classify correctly compared to chance, ranged from 0 to 0.24, falling below a desired minimum of 0.4 in all categories (Fielding 2002).

A cut-point of 0.5 is often used as a default and in this evaluation it reflected a level of compromise between sensitivity and correct classification, thus it was chosen to compare specific measures of model performance (Table 6). At this threshold, results were similar for reproductive, cover, feeding, geometric or arithmetic means. Correct classification was moderate (62 to 65%), sensitivity was low (24 to 28%) and specificity was high (82 to 88%). Negative predictive power (63 to 67%) was slightly better than positive predictive power (47 to 54%). Misclassification was fairly high (35 to 38%) and Kappa was low (0.11 to 0.14).

Due to mediocre performance of the CWHR model in an area with a relatively high marten detection rate, habitat characteristics associated with marten detections were reviewed for clues to improve model performance. The greatest number of stations with detections in any one habitat category (32.8%) occurred in Sierran mixed conifer size class 6 (Appendix L). CWHR classifies this category as only moderately suitable (0.66) for marten, so new analyses were conducted with suitability increased to high (1.0). At a cut-point of 0.5, this modified model yielded slightly higher correct classification at 68%, improved sensitivity to 45% and increased Kappa to 0.32 (Table 6). This adjusted Sierran mixed conifer model was included in further model comparisons.

Area under the curve, a measure independent of cut-point, was moderately good and ranged from 66 to 72% across categories (Table 7). The highest AUC and correct classification values were associated with the adjusted Sierran mixed conifer category in combination with arithmetic or geometric mean. Optimal cut-points, calculated under the assumptions that omission errors were either equal to or twice as costly as commission errors, ranged from 0.3 to 0.55 across categories (Table 7). Assuming omission and commission errors were equal, correct classification rate was moderate (66 to 71%), sensitivity was generally low (17 to 41%) and specificity was high (80 to 96%, Table 7). Assuming omission errors were twice as costly, correct classification was moderate (58 to 70%), sensitivity improved (66 to 86%) and specificity went down (46 to 72%, Table 7). Looking at the results of both approaches to calculating optimal cut-points, a notable difference may be the accurate prediction of presences. For example, the number of correctly predicted presences with a geometric mean and assuming errors were equal in

cost (cut-point = 0.55) was 5 of 29 compared to assuming omission was twice as costly as commission error (cut-point = 0.30) which predicted 25 of 29 correctly (Table 7).

Ranked categories of area-adjusted frequency of marten detections displayed a positive association with binned ranks of CWHR suitability values in Spearman rank correlation analyses (Figure 4). A model incorporating an arithmetic mean and increased values for Sierran mixed conifer tree size class 6 showed a slightly stronger correlation (r_s = 0.712, P = 0.01) than did a model using arithmetic mean and original CWHR values (r_s = 0.524, P = 0.06). A similar relationship existed using the geometric mean. This pattern demonstrated that as CWHR suitability values increased, proportion of marten detections at sites also increased.

Output from the CWHR ArcInfo model did not perform well in statistical evaluation, but showed promise in a visual assessment (Table 6). Using a cut-point of 0.5 and a geometric mean, the model predicted all absences, correct classification was 63%, sensitivity was 0%, specificity was 100%, and Kappa was 0. At an optimal cut-point of 0.38 (omission error twice as costly as commission), correct classification remained at 63%, sensitivity went up to 48%, specificity went down to 72%, and Kappa improved to 0.2. In a visual evaluation of the map, martens occurred in correctly predicted suitable habitat in continuous forest on the western half of the Parks, but not in eastern and northern areas where they were detected in narrow riparian forest and barren or subalpine habitats with boulder cover (Figure 5). Omission errors occurred at sites not identified as suitable (e.g., barren) and in patches of suitable habitat (e.g., riparian forest) deemed too small or out of dispersal distance from the closest suitable habitat.

Discussion

California Wildlife Habitat Relationships model performance

This evaluation was conducted in an attempt to provide a constructive assessment of the CWHR model's capabilities and limitations in predicting marten habitat in the southern part of its range in California (Brooks 1997, Van Horne 2002, California Department of Fish and Game 2002). Confirming initial predictions, probability of marten occurrence increased with increasing CWHR suitability values and frequency of marten detections was positively correlated with suitability values. At the same time, many sites classified as highly suitable appeared to be unoccupied. Martens were chiefly detected in habitat types, tree size classes, and canopy cover combinations predicted as suitable by the model. However, within available habitats, martens occurred at more sites in Sierran mixed conifer tree class 6 than in any other category, a classification assigned only moderate suitability. Martens were found in one habitat type not defined as suitable by CWHR: this was barren habitat with boulder cover at high elevations.

Overall, the CWHR model worked best to broadly identify potential marten habitat in continuously forested landscapes, but should still be combined with surveys to establish occupancy. This evaluation suggested the model needs modification to identify habitat at high elevations and improve predictive abilities in coniferous forests. Raising the value of Sierran mixed conifer tree size class 6 and altering the barren category would likely enhance accuracy and utility of CWHR for biologists involved in managing lands. In its current form, the model should not be used to identify habitat in rock dominated alpine areas and the ArcInfo model should be used with caution if high elevations or

narrow riparian forests are in the landscape. Further evaluation on lands managed for timber harvest and other parts of California would more fully assess model performance.

Sites with marten detections generally occurred in habitats deemed moderate to highly suitable by CWHR. However, if a marten was not detected at a site classified as suitable, it was unclear whether model predictions were incorrect or a detection did not occur for another reason. Four scenarios could explain these cases. First, predicted suitability may be correct, but another factor inhibited marten presence. Second, predicted suitability may be correct and a marten was present but not detected. Third, predicted suitability may be correct, but spatial-temporal effects could leave some habitat patches unoccupied during surveys. Fourth, predicted suitability may in fact be incorrect.

Martens might not be present at sites with suitable vegetation for several reasons. If population numbers were down due to historic trapping, disease, or a low cycle in the prey base, all suitable sites may not be occupied (Pullman 2000). However, this project generally had a high detection rate, similar numbers of detection across years, and a relatively broad distribution of martens over the study area, thus lending little support to this argument. An exception to this generality may be Sugarloaf Valley, an area trapped by Shorty Lovelace until 1940 (Tweed 1976); martens may not have been detected because the local population has not yet fully recovered. Presence of potential predators (assumed to be any larger bodied carnivore) may have deterred martens from using some sites, but there is mixed evidence for this explanation. Martens were not detected at six moderate to highly suitable sites where fisher (4) or gray fox (2) occurred, but were detected at other sites occupied by fisher (2), coyote (1), and mountain lion (1). Finally,

martens are known to occur at low densities, so even stable populations may not satiate all suitable habitats (Thompson and Colgan 1987, Pullman 2000).

Another explanation for perceived absence at sites predicted to be suitable is that lack of detection did not reflect true absence. Absences are nearly impossible to verify, but these surveys yielded a high estimated probability of detection (94.7%). A slightly shorter survey period than other studies or use of canned cat food instead of chicken (Fowler and Golightly 1994, Zielinski et al. 2005) may have led to fewer detections, but a mean latency to first detection of 6.1 days suggests martens found devices relatively quickly. Anecdotally, all sites where a marten was reportedly seen in the area around the time of the survey detected a marten. In all but two cases where suspected marten scat (based on size, shape) was seen near a site, one was also detected. Finally, bears may have inhibited detections on occasion, but martens were also found at 25 sites with bears.

Combined spatial and temporal effects may also have resulted in some suitable habitat patches being unoccupied by martens during the survey period. Female martens may restrict travel when kits are young and individuals may shift their home ranges seasonally (Ellis 1998, Powell et al. 2003). Martens detected in barren habitats may reside in other geographic areas or more forested habitats during other parts of the year. As a result, timing of surveys may have influenced where detections did or did not occur.

Finally, discrepancies between marten occurrence and site suitability may have arisen because some sites were ranked too high. There was no evidence that any CWHR habitat categories predicted to be suitable were actually unsuitable, but there were indications that suitability may be over- or underestimated in a few cases. Based on

CWHR suitability values and relative availability, it was surprising that more detections occurred in Sierran mixed conifer than lodgepole or subalpine forest. It is possible that lodgepole and subalpine forests may generally be of higher suitability further north in the Sierra Nevada (Spencer 1987) than in my area, or Sierran mixed conifer may be undervalued relative to other habitat types. Finally, scarcity of habitat elements may have reduced suitability of individual sites in lodgepole and subalpine forests.

The results of this study suggest that increasing suitability of Sierran mixed conifer forest in the CWHR marten model should be considered. To determine an appropriate state-wide suitability value, records of marten across the Sierra Nevada could be compared with regional availability of tree size classes 4, 5 and 6 with >40% canopy cover in this habitat type. In other surveys conducted in California, 20% of all marten detections were in Sierran mixed conifer forest (B. Zielinski, Pacific Southwest Research Station, unpublished data) and a separate study in Lassen Volcanic National Park yielded a high number of marten detections in mixed conifer forest (Perrine 2005). Sierran mixed conifer on lands with increased fragmentation, small trees, reduced canopy cover, or fewer mature forest features may be less suitable for marten, so increasing suitability of only tree size class 6 from moderate to high would be a conservative first step. Re-assessing the value of Sierran mixed conifer forest may be important for management as it is more likely to be altered by timber harvest or catastrophic fire than other habitats used by martens at higher elevations (Sierra Nevada Ecosystem Project 1996).

A few differences exist between Sierran mixed conifer forest in the northern and southern part of its range which may influence regional suitability for marten. In the

north, this habitat occurs in elevations of 770 to 1,230 m and in the south it extends from 1,230 to 3,076 m (Mayer and Laudenslayer 1988). At higher elevations with deep snow, martens may have an advantage in winter over larger competitors as their foot size to body weight ratio allows them to be highly mobile (Krohn et al. 1997). Douglas-fir trees occur in forests in the north but not the south, while the opposite is true for giant sequoias (Mayer and Laudenslayer 1988), but both may benefit marten. Lastly, logging has been more extensive in northern than southern forests, so mature Sierran mixed conifer may not be equally available in both areas (Sierra Nevada Ecosystem Project 1996).

Martens were only found in one category predicted to be unsuitable by the model: barren habitat at high elevations (Appendix K). Martens have demonstrated reluctance to cross open areas in forested landscapes, perhaps due to risk of predation (Hargis and McCullough 1984). However, martens can move through talus slopes and boulders while remaining under cover (Grinnell et al. 1937), and have denned in rock crevices (Ruggiero et al. 1998). Occupied sites with few or no trees had numerous openings in rock cover, suggesting that a decrease in tree cover must be balanced by an increase in another form of cover. A number of barren sites did not yield marten detections, so unique traits (e.g., openings in rock cover, proximity to forest, prey abundance) may be required for non-forested sites to be suitable. Further study could help identify the attributes martens need in rock dominated habitats, seasonality of use, and if these areas play a role in dispersal.

