AN ABSTRACT OF THE THESIS OF

Katie M. Moriarty for the degree of Master of Science in Wildlife Science presented on August 19, 2009.

Title: American Marten Distributions over a 28 Year Period: Relationships with Landscape Change in Sagehen Creek Experimental Forest, California, USA

Abstract approved:

Eric D. Forsman

The distribution of American martens (*Martes americana*) within Sagehen Creek Experimental Forest (SCEF), Tahoe National Forest, California has been periodically documented from 1980–1993. This area has been the location of nine marten surveys, each involving a systematic detection/nondetection survey on the same grid. These data are an unprecedented time series of information on the distribution of martens that can be related to habitat change in the study area. My four objectives were to (1) resurvey SCEF using similar methodology as in previous studies to assess the current marten distribution, (2) evaluate marten

distribution over the last 28 years, (3) create maps to depict potential high-reproductive habitat at the beginning (1978) and end (2007) of the series, and lastly, (4) examine marten occurence relative to changes in habitat and landscape metrics. Marten surveys were conducted in summer 2007, in winter 2007–2008, and in summer 2008. Habitat was characterized both in 1978 and 2007 by interpreting remotely sensed vegetation information from the California Wildlife Habitat Relationship (CWHR) system. I used FRAGSTATs to quantify landscape change.

There was a dramatic decline in marten occurrence since they were first studied in this area. No martens were detected in either the summer of 2007 or summer 2008, but there were 10 detections in winter 2007–2008 limited to the southwestern portion of SCEF. Predicted habitat patch size, core area, and total amount of predicted habitat in the study area decreased. Distance between these patches increased. There was a relationship between these changes in landscape configuration and the reduction of marten detections; no martens were detected in the lower elevations where most previous management activity occurred.

I have five recommendations to managers to make the landscape more amenable for martens: (1) strive to retain the remaining contiguous large patches of predicted marten reproductive habitat, (2) maintain corridors of dense, multi-layered vegetation between the contiguous habitat patches, (3) retain varied amounts of canopy and shrub cover for visual camouflage between habitat patches, (4) reduce the number of cleared forest gaps >80 m across, and (5) strive for a silvicultural paradigm that retains large snags, diverse tree structure, and patches of decadent trees.

American Marten Distributions over a 28 Year Period: Relationships with Landscape Change in Sagehen Creek Experimental Forest, California, USA

by

Katie M. Moriarty

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APPROVED:

Major Professor, representing Wildlife Science

Head of the Department of Fisheries and Wildlife

Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Katie M. Moriarty, Author

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One of the most difficult pieces to this puzzle was to develop an understanding of the history of marten surveys and vegetation change in Sagehen and the surrounding area. This knowledge was collected not only from theses and records, but directly from the people who had studied marten in SCEF in the past. I'd like to recognize Bill Zielinski again for his continued enthusiasm concerning the Sagehen Basin. Wayne Spencer, Sandy Martin, and Terri Simon-Jackson also provided data, advice, and wisdom from their projects.

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DEDICATION

I dedicate this work to my family:

to my brother, Jason Moriarty, who has been a large focus of my life.

to my mother, Rita, whose constant support is immeasurable and ever appreciated.

and to my recently departed father.

INTRODUCTION

Significant contractions have occurred in the ranges of many mammalian carnivores since the 19th century (Laliberte and Ripple 2004). One carnivore species, the American marten, *Martes americana*, is particularly vulnerable to local extirpations (Bissonette et al. 1997, Chapin et al. 1998, Hargis et al. 1999, Fuller 2006). The American marten, hereafter marten(s), is considered a U.S. Forest Service species of special concern under the National Forest Management Act of 1976, and is a management indicator species for seven national forests in California.

Comparisons of the historical and current distribution of martens indicate a decline within their range in the northern Sierra Nevada and southern Cascade mountain ranges (Zielinski et al. 2005). In these mountains, martens reside in high elevation forests with late-successional attributes (Spencer et al. 1983, Smith and Schaefer 2002). They are associated with areas with high canopy cover, especially in winter (Spencer et al. 1983, Thompson and Harestad 1994), and often occupy areas where more than two-thirds of the landscape is covered by closed canopy forests (Bissonette et al. 1997, Chapin et al. 1998, Hargis et al. 1999, Fuller 2006). Martens are thought to prefer dense forests with complex structure because they are able to forage most effectively in such forests (Bissonette et al. 1997, Andruskiw et al. 2008), and because such forests provide resting and denning sites (Spencer 1987), as well as escape and thermal cover (Strickland and Douglass 1987, Drew 1995). Due to their specialized habitat requirements, martens are sensitive to land management activities that reduce forest cover and continuity (Buskirk and Powell 1994, Fuller and Harrison 2005).

Habitat loss and fragmentation are concerns for the viability of marten populations (Hargis et al. 1999, Carroll 2007, Kirk 2007, Kirk and Zielinski 2009). Herein, habitat loss refers to a reduction in the amount of habitat that is thought to be suitable for martens. Fragmentation refers to an increase in the number of suitable patches, a decrease in the size of suitable patches, or an increase in patch isolation (Fahrig 2003). For forest dwelling species like martens, fragmentation and habitat loss are thought to influence patch and landscape occupancy by decreasing colonization rates and increasing rates of local extirpation (MacAuthur and Wilson 1967, Andren 1994, With and King 1998). Landscape metrics measure fragmentation and loss by describing habitat composition, the variety and abundance of patches, or their configuration, which is the spatial character, arrangement, position, and orientation of patches (Leitão et al. 2006). Habitat metrics can be used to predict the distribution and behavior of many organisms, including martens (MacDonald and Rushton 2003, Broquet et al. 2006).

The distribution of martens in Sagehen Creek Experimental Forest (SCEF) on the Tahoe National Forest near Truckee, California was documented in a series of nine systematic surveys completed during the period 1980–1993 (Spencer 1981, Zielinski 1981, Martin 1987, 1995). This rich data set provides a time series of information on the distribution and abundance of martens as well as forest management history in SCEF. The vegetation types and range of elevations within SCEF are representative of much of the range of the marten in the southern Cascades and Sierra Nevada. Thus, patterns observed within SCEF may be indicative of changes throughout the region. In particular, regional data suggest marten declines in the Cascades and northern Sierra mountain ranges (Zielinski et al. 2005).

My objective was to conduct a contemporary survey of marten distribution and abundance at SCEF that could be compared with results from earlier surveys on this area. I also sought to use these data to explore relationships between marten detections and habitat changes that occurred over time at SCEF. My first goal was to describe the change in marten occurrence during the 28-year period from the initial marten surveys in 1980 to my surveys in 2007–2008. I hypothesized that the percentage of marten detections among survey periods would be similar to the 1980 survey if predicted habitat remained at similar levels because habitat should be closely linked to marten distributions. Conversely, marten detections may have declined, increased, or fluctuated among survey years. If martens were affected by habitat change I would expect to see a pattern similar to the fluctuations in habitat availability. If the amount of prey or predation risk from other carnivores were limiting factors I would expect marten occurrence to be independent of, or weakly correlated with habitat changes. Secondly, the spatial distribution of martens may be linked to both the amount and spatial arrangement of predicted high quality habitat, particularly reproductive habitat. Several forest management events (1988 Golden Timber Harvest, 1990 Salvage Harvest, 1994 Forest Thinning, 2004 Thinning, and 2005 Harvests) occurred within the 28-year period, and much of SCEF is proposed for future management to reduce tree density for the purpose of fuel treatments (Table 1). I used program FRAGSTATs (McGarigal et al. 2002) to calculate habitat composition and configuration in two time periods (1978, 2007). The years 1978 and 2007 were chosen because of their proximity to the initial and contemporary marten surveys as well as availability of both aerial photographs and LANDSAT imagery. I predicted that change in the amount and configuration of habitat between the two time periods would correspond with marten occurrence when accounting for differences in survey season, number of stations, and time since the initial survey.

A secondary objective was to evaluate marten detections in relation to environmental covariates using AIC model selection and logistic regression. I developed three datasets to analyze. The first two analyses served as preliminary explorations of marten habitat use in 1983 and 2007, and the third was used to directly correlate changes in marten detections with changes in environmental variables during 1983–2007. I predicted that marten detections would be best explained by similar covariates in the first two analyses, as I assumed that the features that martens select would be the same during both time periods. Spencer (1981) found martens selected habitat differently between a co-variate designated as the upper and lower basin (divided by the 2050 m contour line) within SCEF.

Based on earlier work at SCEF (Spencer 1981, Martin 1987) I predicted that my models for 1983 and 2008 would reflect a preference for red fir or riparian vegetation types, dense cover, large tree size, and close proximity to water or meadow systems. Fuller (2006), Chapin et al. (1999), and Hargis et al. (1999) observed that martens are sensitive to habitat fragmentation. For this reason in the third analysis I predicted that decreasing patch size, increasing distance of patches from stations, and decreasing elevation would be included in the most parsimonious model for predicting change in marten detections.

STUDY AREA

Sagehen Creek Field Station has been managed by the University of California, Berkeley since 1951 and was designated as California's 11th experimental forest in November 2005. The experimental forest occupies most of the Sagehen Creek watershed, which is located on the eastern slope of the Sierra Nevada Mountains approximately 12 km northwest of Truckee, California (Figure 1). Elevations on the 40 km^2 experimental forest range from 1862–2670 m. Climate is characterized by short dry summers with moderate temperatures (0 to 21˚C) and long, cold winters (-8 to 7˚C), during which the majority of precipitation occurs as snow. Average annual precipitation is 85 cm, of which ~80% occurs as snow in winter. Total annual snowfall depth averages 515 cm (Western Regional Weather Center 1953–2006). In a typical year, snow is present from December to April.