One marten (female based on track size, Slauson et al., in prep.) with a unique toe pattern was detected on every visit in a talus and boulder dominated site at 3,300 m, implying that her presence was not just transitory. Martens may only use this habitat type

seasonally, but it could represent an important part of a home range for an individual living in high elevations. Alpine boulder-dominated habitat may warrant a new name or category to better distinguish it from barren or alpine dwarf-shrub habitats, especially as other species in the CWHR matrix (e.g., pika (*Ochotona princeps*), Mount Lyell salamander (*Hydromantes platycephalus*)) also use this unique habitat.

The ArcInfo version of the CWHR model for marten did not yield favorable results in statistical evaluation, which may have been due to combined problems with the original model, estimations of spatial parameters, or available GIS vegetation layers. Some of the spatial parameters (e.g., colony area, dispersal distance) have not been well studied, and should be amended as improved estimates become available. The ArcInfo application performed best in continuous forests at middle elevations where it is most likely to be used in management, but adjustments will be needed to accurately classify high elevation areas. Further testing is also needed in lands managed for timber harvest.

Areas where martens were detected but the ArcInfo model did not predict suitable habitat were narrow riparian forests and high elevations with extensive boulder cover. For example, martens were detected at five sites near Le Conte Canyon in northeastern Kings Canyon National Park, an area defined as unsuitable in the grid output (Figure 5). Two sites were dominated by rock cover, but the others were in narrow patches of aspen, lodgepole, and subalpine forest connected by talus and shrub cover. The CWHR model recognized the forested areas as suitable based on data collected at the site, but the GIS application did not because the patches were too small or too far from other suitable habitat. To avoid including truly unsuitable forest fragments at low elevations, an

elevation component could be added to the model. Related to this problem, available digital vegetation data had insufficient detail in riparian forest and did not distinguish smooth granite (unsuitable) from boulders (potentially suitable). Detailed digital data could improve the ArcInfo model, particularly in landscapes with high elevations.

Model evaluation process

Although some recommendations on evaluating the CWHR model are available (Barrett et al. 1999), further clarification might help standardize efforts and encourage others to collect compatible data in the future. In this evaluation, several approaches were used to calculate suitability values and a variety of statistical methods helped assess model performance. Averaging suitability values from multiple stations at a site yielded better results across analyses compared to maximum or minimum values from individual stations. Geometric and arithmetic means generally performed better than cover, reproductive, or feeding categories alone. Geometric and arithmetic means produced similar results in this area, suggesting that one calculation method may be enough. The approaches used here are recommended based on performance in the Parks, but further investigation in lands with a broader spectrum of age classes and suitability values is needed to assess applicability elsewhere (e.g., a site with clear-cut, regenerating and mature forest with station suitability values of 0, 0.33, 0.33, 1.0, 1.0).

Logistic regression and Spearman rank correlation analyses contributed to assessing model performance in different but complementary ways. Logistic regression and associated measures of performance identified problem areas such as rate of correct classification, while Spearman rank correlation revealed a relatively good association

between suitability values and marten occurrence. Using a single analysis might have led to a poor interpretation of the model's performance by overstating or underestimating its abilities. Optimal cut-points appeared to be a better option than pre-selected cut-points, resulting in improved balance between correct classification, specificity, and sensitivity for each set of criteria and a fairer assessment of the model's abilities.

Recommendations, management implications, and future research

The CWHR model for marten faces challenges in remaining a simple yet broadly applicable model while improving its ability to predict suitable habitat. First, predictive power may be compromised by using state-wide suitability values. Regional values for habitat types could resolve this issue, but would increase model complexity. Second, habitat elements are undoubtedly important in assessing habitat suitability but the current model format does not allow them to be used effectively (e.g., there are no options to distinguish a site with one snag from a site with ten). Individual martens use numerous rest sites (Spencer 1987, Bull and Heater 2000), so availability of structures likely relates to suitability. Elements need clearer definition, quantification, and integration into the model, otherwise it may be appropriate to refer to them only in the text document. Element descriptions could be improved with guidelines on minimum quantities or assignment of functional groups (e.g., den sites, diet) based on ecological role. Finally, designating reproductive, cover, and foraging habitat without clarifying patch size, associated elements, or proximity of food to cover may overstate the model's capabilities.

Future research and adjustments could improve the CWHR model's ability to predict suitable habitat for marten. Presence-absence and vegetation data from other

parts of California could be used to examine model performance in habitat types, tree size classes, and canopy cover categories not covered in this study. In particular, large tree size classes of Sierran mixed conifer forest in other geographic areas should be compared with marten records to decide if an increase to high suitability is justified. Restructuring the CWHR model's format to better incorporate habitat elements might improve model performance for marten and other species that require specific structures to survive or reproduce. Finally, the ArcInfo model needs further development, but inclusion of factors like home range size, dispersal distance, and availability of suitable habitat at a landscape scale are invaluable in land management and conservation planning.

One of the next steps in evaluating the CWHR model for marten should be to investigate its performance in a landscape more altered by human activities (e.g., timber harvest, catastrophic fire) than the Parks. While the original purpose of CWHR may not have been to determine habitat suitability for use in management documents such as Environmental Impact Statements or Conservation Assessments, there are few other habitat models available for marten in California and it is the only one applicable to the entire state. The Parks were an ideal starting point for evaluation because many of the model's assumptions were likely met (e.g., adequate amounts of habitat elements, sufficient habitat patch size, California Department of Fish and Game 2000). However, it is important that the model perform well on lands where forests are undergoing alteration and assumptions may not be met. Further evaluation on lands with a broad range of tree size classes, canopy cover categories, and habitat elements could help identify strengths and weaknesses of the model and provide new opportunities to improve its performance.

Literature cited

Allen, A. W. 1982. Habitat suitability index models: Marten. United States Fish and Wildlife Service, FWS/OBS-82/10.11, Fort Collins, CO, USA.

Barrett, R. H., M. White, and M. Parisi. 1999. Guide for designing field validation studies of the California Wildlife Habitat Relationships System. Report No. 30, California Department of Fish and Game, Sacramento, California, USA.

Barry, S. and J. Elith. 2006. Error and uncertainty in habitat models. Journal of Applied Ecology 43:413-423.

Block, W. M., M. L. Morrison, J. Verner, and P. N. Manley. 1994. Assessing wildlife-habitat-relationships models: a case study with California oak woodlands. Wildlife Society Bulletin 22:549-561.

Boyce, M. S., P. R. Vernier, S. E. Nielsen, and F. K. A. Schmiegelow. 2002. Ecological Modeling 157:281-300.

Brooks, R. P. 1997. Improving habitat suitability index models. Wildlife Society Bulletin 25:163-167.

Bull, E. L., and T. W. Heater. 2000. Resting and denning sites of American marten in northeastern Oregon. Northwest Science 74:179-185.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and mulitmodel inference: A practical information-theoretic approach. Second edition. Springer-Verlag, New York, New York, USA.

Buskirk, S. W., and L. F. Ruggiero. 1994. American 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. United States Forest Service, Rocky Mountain Forest and Range Experimental Station, General technical report RM-254, Fort Collins, Colorado, USA.

California Department of Fish and Game and California Interagency Wildlife Task Group. 2000. Standards and guidelines for CWHR species models. California Department of Fish and Game, Technical Report No. 31. Sacramento, California, USA.

California Department of Fish and Game. 2002. California Interagency Wildlife Task Group. CWHR version 8.0 computer program. Sacramento, California, USA.

Carroll, C., W. J. Zielinski, and R. F. Noss. 1999. Using presence-absence data to build and test spatial habitat models for the fisher in the Klamath Region, USA. Conservation Biology 13:1344-1359.

Ellis, L. M. 1998. Habitat-use patterns of the american marten in the southern Cascade Mountains of California, 1992-1994. Thesis, Humboldt State University, Arcata, California, USA.

Fielding, A. H. 2002. What are the appropriate characteristics of an accuracy measure? Pages 271-280 *in* J. M. Scott, P. J. Heglund, M. L. Morrison, J. B. Haufler, M. G. Raphael, W. A. Wall, and F. B. Samson, editors. Predicting species occurrences: issues of accuracy and scale. Island Press, Washington, D.C., USA.

Fielding, A. H., and J. F. Bell. 1997. A review of methods for the assessment of prediction errors in conservation presence/absence models. Environmental Conservation 24:38-49.

Fowler, C. H., and R. T. Golightly. 1994. Fisher and marten survey techniques on the Tahoe National Forest. California Department of Fish and Game, Nongame bird and mammal section report 94-9, Arcata, California, USA.

Franklin, J. F., and J. A. Fites-Kaufmann. 1996. Assessment of late-successional forests of the Sierra Nevada. Sierra Nevada Ecosystem Project: Final report to congress, vol. II. University of California, Davis, California, USA.

Garrison, B. A., R. A. Erickson, M. A. Patten, and I. C. Timossi. 2000. Accuracy of wildlife model predictions for bird species occurrences in California counties. Wildlife Society Bulletin 28:667-674.

Garrison, B. A., M. D. Parisi, K. W. Hunting, T. A. Giles, J. T. McNerney, R. G. Burg, and K. J. Sernka. 1999. Training manual for the California Wildlife Habitat Relationship System, CWHR database version 7.0, 8th edition. California Department of Fish and Game, Sacramento, California, USA.

Garshelis, D. L. 2000. Delusions in habitat evaluation: measuring use, selection, and importance. Pages 111-164 *in* L. Boitani and T. K. Fuller, editors. Research techniques in animal ecology: controversies and consequences. Columbia University Press, New York, New York, USA.

Gompper, M. E., R. W. Kays, J. C. Ray, S. D LaPoint, and D. A. Bogan. 2006. A comparison of non-invasive techniques to survey carnivore communities in Northeastern North America. Wildlife Society Bulletin 34:1142-1151.

Grinnell, J., J. S. Dixon, and J. M. Linsdale. 1937. Fur-bearing mammals of California: their natural history, systematic status, and relations to man. Volume 1, 2. University of California, Berkeley, California, USA.

Hargis, C. D., and D. R. McCullough. 1984. Winter diet and habitat selection of marten in Yosemite National Park. Journal of Wildlife Management 48:140-146.

Hejl, S. J., and J. Verner. 1988. Evaluating avian-habitat relationships in red fir forests of the Sierra Nevada. Transactions of the Western Section of the Wildlife Society 24:121-134.

Hosmer, D. W., and S. Lemeshow. 2000. Applied logistic regression. Second edition. John Wiley and Sons, Inc., New York, New York, USA.

Howell, J. A., and R. H. Barrett. 1998. California wildlife habitat relationships system: a test in coastal scrub and annual grassland habitats. California Fish and Game 84:74-87.

Knapp, R. A., K. R. Matthews, H. K. Preisler, and R. Jellison. 2003. Developing probabilistic models to predict amphibian site occupancy in a patchy landscape. Ecological Applications 13:1069-1082.

Krohn, W. B., W. J. Zielinski, and R. G. Boone. 1997. Relations among fishers, snow, and martens in California: results from small-scale spatial comparisons. Pages 211-232 *in* B. Proulx, H. N. Bryant, and P. M. Woodard, editors. *Martes*: Taxonomy, ecology, techniques, and management. Provincial Museum of Alberta, Edmonton, Alberta, Canada.