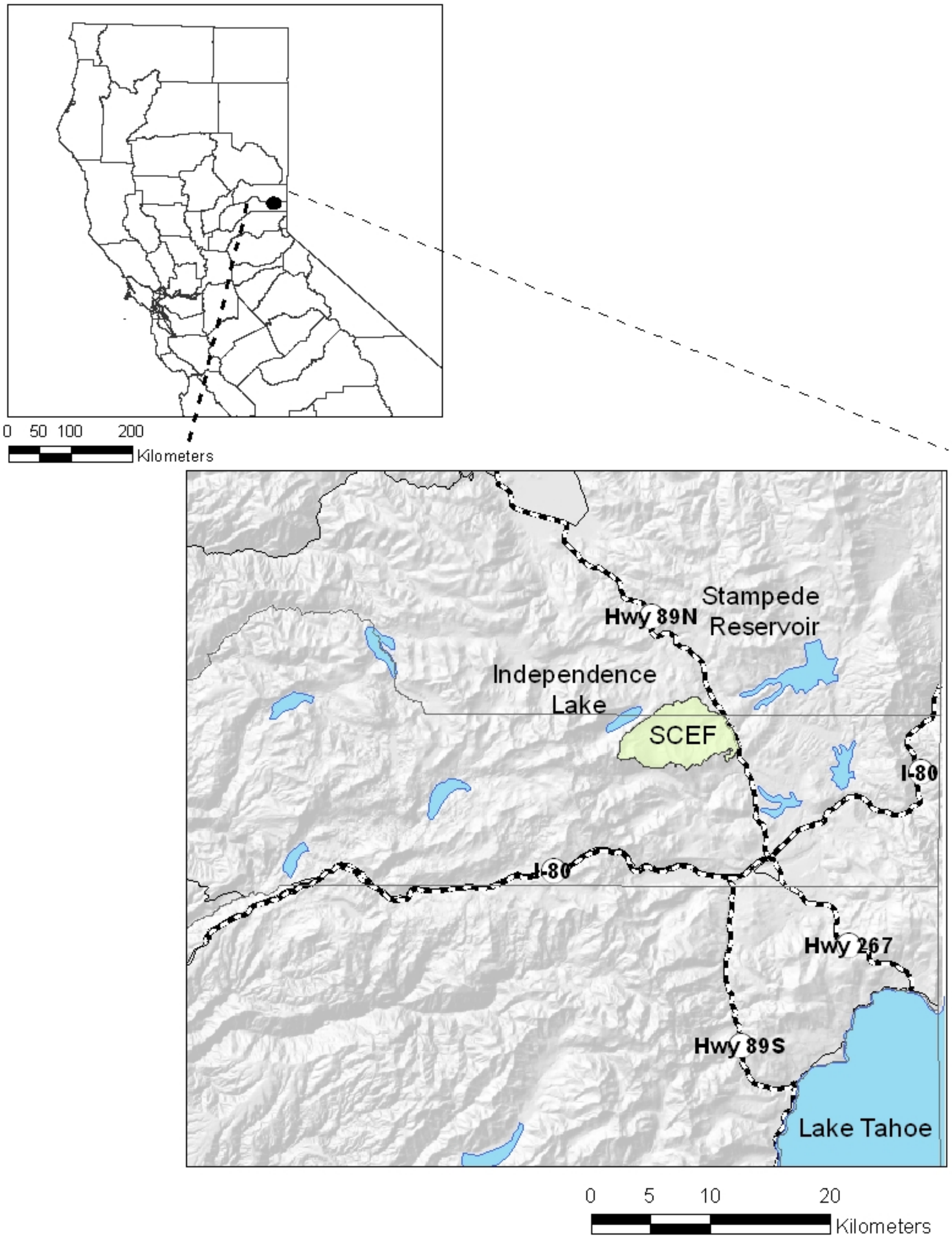


Figure 1. Sagehen Creek Experimental Forest study area, Nevada and Sierra Counties, CA.

Sagehen contains both montane and subalpine flora (Barbour et al. 2007). Major vegetation cover types include a mixture of riparian corridors, fens and wet meadows at lower elevations, and mixed-conifer forests throughout the study area (Savage 1973). Riparian and mesic areas at lower elevations are dominated by lodgepole pine (*P. contorta*) with a ground cover of sedges, forbs, and willow shrubs (*Salix spp.*). Xeric south-facing slopes are covered by Jeffrey pine (*Pinus jeffreyi*) or mixed stands of Jeffrey pine and white fir (*Abies concolor*). Above the Jeffrey pine zone, there are mixed stands of white and red fir (*A. magnifica*) with intermixed lodgepole stands. Red fir is dominant at high elevations and often associated with mountain hemlock (*Tsuga mertensiana*) and western white pine (*P. monticola*). Patches of mountain mahogany (*Cercocarpus montanus*) occur at the highest elevations. Where forest canopy is lacking, snowbush (*Ceanothus velutinus*), gooseberry (*Ribes spp.*), and green-leaf manzanita (*Arctostaphylos patula*) are common.

During the last century four large wildfires and periodic timber harvests have occurred at SCEF (Figure 2, Table 1). The four fires occurred from 1914 to 1960, all prior to the first marten surveys in 1980. Most of the burned areas have since become covered by early-successional vegetation. Approximately 45% of SCEF was logged during the 28 years that spanned the period from the earliest marten surveys to my study in 2007–2008 (Figure 2, Table 1). Of the area logged, 4.3% was clear-cut, 38.3% was thinned from above and below, 41.4%