Kucera, T. E., W. J. Zielinski, and R. H. Barrett. 1995. Current distribution of the American marten, *Martes americana*, in California. California Fish and Game 81: 96-103.

Lauver, C. L., W. H. Busby, and J. L. Whistler. 2002. Testing a GIS model of habitat suitability for a declining grassland bird. Environmental Management 30:88-97.

Mayer, K. E., and W. F. Laudenslayer. 1988. A guide to wildlife habitats of California. California Department of Forestry and Fire Protection, Sacramento, California, USA.

Mladenoff, D. J., T. A. Sickley, and A. P. Wydeven. 1999. Predicting gray wolf landscape recolonization: logistic regression models vs. new field data. Ecological Applications 9:37-44.

Morrison, M. L., B. G. Marcot, and R. W. Mannan. 1998. Wildlife-habitat relationships: concepts and applications. Univ. of Wisconsin Press, Madison, Wisconsin, USA.

National Park Service. 1996. Sequoia National Park: Official National Park Handbook. Division of Publications, National Park Service, Washington, D.C., USA.

Perrine, J. D. 2005. Ecology of red fox (*Vulpes vulpes*) in the Lassen Peak region of California. Dissertation, University of California, Berkeley, California, USA.

Powell, R. A., S. W. Buskirk, and W. J. Zielinski. 2003. Fisher and marten. Pages 635-649 *in* G. A. Feldhamer, B. C. Thompson and J. A. Chapman, editors. Wild Mammals of North America: biology, management and conservation. Johns Hopkins University Press, Baltimore, Maryland, USA.

Pullman, H. R. 2000. On the relationship between niche and distribution. Ecology Letters 3:349-361.

Rowland, M. M., J. J. Wisdom, D. H. Johnson, B. C. Wales, J. P. Copeland, and R. B. Edelmann. 2003. Evaluation of landscape models for wolverines in the interior northwest, United States of America. Journal of Mammalogy 84:92-105.

Ruggiero, L. F., D. E. Pearson, and S. E. Henry. 1998. Characteristics of American marten den sites in Wyoming. Journal of Wildlife Management 62:663-673.

Sierra Nevada Ecosystem Project. 1996. Final Report to congress. Centers for Water and Wildland Resources, University of California, Davis, California, USA.

Slauson, K. M. 2003. Habitat selection by American martens (*Martes americana*) in coastal northwestern California. Thesis, Oregon State University, Corvallis, Oregon, USA.

Slauson, K. M., R. L. Truex, and W. J. Zielinski. In Preparation. Distinguishing the sexes of American marten and fisher tracks at track plate stations.

Slauson, K. M., W. J. Zielinski, and G. W. Holm. 2003. Distribution and habitat associations of the Humboldt marten (*Martes americana humboldtensis*), and Pacific fisher (*Martes pennanti pacifica*) in Redwood National and State Parks, final report. United States Forest Service, Pacific Southwest Research Station, Arcata, California, USA.

Spencer, W. D. 1987. Seasonal rest-site preferences of pine martens in the northern Sierra Nevada. Journal of Wildlife Management 51:616-621.

SPSS Inc. 2003. Statistical Package for Social Sciences, Chicago, Illinois, USA.

Taylor, C. A., and M. G. Raphael. 1988. Identification of mammal tracks from sooted track stations in the Pacific Northwest. California Fish and Game 74:4-15.

Thomasma, L. E., T. D. Drummer, and R. O. Peterson. 1991. Testing the habitat suitability index model for the fisher. Wildlife Society Bulletin 19:291-297.

Thompson, I. D., and P. W. Colgan. 1987. Numerical responses of martens to a food shortage in northcentral Ontario. Journal of Wildlife Management 51:824-835.

Timossi, I. C., E. L. Woodward, and R. H. Barrett. 1995. Habitat suitability models for use with Arc/Info: Marten, CWHR technical report number 7. California Wildlife Habitat Relationships Program, California Department of Fish and Game, Sacramento, California, USA.

Tweed, W. C. 1976. Shorty Lovelace: Kings Canyon fur trapper. National Park Service, Western Regional Office, Division of Cultural Resource Management, San Francisco, California, USA.

Van Horne, B. 2002. Approaches to habitat modeling: the tensions between pattern and process and between specificity and generality. Pages 63-71 *in* J. M. Scott, P. J. Heglund, M. L. Morrison, J. B. Haufler, M. G. Raphael, W. A. Wall, and F. B. Samson, editors. Predicting species occurrences: issues of accuracy and scale. Island Press, Washington, D.C., USA.

Zielinski, W. J. 1995. Track plates. Pages 67-89 *in* W. J. Zielinski and T. E. Kucera, editors. American marten, fisher, lynx, and wolverine: survey methods for their detection. United States Forest Service, Pacific Southwest Research Station, General technical report, PSW-GTR-157, Albany, California, USA.

Zielinski, W. J., and H. B. Stauffer. 1996. Monitoring *Martes* populations in California: survey design and power analysis. Ecological Applications 6:1254-1267.

Zielinski, W. J., and R. L. Truex. 1995. Distinguishing tracks of marten and fisher at track-plate stations. Journal of Wildlife Management 59:571-579.

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.

Zweig, M. H., and G. Campbell. 1993. Receiver-operating characteristic (ROC) plots: a fundamental evaluation tool in clinical medicine. Clinical Chemistry 39:561-57.

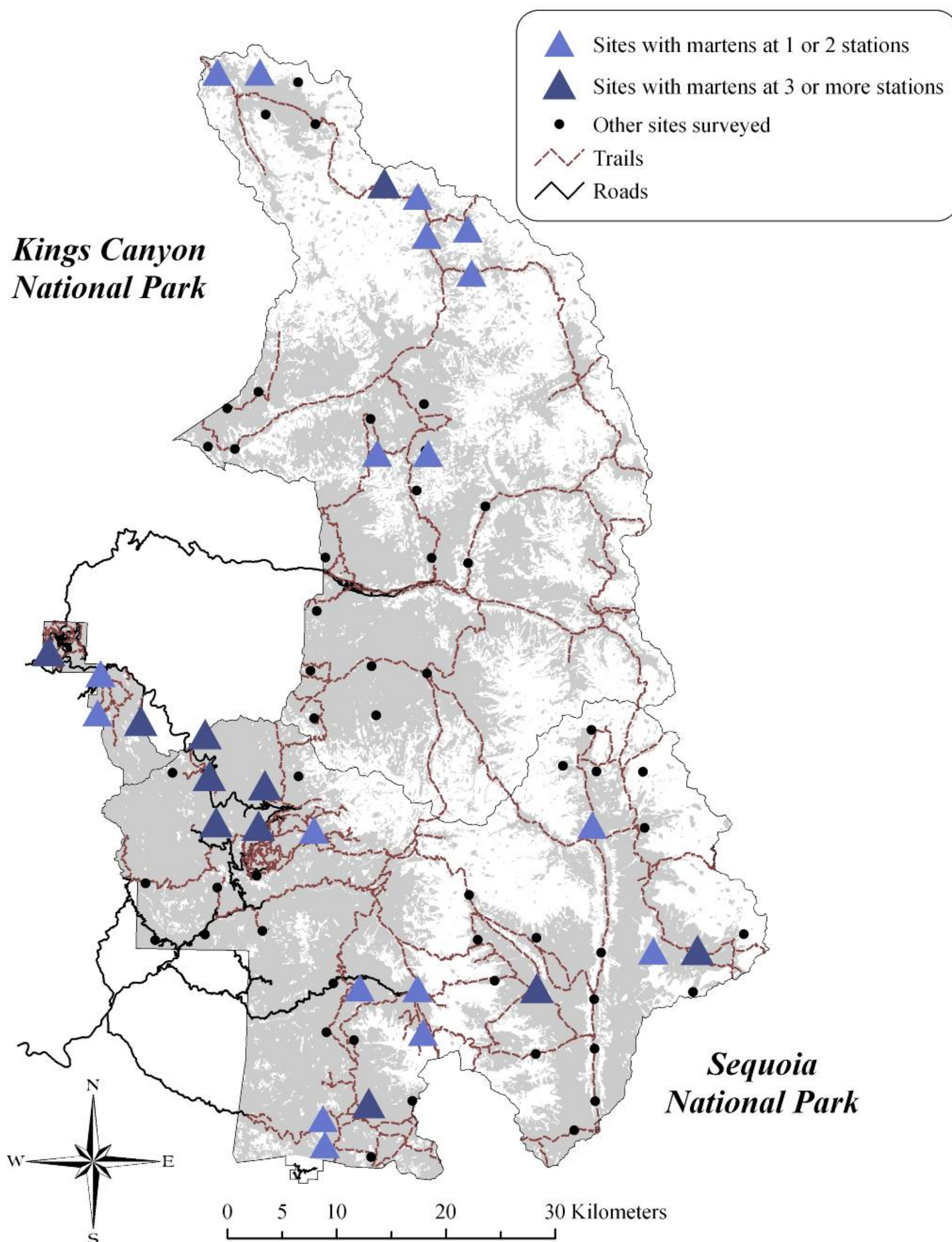


Figure 3. Distribution of sites with detections of American marten in Sequoia and Kings Canyon National Parks, California. Martens were detected by track or photo at 29 (36.7%) of 79 sites surveyed during summer and fall of 2002, 2003, and 2004. Sites have been grouped to show whether martens were detected at ≤2 or ≥3 of the 5 stations at the site. Forest and shrub dominated habitats are shown in gray and rock dominated areas are white

Table 5. Confusion matrices from logistic regression analyses showing predicted and observed presence or absence of American marten and corresponding percent correct classification at five cut-points. Predicted values were based on habitat suitability values from the California Wildlife Habitat Relationships (CWHR) model and observed values are from surveys conducted in Sequoia and Kings Canyon National Parks, California between 2002 and 2004. The geometric mean was used to calculate suitability values in this example; arithmetic mean calculations were nearly identical.

Cut-point	CWHR predicted	Observed		Total	Correct classification
		Present	Absent		
0.1	Present	29	50	79	0.37
	Absent	0	0	0	
0.3	Present	25	29	54	0.58
	Absent	4	21	25	
0.5	Present	8	9	17	0.62
	Absent	21	41	62	
0.7	Present	0	0	0	0.63
	Absent	29	50	79	
0.9	Present	0	0	0	0.63
	Absent	29	50	79	

Table 6. Measures of model performance calculated from confusion matrices using suitability values from the California Wildlife Habitat Relationships (CWHR) model and presence-absence data for American marten collected in Sequoia and Kings Canyon National Parks, California between 2002 and 2004. Values shown are for the original CWHR model, a model with increased values for Sierran mixed conifer (SMC), and the CWHR ArcInfo model. A cut-point of 0.5 was used.