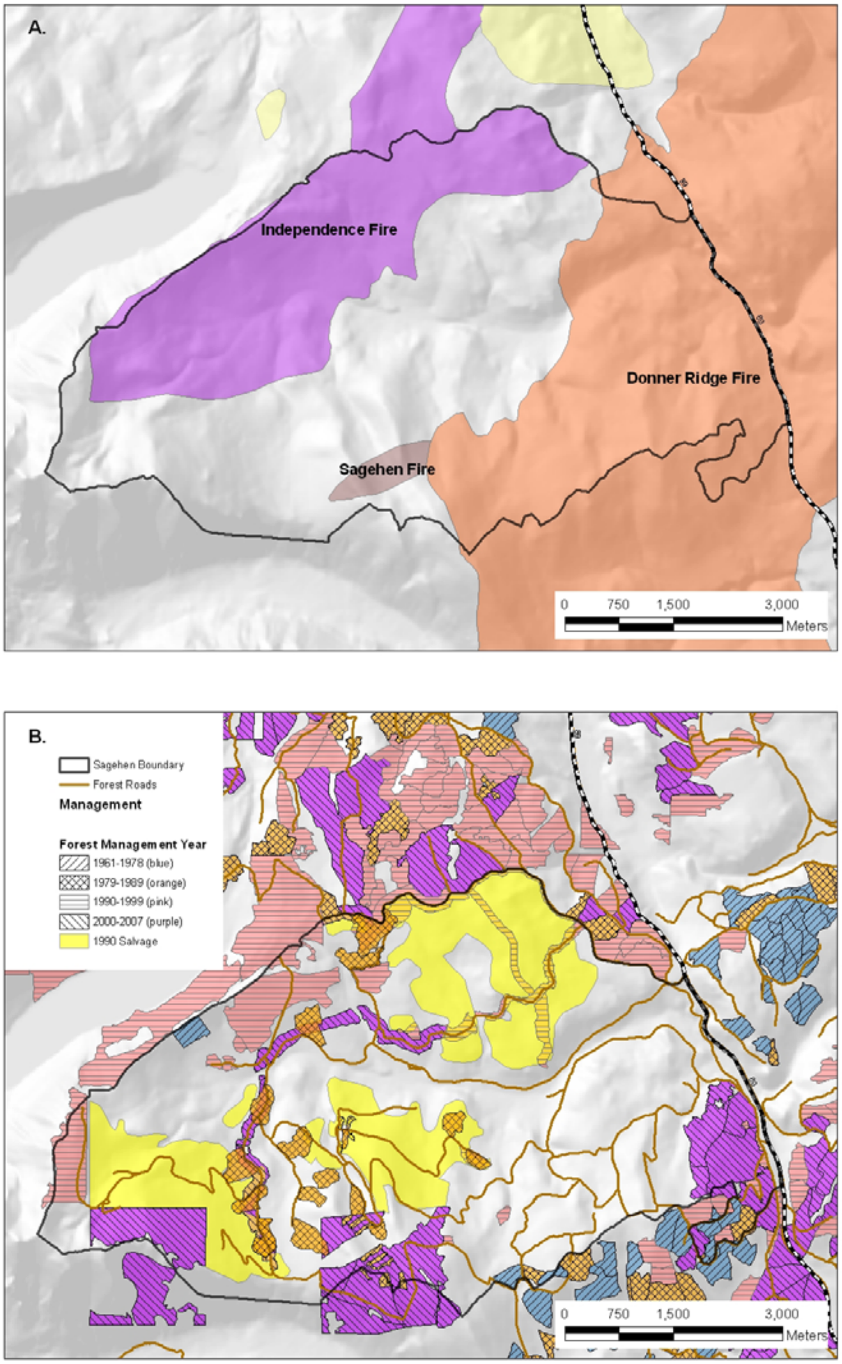


Figure 2. Locations of recent fires (A) and roads and harvest activities (B) in and around Sagehen Creek Experimental Forest, CA. Harvest information only includes activities from 1980–2007. GIS data from the Tahoe National Forest Fire History Layer and East Side Disturbance Layer.

Table 1. Forest disturbance history at Sagehen Creek Experimental Forest, CA, based on data from the Tahoe National Forest Fire History Layer and East Side Disturbance Layer.

Disturbance type	Year	Type	Km^2	Notes
1914 Fire	1914	Fire	0.45	No polygon available
Independence Fire	1926	Fire	15.78	Large fire primarily in SCEF
Donner Fire	1960	Fire	181.35	Extends beyond SCEF
Sagehen Fire	1968	Fire	0.61	Small fire, Section 13
Harvest	1984	Clear-cut	0.15	Many small patches
Harvest	1988	Clear-cut, Shelterwood	1.5	16 patches
Salvage and release	1990	Shelterwood, salvage	10.35	7 patches
Harvest	1994	Salvage, thin	0.92	4 patches
Roadside fire prevention	1996	Thin, under burn	0.48	3 patches, narrow strips along road
Harvest	1998	Thin, clear cut	0.27	4 patches
Roadside fire prevention	1999	Thin, under burn	0.27	1 patch
Roadside fire prevention	2000	Thin, under burn	0.11	1 patch
Roadside fire prevention	2004	Thin, under burn	0.93	6 patches
Harvest	2005	Thin	2.57	5 patches

was salvage-logged, 12.0% was cut with shelterwood methods, and 4% was unlabeled in the Tahoe National Forest East Side Disturbance Layer (TNFESDL). Clear-cut designates an area where all trees have been removed. Shelterwood cuts were similar to clear-cuts except that a few mature trees were left standing to reseed the cutover area and to provide structural variation in the regenerating stands. Salvage logging primarily involved the removal of diseased or damaged trees (Smith et al. 1997). Most clear-cut harvests were replanted with monotypic stands of Jeffrey pine (West 1982). Forest thinning was a common practice along roads as fuel treatments. Thinning projects retained an even distribution of trees such that at least 40% canopy cover remained after harvest. Approximately 20% of the thin treatments occurred in late-seral red fir or mixed conifer stands. Approximately 16.3% of SCEF had not been harvested or burned according to the TNFESDL.

METHODS

Marten sampling

Historically, marten surveys at SCEF were conducted with a semi-permanent rectangular grid established in 1980 by Spencer (1981) and Zielinski (1981). This grid included 336 stations spaced at 400 x 600 m intervals and covered 65% of the area (Figure 3A). A maximum of 84 stations were surveyed during each of the nine historic sampling periods (Spencer 1981, Zielinski 1981, Barrett 1983, Martin 1987) using track plates (Ray and Zielinski 2008). Track plates consisted of a thin aluminum plate covered with fine soot or black copy toner lying on the floor of a rectangular box (approximately 10 x 10 x 30 cm). The track plate boxes were deployed so animals could enter the box from only one direction to approach bait at the back of the box, thus leaving prints that could be identified to species. Track plate protocols used by Spencer (1981), Zielinski (1981), and Martin (1987) included wooden boxes placed in trees and baited with various materials. In my study I used track plate boxes placed on the ground, and I used boxes made from black corrugated plastic instead of wood (Coroplast Inc, Dallas, TX). I used a light dusting of black copy toner as an artificial tracking medium on Con-Tact paper (Kittrich Corp., La Mirada, CA) that was affixed to the bottom of the box (Ray and Zielinski 2008).

Some of the early surveys at SCEF used a combination of non-invasive survey methods (e.g. track plates, snow tracking) and live trapping to evaluate marten distribution (Spencer 1981, Martin 1987). My analysis of these early studies was limited to the results from non-invasive methods, which were comparable to the methods that I used (Appendix 1). I used data from theses (Spencer 1981, Zielinski 1981, Martin 1987), published results (Spencer et al. 1983, Spencer 1987), and field notes to estimate marten occurrence during each survey period. These records were summarized as binary detection/non-detection data. For this analysis, the 400 x 600 m grid was converted to a geo-referenced GIS layer (Figure 3A).