Measures of model performance	Arithmetic mean	Geometric mean	Reproductive habitat	Cover habitat	Feeding habitat	SMC adjusted[a]	ArcInfo model[b]
Prevalence	0.37	0.37	0.37	0.37	0.37	0.37	0.37
Correct classification rate	0.62	0.62	0.62	0.62	0.65	0.68	0.63
Sensitivity	0.28	0.28	0.28	0.28	0.24	0.45	0.00
Specificity	0.82	0.82	0.82	0.82	0.88	0.82	1.00
Positive predictive power	0.47	0.47	0.47	0.47	0.54	0.59	(∞)[c]
Negative predictive power	0.66	0.66	0.66	0.66	0.67	0.72	0.63
Misclassification rate	0.38	0.38	0.38	0.38	0.35	0.32	0.37
Kappa	0.11	0.11	0.11	0.11	0.14	0.28	0.00

[a]SMC adjusted = CWHR values with increased suitability for class 6 Sierran mixed conifer from 0.66 to 1.0. Values were the same using either the arithmetic or geometric mean.
[b]ArcInfo model = Results from the CWHR GIS spatial model using the geometric mean calculation.
[c](∞) = Cases where a zero was present in the denominator.

Table 7. Measures of performance for the California Wildlife Habitat Relationships (CWHR) model for American marten and confusion matrices associated with two approaches to calculating optimal cut-points. Predicted values are based on CHWR habitat suitability classifications and observed presences or absences are from surveys conducted in Sequoia and Kings Canyon National Parks between 2002 and 2004.

Model	Cut point	OC[a]	AUC[b]	CC[c]	Sensitivity	Specificity	PrP|ObP[d]	PrP|ObA[d]	PrA|ObP[d]	PrA|ObA[d]
SMC[e] arithmetic	0.55	1	0.72	0.71	0.34	0.92	10	4	19	46
SMC arithmetic	0.45	2	0.72	0.70	0.66	0.72	19	14	10	36
SMC geometric	0.55	1	0.72	0.71	0.34	0.92	10	4	19	46
SMC geometric	0.45	2	0.72	0.70	0.66	0.72	19	14	10	36
Geometric mean	0.55	1	0.66	0.67	0.17	0.96	5	2	24	48
Geometric mean	0.30	2	0.66	0.58	0.86	0.42	25	29	4	21
Reproductive/Cover[f]	0.55	1	0.66	0.67	0.17	0.96	5	2	24	48
Reproductive/Cover	0.30	2	0.66	0.58	0.86	0.42	25	29	4	21
Feeding	0.55	1	0.66	0.67	0.17	0.96	5	2	24	48
Feeding	0.35	2	0.66	0.60	0.83	0.46	24	27	5	23
Arithmetic mean	0.45	1	0.66	0.66	0.41	0.80	12	10	17	40
Arithmetic mean	0.35	2	0.66	0.60	0.83	0.46	24	27	5	23

[a]OC = Cost of omission errors in calculation of cut point: 1 denotes equal cost of commission and omission errors, 2 means omission errors were twice as costly.
[b]AUC = Area under the curve calculated from receiver operator characteristic plots, a measure of model performance independent of cut point.
[c]CC = Rate of correct classification
[d]PrP|ObP: predicted and observed presence, PrP|ObA: predicted presence, observed absence, PrA|ObP: predicted absence, observed presence, PrA|ObA: predicted and observed absence
[e]SMC = CWHR suitability values for Sierran mixed conifer tree size class 6 were increased from 0.66 to 1.0.
[f]Reproductive/Cover = Values for reproductive and cover suitability categories were identical in this example and have been listed together.

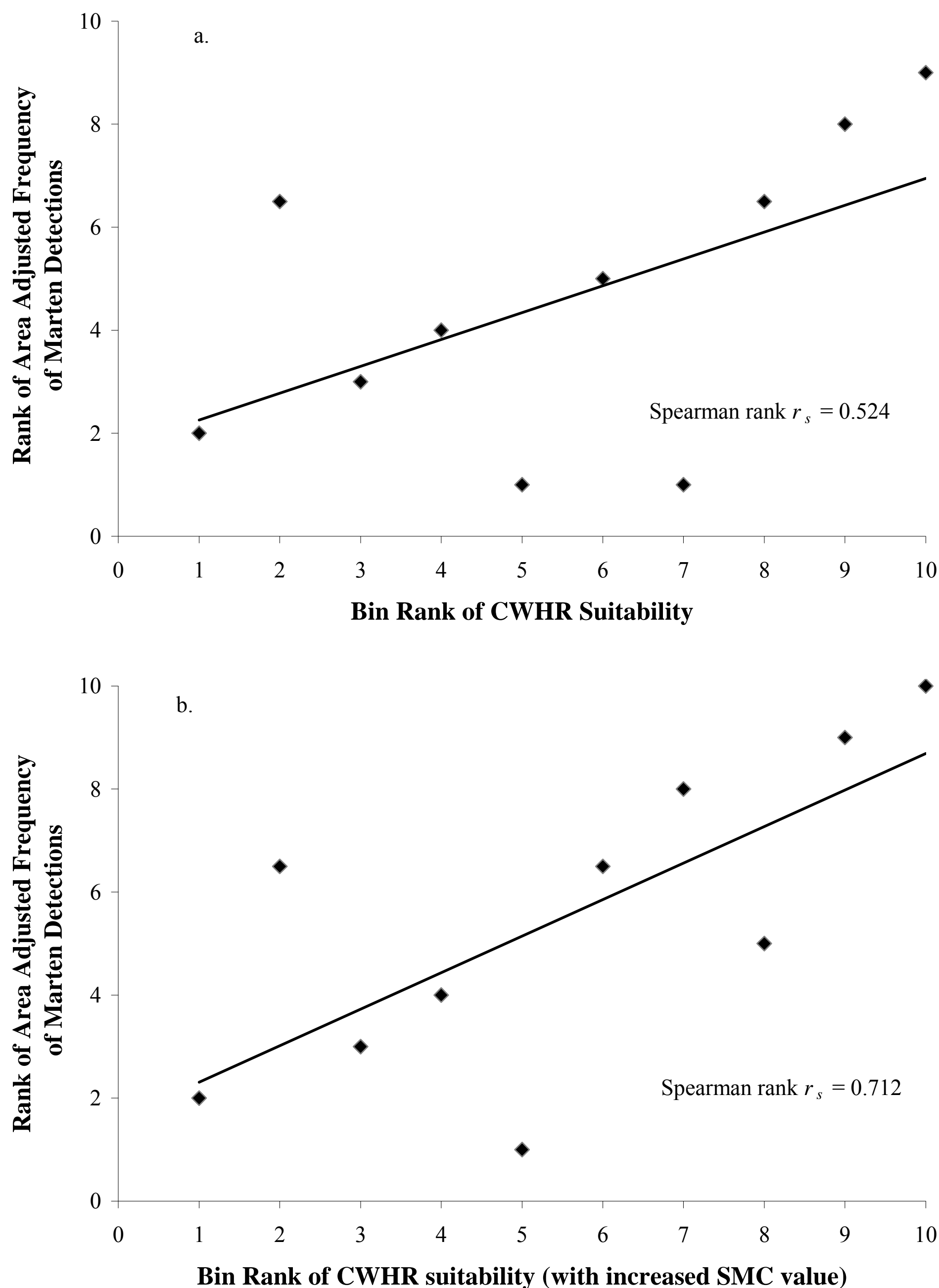


Figure 4. Relationship between ranked area-adjusted frequency of American marten detections and ranked bins of habitat suitability values based on the California Wildlife Habitat Relationships (CWHR) system. Spearman rank correlations were calculated using original suitability values in graph a ($P = 0.06$) and increased values for Sierran mixed conifer tree size class 6 in graph b ($P = 0.01$). The arithmetic mean calculation was used.