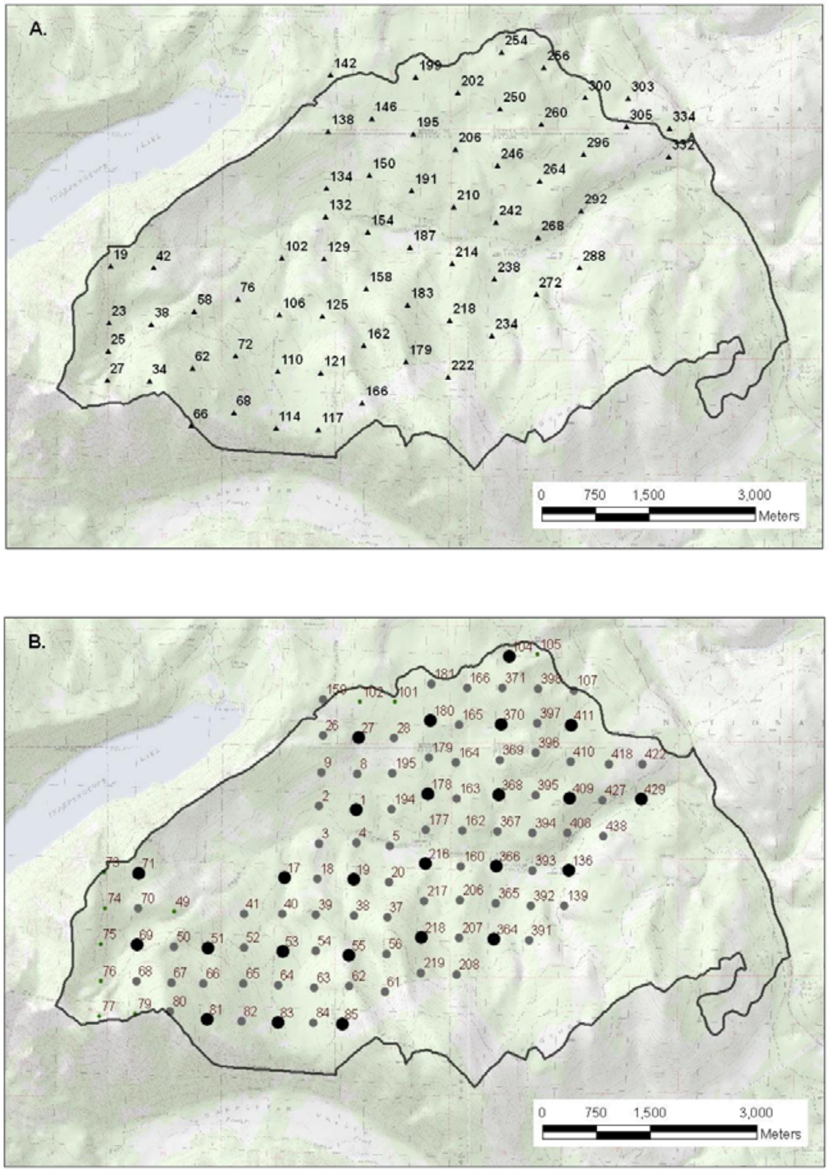


Figure 3. Marten survey stations in Sagehen Creek Experimental Forest, California. A = 400 x 600 m grid established in 1980 and used for marten surveys by Spencer (1981), Zielinski (1981), and Martin (1987, 1995). B = 500 x 500 m grid (n = 104 stations) used in the 2007–2008 marten study. Track plate surveys were conducted at all 104 stations in summer 2007. Most stations (n = 94) were resurveyed during winter 2007–2008 as bait stations (n = 79, small gray shaded circles) and alternating camera stations (n = 25, larger black filled circles).

Table 2. Timing, duration, and number of track plate stations used in marten surveys in Sagehen Creek Experimental Forest, CA. Surveyors were Wayne Spencer, Sandy Martin, and William Zielinski (Spencer 1981, Zielinski 1981, Martin 1987, 1995). Sample periods were designated by these researchers as snow (1 Dec-31 May) or snow-free (1 Jun-30 Nov).

Surveyor	Date begin	Date end	Time after 1980 (yrs)	Season	Survey nights	No. stations
Spencer and Zielinski	1-Jan-80	1-Jun-80	0.00	snow	180	53
Martin	15-Apr-82	24-Jun-82	1.9	snow	69	60
Martin	21-Oct-82	19-Nov-82	2.4	snow-free	27	80
Martin	1-Aug-83	27-Aug-83	3.2	snow-free	25	74
Martin	15-Oct-90	23-Nov-90	10.4	snow-free	38	59
Martin	27-Feb-91	11-Apr-91	10.8	snow	41	32
Martin	11-Oct-91	14-Nov-91	11.4	snow-free	22	62
Martin	2-Mar-92	7-Apr-92	11.8	snow	40	62
Martin	18-May-93	25-Jun-93	13.0	snow-free	38	62
Moriarty	20-Jun-07	03-Sep-07	27.1	snow-free	35	104
Moriarty	10-Jan-08	23-Mar-08	27.6	snow	40	94
Moriarty	26-Jul-08	27-Aug-08	28.2	snow-free	35	10

All of the nine surveys conducted prior to my surveys were conducted on the same grid system, but the number of stations surveyed and the number of trap nights per station varied among studies (Table 2). I resampled the same area surveyed in the previous surveys using a 250 x 250 m grid that was established at SCEF for interdisciplinary studies of fire behavior, vegetation, and wildlife (Battles 2004). This grid covered the entire SCEF basin and underwent intensive vegetation surveys during 2004–2006 (Vaillant 2008). To more closely mimic the grid spacing of earlier studies I sampled every other grid station in the Battles (2004) grid, which produced a 500 x 500 m grid, with each station within a 500-meter radius of one or more stations surveyed in the 1980 grid (Figure 3B). Because marten home ranges are large relative to the spacing of sample points in the 500 m grid (Spencer 1981), any martens on the area should have encountered multiple sample stations within their home ranges, thus ensuring a high probability of detection at ≥ 1 station if they were present (MacKenzie et al. 2006)

I conducted surveys during summer 2007 (n = 104), winter 2007–2008 (n = 94), and summer 2008 (n = 10). I set track plate boxes for a minimum of 35 trap nights at each of 104 stations during summer (June-September 2007). Track plate boxes were placed near natural features (e.g. logs or trees) and covered in vegetation to reduce thermal fluctuations. Boxes were baited with chicken, and a commercial trapping scent lure (Gusto, Minnesota Trapline Products, Pennock, MN) was hung from a nearby tree. If marten tracks were observed, they were measured to estimate sex based on interdigital pad height and width, and total track length (Slauson et al. 2008). If martens were detected at track plates, I placed hair snare devices inside those boxes in an attempt to collect hair samples for genetic determination of species, gender, and number of unique individuals (Kendall and McKelvey 2008; Appendix 1; Figure A1.3). All genetic analyses of tissues (hair, scat) were conducted at the Rocky Mountain Research Station, Wildlife Genetics Laboratory, Missoula, MT. Mitochondrial sequencing was used to confirm the sample was from a marten, and microsatellite analysis was used to determine gender and individual identification (Riddle et al. 2003, Schwartz et al. 2006, Schwartz and Monfort 2008).