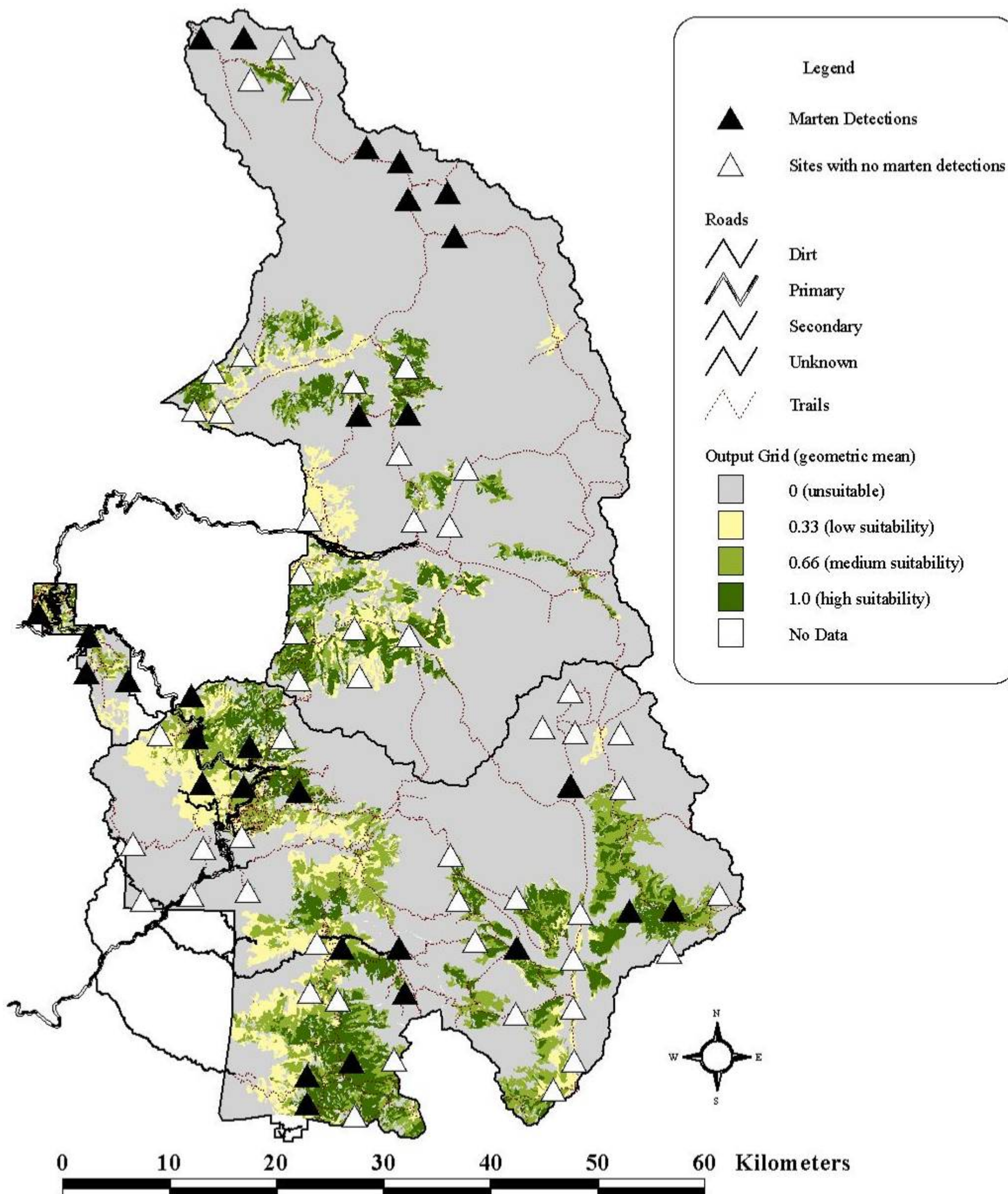
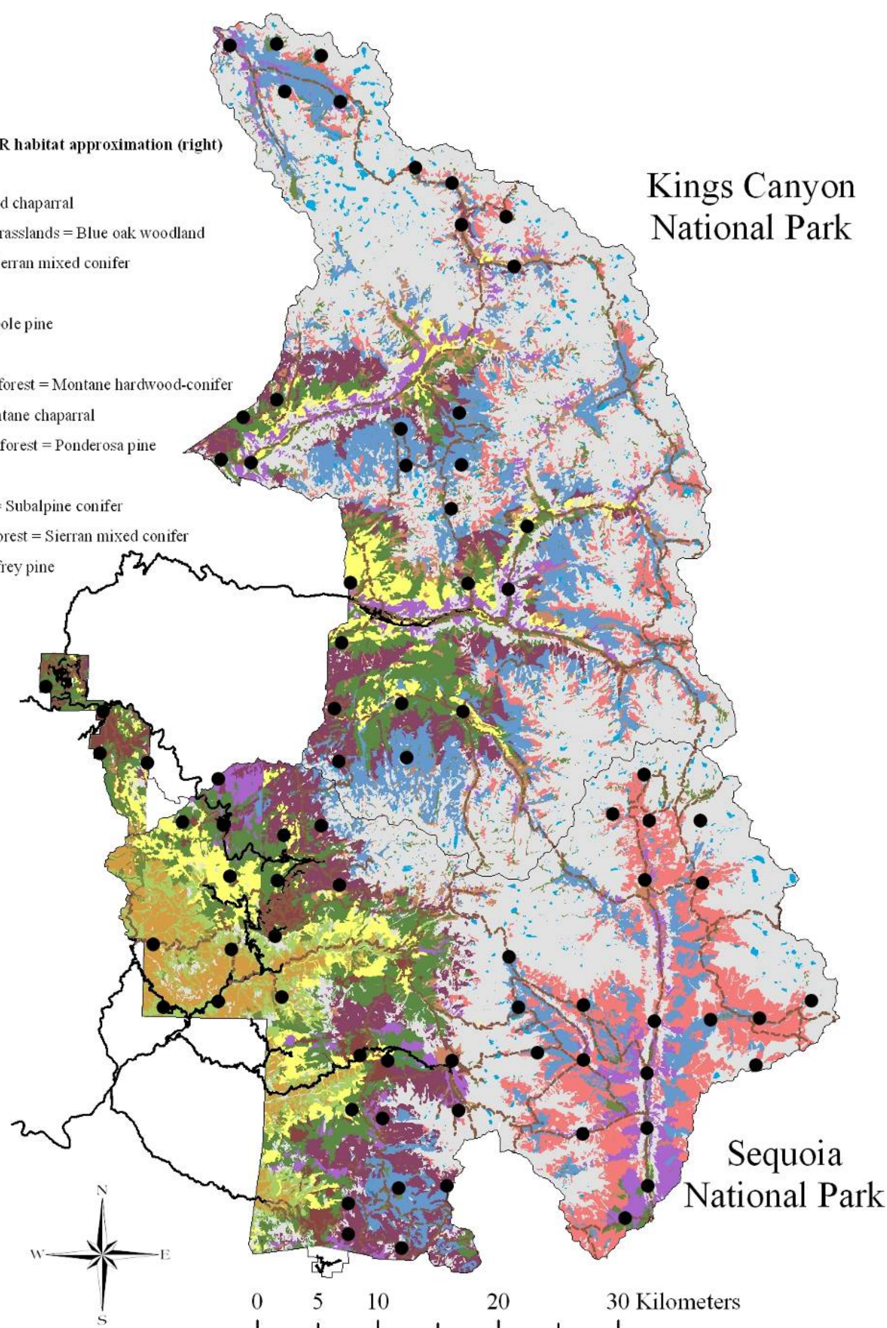
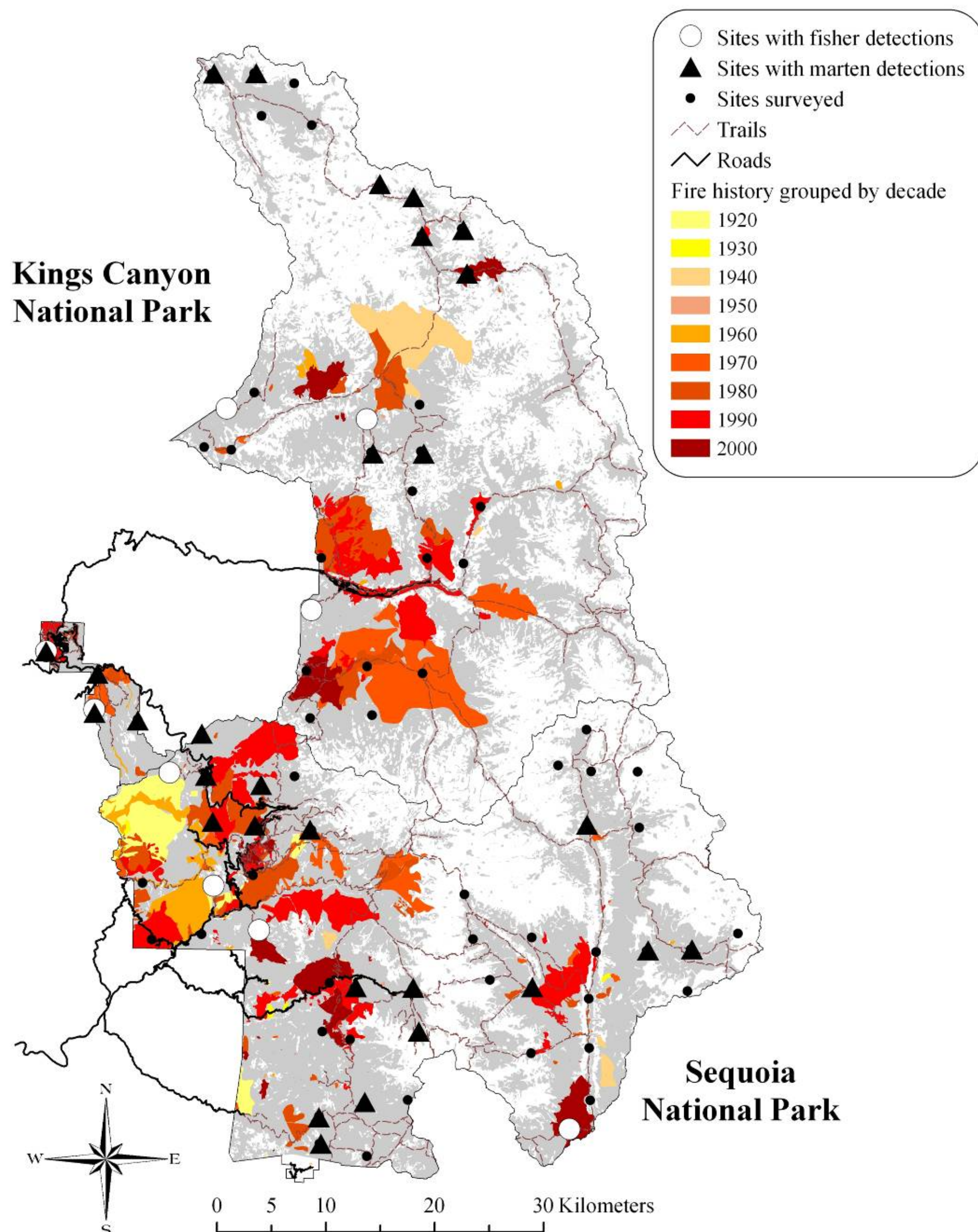


Figure 5. Output grid from the California Wildlife Habitat Relationships (CWHR) ArcInfo model showing predicted habitat suitability for American marten in Sequoia and Kings Canyon National Parks. Suitability values ranged from unsuitable at 0 to highly suitable at 1.0. Sites with and without detections of martens from surveys conducted between 2002 and 2004 are displayed.

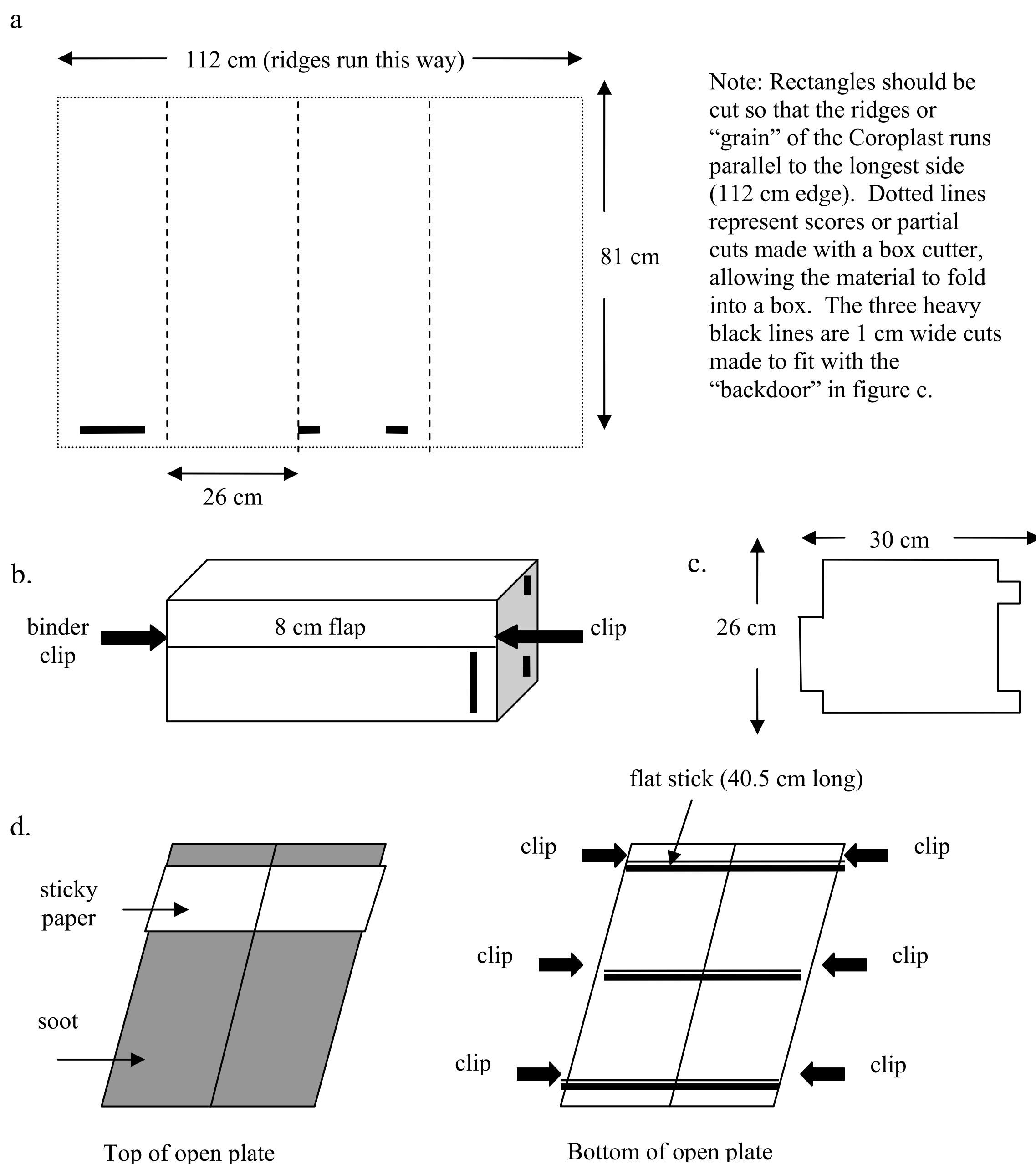


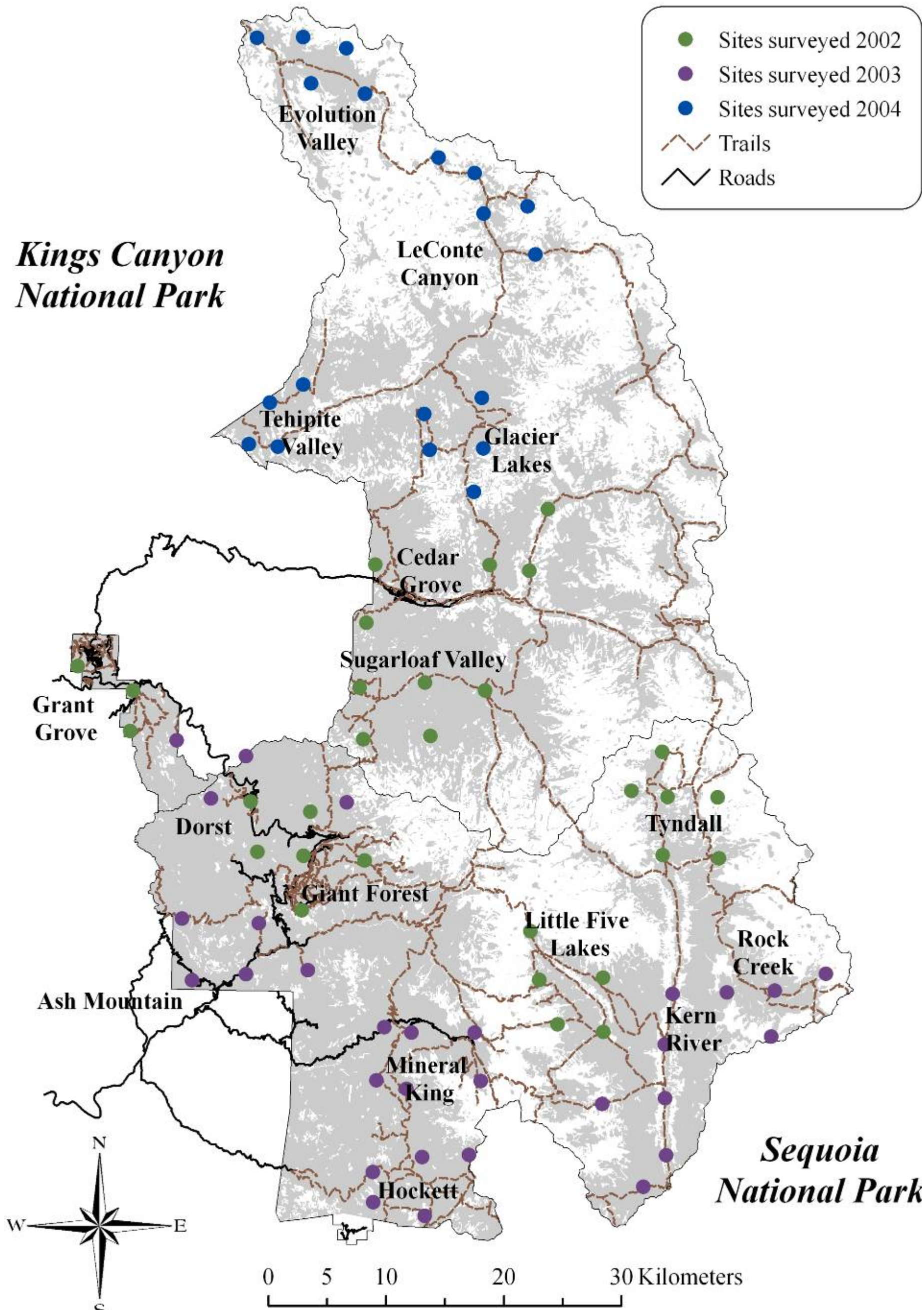
Appendix A. Vegetation categories available to forest carnivores and sites surveyed in Sequoia and Kings Canyon National Parks between 2002 to 2004. Digital National Park Service (NPS) vegetation categories were transformed to the closest California Wildlife Habitat Relationships (CWHR) classification for use in the ArcInfo model for American marten.



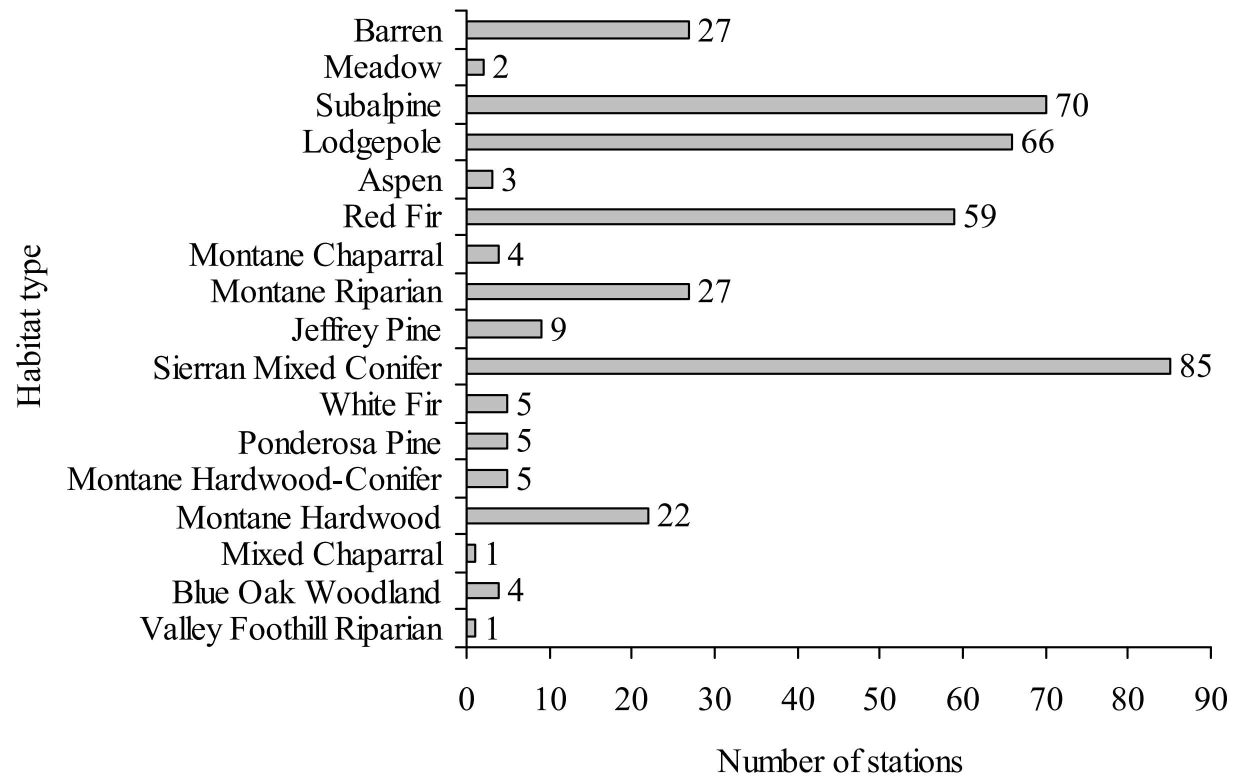
Appendix B. Recent and historic fire history (1920-2006) patterns in Sequoia and Kings Canyon National Park displayed by decade. This map reflects extent but not severity of the fires and includes prescribed, natural and accidental sources of ignition. Sites surveyed for forest carnivores between 2002 and 2004 are shown with corresponding detections of American marten and fisher. Forest and shrub dominated habitats without associated fire history are shown in gray and rock dominated habitats are in white.

Appendix C. Diagrams for the Coroplast track plate box and open plate used in this project: (a) pattern to cut Coroplast, (b) folded box secured by binder clips, (c) pattern for "backdoor" to seal off baited end of box, and (d) open plate configuration using two 20.3 x 76.2 cm aluminum plates, flat wooden sticks, and binder clips. Box design attributed to Gomper et al. 2006 with help from Chet Ogan of PSW Research Station. Open plate developed from ideas in Fowler and Golightly 1994 and Zielinski 1995.





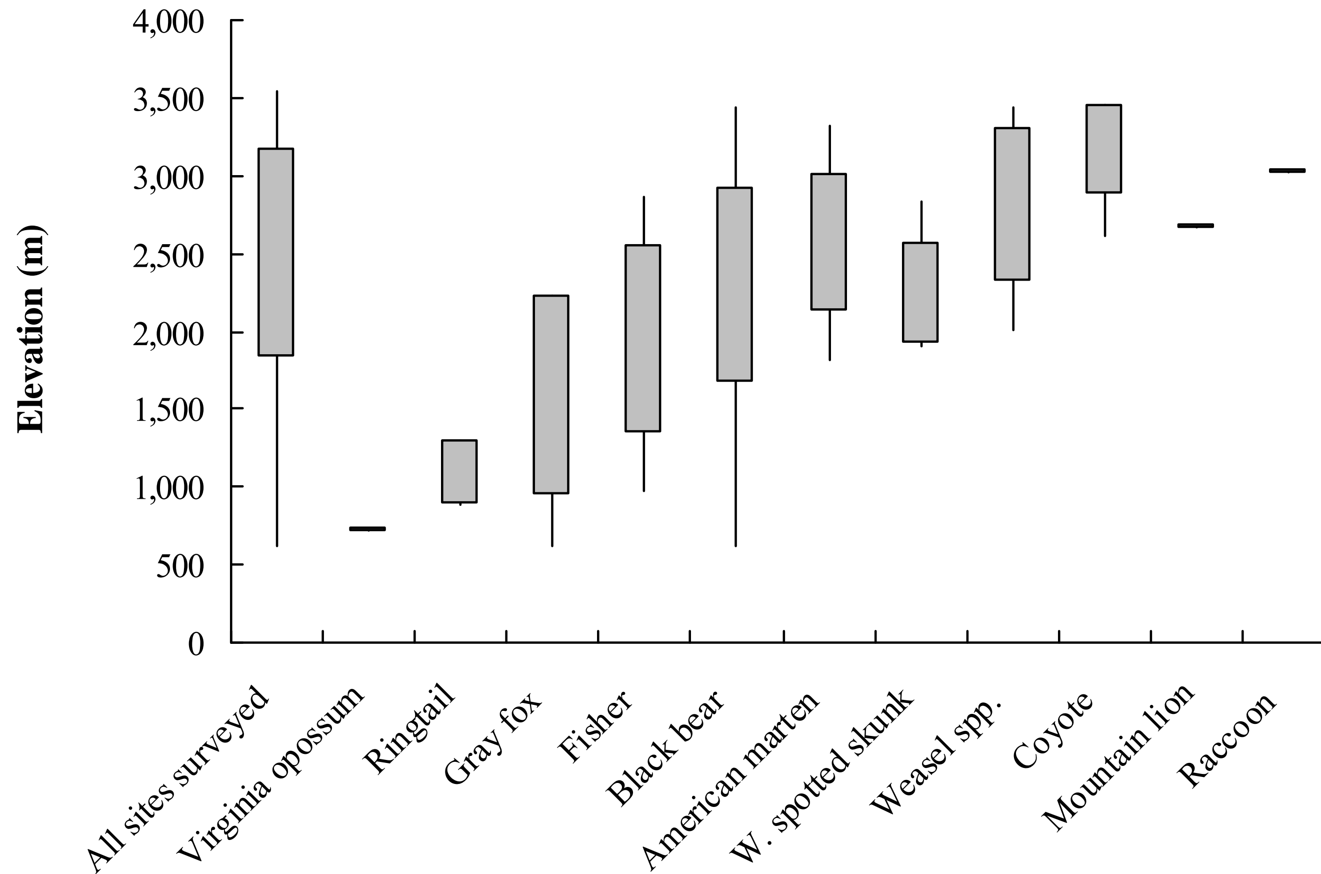
Appendix D. Map of Sequoia and Kings Canyon National Parks with place names of base camps and other locations used in describing the distribution of carnivores detected during surveys in 2002, 2003, and 2004. Forest and shrub dominated habitats are shown in gray, while rock dominated habitats are shown in white.