During winter 2007–2008, I sampled martens at 94 stations using digital cameras (Kays and Slauson 2008) and bait stations, accompanied with snow tracking and hair snares (Kendall and McKelvey 2008). Ten of the 104 stations sampled in summer were not sampled in winter because of avalanche danger. Cameras and bait stations were more appropriate for winter because snow often made track plate boxes inoperable. I used Cuddeback model Excite 2006 cameras (Non Typical Inc., Green Bay, WI), each of which was attached to a tree and aimed at bait and lure that was placed ~1.5 m above the snow on an adjacent tree (Kays and Slauson 2008). Cameras and bait stations were set using the same bait and lure as was used during summer. I used snow tracking to identify species that visited bait stations. I alternated cameras and bait stations at 500 m intervals on the grid (Figure 3B). Where a marten was detected, I placed a hair snare at that station. Hair snares used in winter consisted of gun cleaning brushes attached to a

Coropast strip that was wrapped around the tree trunk so that the animal had to climb between the brushes to get at the bait (Appendix 1, Figure A1.6). I counted photographs, snow tracks, or positively identified genetic samples (hair, scat) as verifiable detections. Marten tracks within 50 m of a station were included as a detection for that station only when the snow quality was considered "good" or "excellent" (i.e. every footprint registered, details were usually visible in covered sites, and species identification was made by both print details and gait patterns (Halfpenny et al. 1995).

Probability of Detection

Imperfect detection, or false absences, will cause estimates of occupancy to be a biased low if not accounted for (MacKenzie et al. 2002, Tyre et al. 2003, MacKenzie 2005, MacKenzie et al. 2006). Imperfect detections occur when sampling for elusive and wide ranging carnivores when (1) the station density does not adequately cover an animal's expected home range (MacKenzie et al. 2006), (2) the animal of interest exists at low densities and is less likely to encounter the survey device (MacKenzie et al. 2006), or (3) increased habitat fragmentation and landscape discontinuities as perceived by the animal are a barrier to movement (Andren 1994). Imperfect detection can be accounted for using a sampling detection history, which is a record of presence/non-presence at each station. For marten surveys with complete detection histories at each station, I estimated the per sample unit probability of detecting a marten in a survey ($\hat{p}$) at least once after K surveys with the formula: $1 - (1-p)^K$ (i.e. 1 minus the probability of not detecting the species in any of the K surveys; MacKenzie et al. 2006). Estimates of occupancy ($\hat{\psi}$), or the expected percentage of detections if martens were present assuming imperfect detection, were compared with the naïve detection percentages or the number of detections/total number of stations. Of the 12 surveys conducted since 1980, probabilities of detection were calculated for the four surveys with complete detection history records using best fit Akaike's Information Criterion (AIC) models with 500 bootstrap simulations in program PRESENCE (Hines 2006). If the estimated occupancy ($\hat{\psi}$) significantly differed from the naïve detection percentages, all surveys could be adjusted to reflect an averaged expected occupancy. It is likely that each method used in winter had differing effectiveness to detect marten. Although it would be ideal to evaluate probability of detection for each method separately, the total number of detections was small so I combined results from the different methods to create a detection history similar to the approach used by Long et al. (2007).

To explain variation in habitat use by martens at SCEF, previous researchers used seasonal periods (snow vs. snow-free) as covariates in their analyses (Spencer 1981, Zielinski 1981, Martin 1987, Martin 1995). They designated the snow period as 1 December-31 May and the snow-free period as 1 June-30 November. I used the same seasonal periods in my analysis to account for potential seasonal differences in detection probability and to increase the likelihood of detection of martens if they were present (Kirk and Zielinski 2009, Zielinski et al. 2009).

Spencer (1981) and Martin (1987) found differences in habitat selection by martens in the upper and lower basins at SCEF. They subdivided the upper and lower basins at the 2050 m elevation contour (Figure 6). Habitat in the upper and lower basins primarily consisted of forests dominated by red fir and mixed-conifer, respectively. I used the same geographic subdivision as a covariate in my analyses I used an estimated odds ratio and a z-test of equal proportions to compare marten detections between the upper and lower basins (Ramsey and Schafer 2002).

After adjusting for the probability of detection if necessary, I used an arcsine square root transformation to transform the data to improve the fit to the assumptions necessary for generalized linear models. The arcsine transformation was used to ensure that the percentage data did not violate the homogeneity of variance assumption across time periods. The square root transformation also resulted in the data being more normally distributed (Ramsey and Schafer 2002). I used a general linear model to evaluate the trend in transformed marten detections while accounting for season (snow vs. snow-free), survey duration (number of trap nights per station), number of stations, and time since the initial survey in 1980.