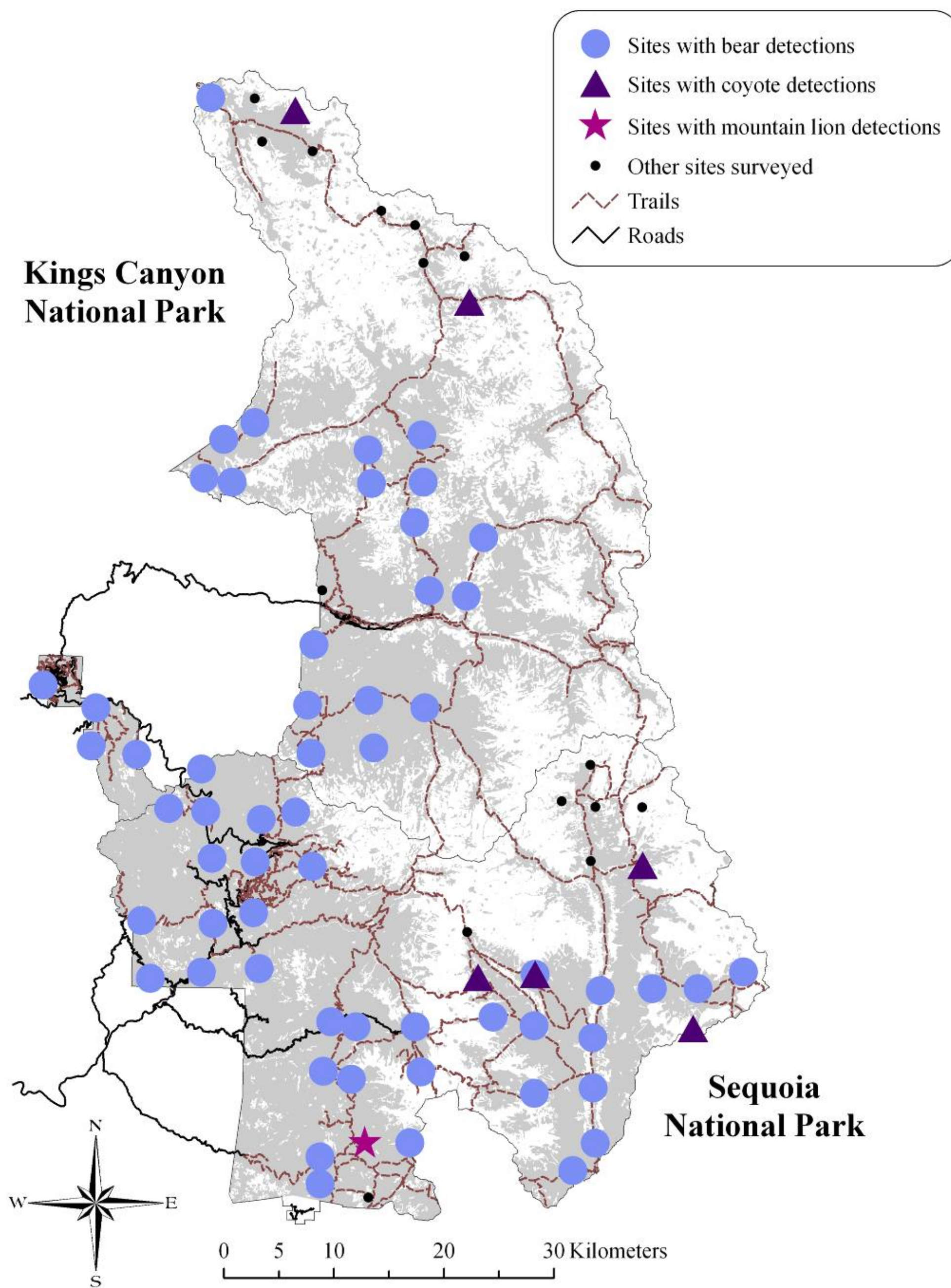
Appendix E. Habitat types, as classified by the California Wildlife Habitat Relationships (CWHR) system, at 395 stations surveyed for forest carnivores in Sequoia and Kings Canyon National Parks between 2002 and 2004. Habitat types are ordered by elevation, with foothill habitats at the bottom and alpine habitats at the top of the figure. The number of stations in each habitat type is noted at the end of the bar.

Appendix F. Detections of carnivores and one marsupial from surveys conducted in Sequoia and Kings Canyon National Parks, California using track plates and remote cameras. Sites (n = 79) were surveyed during summer and fall of 2002, 2003, and 2004. Each site consisted of five stations and sites were checked every three days for fifteen days.

Detections	Species										
	Black bear	American marten	Weasel sp.	Fisher	Western spotted skunk	Coyote	Gray fox	Ringtail	Mountain lion	Raccoon	Virginia opossum
Number of sites with detections	58	29	11	9	9	6	5	3	1	1	1
Number of stations with detections	192	67	12	13	13	7	11	8	1	1	1
Percent of sites with ≥ 1 detection	73.4	36.7	13.9	11.4	11.4	7.6	6.3	3.8	1.3	1.3	1.3
Total detections	374	140	13	18	16	9	19	19	1	1	1
Mean latency to first detection (days ± SD)	5.8 ±3.6	6.1 ± 4.6	10.6 ± 4.3	9.0 ±5.0	6.7 ± 4.9	6.5 ±3.5	6.6 ±3.9	3.0 ± 0	15.0 ± 0	3.0 ± 0	6.0 ± 0



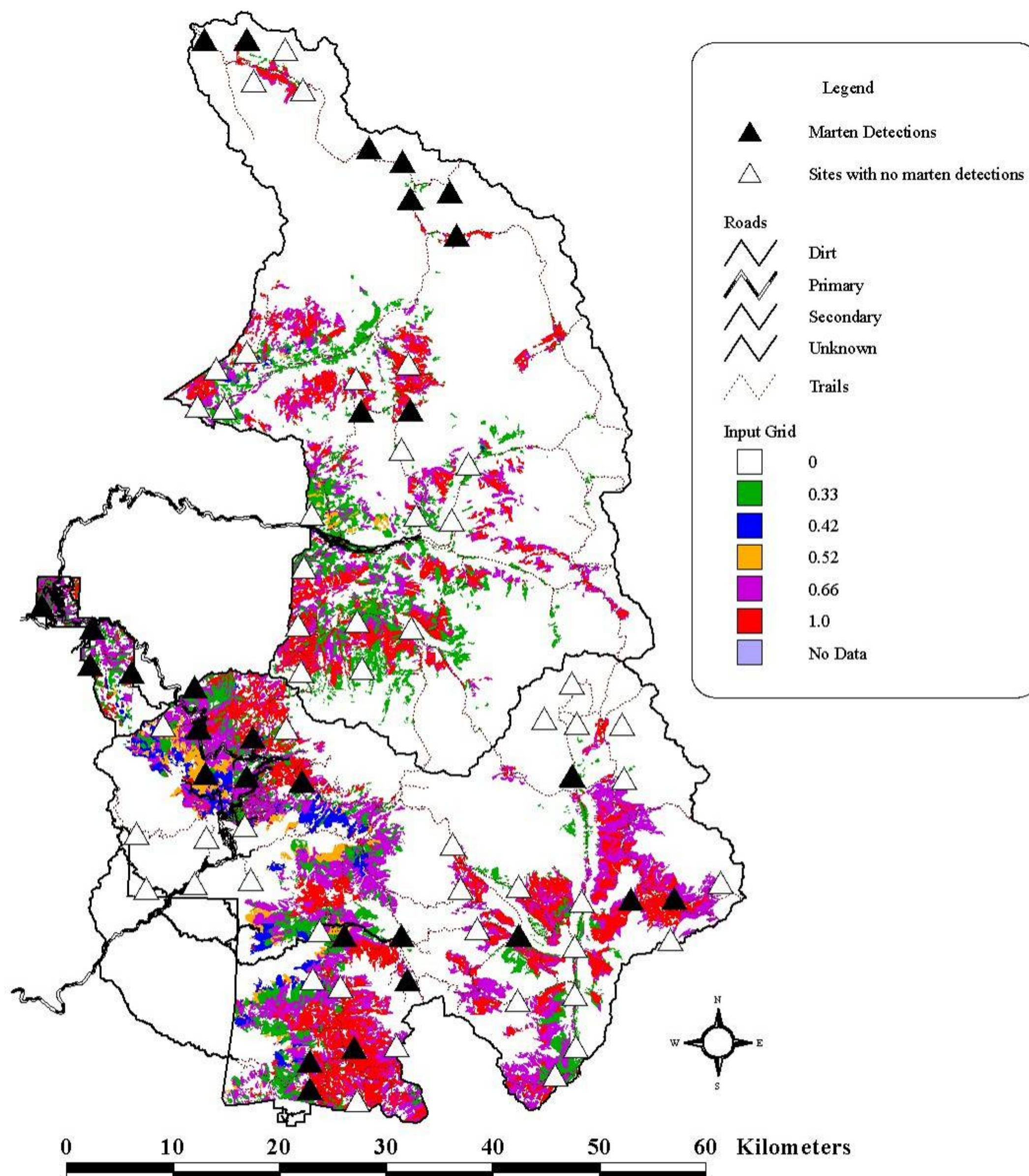
Appendix G. Distribution of sites with detections of carnivore and marsupial species by elevation from surveys conducted in Sequoia and Kings Canyon National Parks between 2002 and 2004. Elevations of the five stations at each site were averaged to represent the site, and elevations ranged from 614 to 3,536 m across sites (*n* =79) surveyed. Vertical lines illustrate the range of detections for each species, gray bars signify ± 1 SD from the mean, and horizontal bars denote single detections.