Disturbance History

To document habitat change (disturbance history) on the study area I used the TNFESDL, which is a spatially and temporally explicit geo-database maintained by the Tahoe National Forest. This database was created from a variety of sources, including Stand Record System Cards, California Timber Harvest Plans, orthophotos, approved planned activities from National Environmental Policy Act maps, timber sale maps, and information from the Forest Service Activity Tracking System. Where multiple disturbances occurred at the same location, the action having the most relevant disturbance potential was applied to the disturbance polygon. All disturbances that occurred in the previous 30 years were recorded. For my study, the disturbance polygons in the TNFESDL were checked against Landsat TM imagery (Carlos Ramirez, USFS R5 Remote Sensing Laboratory, personal communication) and with aerial photographs to assure their accuracy. In addition to the TNFESDL, I examined timber sale reports and maps from two prominent harvests within SCEF, the "Golden Harvest", which occurred in 1988, and a large salvage harvest that took place in 1990. Some polygons within the TNFESDL did not fully represent the extent of the 1988 Golden Harvest, so I modified this portion of the layer to reflect the actual boundaries of the harvest unit which were documented in stand survey reports at the time of harvest. The 1990 Salvage was not included in the TNFESDL layer, so I added polygons for the salvage event by tracing a hand drawn 1:24,000 scale boundary map of the sale unit that included contour lines. Salvage cuttings are used to remove living or dead trees that are threatened by mortality, damage, or loss from injurious agencies other than competition between trees (Smith et al. 1997). Because areas salvaged were primarily near roads, and the number of trees removed within these areas was unknown, these polygons were included in my analyses but were mapped separately from the TNFESDL layer.

Vegetation Mapping

I used satellite imagery with supervised and unsupervised algorithms to transform spectral data into vegetation maps. Vegetation maps were reviewed using 235 randomly selected reference points verified by an aerial photo-interpretation analyst. These vegetation maps were then re-classified through several systems to create a polygon delineated GIS layer that displayed vegetation type, tree size, and canopy cover density. I used California Wildlife Habitat Models (CWHR 2006) to create maps which predicted high or low quality marten habitat for both 1978 and 2008.

The vegetation maps for 1978 and 2007 were created using an identical process by the US Forest Service Region 5 Remote Sensing Laboratory to assure accuracy and comparability. A 1978 Multi-spectral scanner (MSS) Landsat-3 image and a 2007 Thematic Mapper (TM) Landsat-5 image were resampled to a 57 m spatial resolution to enable execution of identical analysis procedures and grain size for both years. The images were then co-registered using the AutoSync module in ERDAS Imagine using the nearest neighbor method (ERDAS 2008). Spectral bands from the Landsat imagery and vegetative indices served as the inputs to the segmentation algorithm in Definiens Professional eCognition (Baatz et al. 2006). The segmentation algorithm groups pixels into image objects based on spectral and textural homogeneity (Ryerd and Woodcock 1996, Baatz et al.

2006). At this phase, all polygons had a 2-pixel minimum mapping unit with the exception of aspen and meadows, which were classified close to their actual area.

Broad vegetation site classifications such as conifer, hardwood, mixed, shrub, barren, and water were produced using lifeForm, a program that uses an unsupervised procedure to classify spectrally similar pixels into categories (Brohman and Bryant 2005). LifeForm classifications were verified through aerial photo interpretation. Aerial photographs from 1977 were scanned, georeferenced, and transformed into photo-mosaics in ERDAS Imagine (ERDAS, Inc., Norcross, GA). A 100-m grid was overlaid on the study area and 235 randomly-selected reference sites were chosen. A remote sensing analyst and photo-interpreter confirmed or modified the 1977 lifeForm classifications using the photo-mosaic. Similarly, the 2007 lifeForm site classifications were checked against 2005 National Agriculture Imagery Program images at 1-m resolution at the same 235 reference sites.

To make my results comparable with other recent marten research in California, the lifeForm vegetation classes were transformed into a standardized vegetation system, CalVeg, and then to a more commonly used vegetation classification system for wildlife applications, California Wildlife Habitat Relationships (USDA 1981, Mayer and Laudenslayer 1988). With 178 designated CalVeg types, it was the most accurate unsupervised classification system available for SCEF. The CalVeg system was developed for ecological applications, vegetation change analyses, and automatically converts from lifeForm data. These results were checked against the TNFESDL. The final polygons were changed in an automated algorithm from CalVeg to California Wildlife Habitat Relationship vegetation categories (CWHR 2006).

Habitat Designation

I transformed the vegetation type, tree size, and canopy density layers into a marten habitat layer for both the 1978 and 2007 time periods. To do this I reduced the 15 vegetation types, six size classes, and four density classes into two habitat categories (predicted low and high quality marten habitat), which reduced interpretation problems associated with multivariate correlation analyses (Li and Wu 2004). These habitat values were modified from a pre-existing CWHR model (Mayer and Laudenslayer 1988), which depicts habitat for many California species as being low, moderate, or high quality for the life history categories of reproduction, feeding, and cover. Predicted high quality reproductive habitat, hereafter "marten habitat", was considered the limiting factor for martens and permitted a more strategic evaluation of change in habitat over time. As such, I altered CWHR's marten habitat to include changes made by Kirk and Zielinski (2009) as well as adding recommendations from Green (2007) to include late-seral Sierra Mixed Conifer for areas previously classified as Mixed conifer-fir in CalVeg (Table 3). I ground-checked 10 of the 235 points for accuracy in vegetation assignment, size, and canopy cover accuracy. To ensure that my designation of marten habitat depicted potential areas used by martens in this

Table 3. Definitions of high quality marten reproductive habitat based on forest types and metrics published by the California Department of Fish and Game (CWHR 2006) and modified metrics based on Kirk (2007), Spencer (1981), Martin (1987), and Green (2007).

Forest Type	CDFG High Quality Habitat		Modified High Quality Habitat	
	Size Class[a]	Canopy Closure[b]	Size Class[a]	Canopy Closure[b]
Montane hardwood-conifer (MHC)	4, 5	M, D	——	——
Douglas-fir (DFR)	4, 5, 6	M, D	——	——
Lodgepole pine (LPN)	4, 5	M, D	4, 5	M, D
Montane riparian (MRI)	5, 6	M, D	5, 6	M, D
Red fir (RFR)	4, 5	M, D	4, 5	M, D
Subalpine conifer (SCN)	4, 5	M, D	4, 5	M, D
Mixed-conifer - fir (SMC[c])	——	——	5, 6	M, D
White fir (WFR)	——	——	4, 5, 6	M, D

[a] Diameter at breast height (DBH) class 4 = 28-60cm, class 5 = >60 cm, class 6 = >60 cm with multi-layered canopy.