Appendix H. Distribution of sites with detections of black bear (58), coyote (6), and mountain lion (1) in Sequoia and Kings Canyon National Parks, California. Sites (n = 79) were surveyed using track plates and remote cameras during 2002, 2003, and 2004. Forest and shrub dominated habitats are shown in gray and rock dominated areas are white.

Appendix I. Density of a subset of habitat elements for American marten from the California Wildlife Habitat Relationships model and boulder cover measured at survey stations in Sequoia and Kings Canyon National Parks. Characteristics were determined by tallies from two 50 x 10 m vegetation transects. Numbers presented are the mean density of five stations at each site where martens were determined to be present (*n* = 29) or absent (*n* = 50).

Habitat element	Marten detected		Marten not detected	
	Mean	st dev	Mean	st dev
Density large logs (>20" diam) per ha	16.8	14.0	16.4	13.4
Density medium logs (10-20" diam) per ha	46.5	25.9	43.2	29.2
Density combined logs per ha	63.3	34.4	59.6	37.6
Density large snags (>30" diam) per ha	4.4	6.5	2.6	3.8
Density medium snags (15-30" diam) per ha	9.1	6.8	7.2	7.1
Density combined snags per ha	13.6	11.0	9.9	9.5
Density stumps (<3 m/10' tall) per ha	8.1	8.0	5.3	4.9
Density live firs (>11" dbh) per ha	67.8	68.4	48.9	66.9
Density live pines (>11" dbh) per ha	64.1	63.9	61.8	59.7
Density firs and pines (>11" dbh) per ha	132.0	57.7	110.8	76.0
Density boulder spaces (>6" diam) per ha	39.6	55.0	36.0	41.6



Appendix J. Suitability grid created for use in the ArcInfo application of the California Wildlife Habitat Relationships system model for American marten. This input grid was created using digital vegetation data for habitat type, canopy cover, and a surrogate for tree size class in Sequoia and Kings Canyon National Parks. Numerical values represent habitat suitability for marten and range from 0 (unsuitable) to 1.0 (highly suitable). Sites surveyed during 2002, 2003 and 2004 and associated marten detections are also shown.

Appendix K. Description of habitat at sites in or adjacent to rock cover with detections of American marten in Sequoia and Kings Canyon National Parks.

During surveys conducted in Sequoia and Kings Canyon National Parks between 2002 and 2004, a number of American marten detections occurred in a matrix of rock, shrub, and riparian forests at high elevations (Appendix A, Figure 3). Specifically, detections occurred in habitats where rocks provided overhead cover, in the interface between tree and boulder cover, or along narrow strips of riparian forest adjacent to rock and shrub cover. Following are further descriptions of the habitat characteristics at these sites. CWHR vegetation classifications (e.g., habitat type, tree size class, canopy cover categories) are listed in parentheses. Although I do not know how martens used these areas, detections only occurred at sites with some form of overhead cover (e.g., numerous boulders, shrubs, tree layer) as well as cover linking the site to another area of predicted suitable habitat. Sites are described from north to south (see Appendix D).

In the vicinity of Evolution Valley, one detection (Subalpine, 4, P) occurred north of the densely forested valley on a small nameless plateau at 3,260 m. This station was located in a cluster of white bark pines and was between a meadow and a rock dominated slope near tree line. Numerous boulders provided potential hiding spaces and travel corridors between the nearby rocky slope and forest cover. A creek draining off the plateau into Evolution Valley provided a combination of tree, boulder, and log cover that may have facilitated travel between the two areas. A second detection (Montane Riparian, 4, D) in this general area occurred at a lower elevation site northwest of Evolution Valley along the San Joaquin River. This detection occurred in a mix of aspen

Appendix K. Description of habitat at sites in or adjacent to rock cover with detections of American marten in Sequoia and Kings Canyon National Parks. (continued)

(*Populus tremuloides*), white fir, and willow (*Salix sp.*) in a narrow stretch of canyon situated adjacent to a boulder covered slope.

In the Le Conte Canyon area, marten detections occurred at all five sites in a mix of barren, subalpine, and forested riparian habitats. One site was located next to a small lake at about 3,320 m just east of the much larger Helen Lake, with detections at four of the five stations (three in Barren, one in Subalpine, 4, S). Of the three barren stations, one was in the middle of a boulder field, one was on an edge between a boulder field and a small meadow patch, and the third was on a large rocky outcrop with boulder cover and a few whitebark pines (*Pinus albicaulis*). The fourth station (camera) was located in a clump of whitebark pines adjacent to a section of talus. The boulders and talus provided numerous openings and potential corridors for a marten to travel while remaining mostly, if not entirely, protected by overhead cover. Pikas were present in the talus, mountain yellow-legged frogs (*Rana mucosa*) occurred in the lake, and Douglas squirrels (*Tamiusciurus douglasii*) and several bird species were seen in the whitebark pines. A marten was detected on every visit to this site, and based on a unique toe pattern (one bent toe pad) it appeared to be the same individual (probable female based on track size). Another marten was detected at a similar site at about 3,300 m in Dusy Basin (Barren), at only one station located in a small boulder field with much potential cover. Both the Helen Lake and Dusy Basin sites were connected to a lower and more densely forested section of Le Conte Canyon by a mix of boulder, shrub, and tree cover.

Appendix K. Description of habitat at sites in or adjacent to rock cover with detections of American marten in Sequoia and Kings Canyon National Parks. (continued)

Two sites in Le Conte Canyon and one in adjacent Palisade Creek canyon had marten detections. The Big Pete Meadow site in upper Le Conte Canyon was at 2,830 m, contained a mix of meadow, lodgepole pine (*Pinus contorta*), aspen, boulder, and shrub cover, and was adjacent to a talus covered slope. One station was dominated by aspen and shrub cover (Aspen, 3, S) and the other was on the edge of a boulder field with a few small aspen (Barren). At the first station, manzanita (*Arctostaphylos sp.*), chinquapin (*Chrysolepis sempervirens*), and *Ceanothus* sp. provided ground cover along with small aspen and boulders. Aspen root clusters and trees bent by avalanches offered numerous additional potential hiding spaces. The site named Le Conte was located further south in the canyon at about 2,600 m along the river. The site was forested, but largely surrounded by boulder and shrub cover. Both detections occurred in a mix of relatively large red firs and smaller lodgepole pines, with chinquapin, bracken fern (*Pteridium aquilinum*), aspen, and willow present (Subalpine 4, M, and Subalpine 5, D). The final detection in this area occurred at a site along Palisade Creek at about 2,610 m in lodgepole forest that partially burned a few years before and was bordered by aspen, Jeffrey pine (*Pinus jeffreyi*), meadow, and boulder cover (Lodgepole, 5, M).

Two sites in central Kings Canyon National Parks had marten detections in lodgepole forest with scattered western white pines (*Pinus monticola*) and boulder cover near lakes. The first was at one of the Glacier Lakes around 3,110 m at a station located between a small stream with tree and willow cover, the lake, and a talus slope (Lodgepole

Appendix K. Description of habitat at sites in or adjacent to rock cover with detections of American marten in Sequoia and Kings Canyon National Parks. (continued)

4, P). This station was surrounded by a number of boulders, granite slabs, and willows which could have provided cover between the forested area and the talus slope for a marten. The second site was on a small ridge just above one of the Volcanic Lakes at about 3,100 m (Lodgepole, 4, P). This station was in open forest adjacent to an area with lots of cover in the form of boulders and granite slabs. Detections at both Glacier and Volcanic lakes occurred at open plates which were placed under boulders with overhead cover. Golden-mantled ground squirrels (*Spermophilus lateralis*), Douglas squirrels, and pikas were all seen nearby, along with numerous birds.

The Upper Kern site in the Tyndall area was located in a northern, but still forested, section of the Kern River, and is mentioned primarily because a marten was observed escaping into rock cover by members of the survey crew (R. Green and A. Baltensperger) less than 1 km from the site. Walking south along the trail towards the site in northern Sequoia National Park, Green and Baltensperger briefly saw a marten between the trail and the river in an area with open tree cover and scattered large rocks. Surprised, the marten bolted into an opening about 20 cm wide in the cover of boulders and did not come back out while the hole was watched. A marten detection (possibly the same individual) occurred at the nearby site at 2,720 m in riparian forest dominated by lodgepole pine next to the river, with some log, willow, and boulder cover (Montane riparian, 4, M). Extensive shrub and boulder cover was present upslope from the riparian forest in this part of the canyon.

Appendix L. California Wildlife Habitat Relationships (CWHR) system classifications of vegetation at 67 stations with detections of American marten from surveys in Sequoia and Kings Canyon National Parks between 2002 and 2004.

CWHR habitat type	Tree size[a]	Canopy cover[b]	Arithmetic value[c]	Geometric value[d]	Number of stations with detections (%)
Aspen	Class 3	Sparse	0.11	0	1 (1.5)
Barren	n/a	<10%	0	0	5 (7.5)
Lodgepole	Class 5	Dense	1	1	1 (1.5)
	Class 5	Moderate	1	1	2 (3.0)
	Class 4	Moderate	1	1	3 (4.5)
	Class 4	Open	0.66	0.66	1 (1.5)
	Class 4	Sparse	0.22	0	1 (1.5)
Montane riparian	Class 6	Dense	1	1	5 (7.5)
	Class 4	Dense	0.66	0.66	1 (1.5)
	Class 4	Moderate	0.66	0.66	1 (1.5)
Red fir	Class 5	Dense	1	1	11 (16.4)
	Class 5	Moderate	1	1	1 (1.5)
	Class 4	Dense	1	1	1 (1.5)
	Class 4	Moderate	1	1	1 (1.5)
Sierran mixed conifer	Class 6	Dense	0.66	0.66	22 (32.8)
	Class 4	Dense	0.66	0.66	1 (1.5)
	Class 4	Moderate	0.66	0.66	2 (3.0)
Subalpine	Class 5	Dense	1	1	2 (3.0)
	Class 5	Open	0.66	0.66	1 (1.5)
	Class 4	Moderate	1	1	1 (1.5)
	Class 4	Open	0.66	0.66	2 (3.0)
	Class 4	Sparse	0.22	0	1 (1.5)

[a]Class 3 = 15.2-27.7 cm dbh; Class 4 = 27.9-60.7cm dbh; Class 5 = 61.0 cm dbh; Class 6 = class 5 trees over layer of class 3 or 4 with dense canopy cover.
[b]Sparse = 10-24.9%, open = 25-39.9%, moderate = 40-59.9%, dense ≥60%.
[c]Arithmetic value = (reproductive + cover + feeding suitability)/3
[d]Geometric value = $\sqrt[3]{(\text{reproductive x cover x feeding suitability})}$