[b] M = moderate (40–60%), D = dense (>60%).

[c] Sierra mixed-conifer was split into mixed-conifer-fir and mixed-conifer-pine. Only mixed-conifer - fir was considered reproductive habitat.

region, I compared the location of historical marten locations with the polygons that were labeled as marten habitat and found that all previously known rest sites used by martens at SCEF (Spencer 1981, Martin 1987) occurred in the vegetative types I designated as high quality marten habitat.

Landscape Composition and Configuration

Relationships between marten detections and landscape composition and configuration were evaluated by dividing the landscape into two classes (non-habitat and predicted reproductive marten habitat). Habitat patches were composed of identical, adjacent or diagonal pixels (8-cell rule, pixel grain = 57 m). I described the amount and configuration of habitat for two time periods: 1978 and 2007. I used program FRAGSTATs Version 3.3 (McGarigal et al. 2002) to assess habitat attributes at three spatial scales: the entire SCEF boundary, the upper basin at SCEF (> than 2050 m elevation), and the lower basin at SCEF (≤ 2050 m elevation). I also evaluated habitat change by creating maps that depicted habitat gain and loss over the period from 1978 to 2007. These maps were created by subtracting the habitat value in 1978 from 2007 using the raster calculator tool in ArcMap (Spatial Analysis Toolbox, ESRI, Inc., Redlands, CA). Habitat gain pixels were composed of habitat that did not occur in 1978 but were designated as habitat in 2007. This change was presumed to occur with increased canopy cover or tree diameter growth within vegetative types suitable to martens. Conversely, habitat loss pixels were those labeled as habitat in 1978 and non-habitat in 2007. Loss was assumed to occur when areas had disturbance that decreased the canopy cover or tree diameter in vegetation types previously labeled as suitable for martens (Table 3).

I used five class and six patch metrics to describe habitat configuration (Table 4, McGarigal et al. 2002). Class metrics are those that aggregate properties of habitat patches, and patch metrics are computed for every patch in the landscape. Patch metrics can be summarized similar to class metrics but include the amount of variation among the patches. I used non-parametric Wilcoxon-rank sum tests to evaluate differences in patch metrics between 1978 and 2007 because Levene's Tests for Equality of Variances revealed divergences from normality in all patch metrics. My selected class metrics were relatively robust to changing scales in respect to grain size and ability to detect differences between different spatial extents (Wu 2004). I used simple metrics to increase the likelihood of ecological significance to the study animal (Li and Wu 2004, Kirk and Zielinski 2009). Metrics from previous marten research were used to compare potential effects among studies, including the percent cover of marten habitat (PLAND), the number of patches of marten habitat (NP), mean proximity index (PROX_MN), and snag abundance (Hargis et al. 1999, Kirk and Zielinski 2009). If composition and configuration were closely related to marten occurrence, I would expect the metrics above to be important in relation to marten occurrence at SCEF.

Table 4. Definitions of class and patch metrics used to quantify configuration and amount of predicted high quality reproductive marten habitat at Sagehen Creek Experimental Forest, CA.

Variable Name	Description
Class metrics	
Percentage of landscape (PLAND)	Percentage of habitat in landscape
Number of Patches (NP)	Number of patches of predicted marten habitat
Largest Patch Index (LPI)	Percentage of the landscape comprised by the largest patch of predicted marten habitat
Percent cover of core areas (CPLAND)	Percentage cover of core area in landscape. Core area was denoted with a 100-meter depth-from-edge buffer.
Number of Distinct Core Areas (NDCA)	Number of core-area habitat patches
Patch metrics	
Mean patch area (AREA_MN)	Average size of habitat patches (ha)
Area-weighted core area (CORE_AM)*	Area-weighted mean of habitat patch core area (index)
Area-weighted distinct core area (DCORE_AM)*	Area-weighted mean of disjunct (separate) habitat patch core areas (percentage)
Proximity mean index (PROX_MN)	Measure of average proximity of habitat patches accounting for area and distance (index).
Area-weighted gyration (GYRATE_AM)*	Area-weighted mean of mean distance between each cell in the habitat patch and the habitat patch centroid. Measure of connected habitat per patch (ha)
Mean nearest neighbor distance (ENN)	Mean of the nearest neighbor Euclidean distance from a focal patch to neighboring habitat patch, measured center-to-center (m)

* AM (area-weighted mean) is defined as the patch area divided by the total area of that habitat type multiplied by the proportional abundance of the patch metric; i.e., patch area (m^2)/Σ patch areas (m^2) * metric of interest (Leitão et al. 2006).

Among the metrics that I used to evaluate landscape pattern in program FRAGSTATs were core area (CORE), mean proximity index, and radius of gyration (GYRATE). Standard definitions for the additional metrics can be found within FRAGSTATs and Table 4. I defined CORE as the amount of continuous habitat remaining after subtracting a 100-meter buffer from the patch perimeter. A 100 m buffer is probably conservative for martens, as a 200–250 m edge-effect was recorded for martens in areas with juxtaposed clear-cuts (Heinemeyer 2002). The area-weighted core area was calculated as the sum across all core habitat patches multiplied by the proportional abundance of their associated patch (individual patch area divided by the sum of patch areas). Area-weighted metrics are more robust to differing spatial extents and emphasize larger patches, which are probably more spatially and ecologically relevant for martens (Schumaker 1996). PROX_MN depicts the mean isolation of each habitat patch by accounting for the size and proximity of all patches whose edges are within a specified search radius of the focal patch (Gustafson and Parker 1992, McGarigal et al. 2002). Euclidean nearest neighbor distance (ENN), or the direct distance from the edge of a patch to the closest edge of another patch, differs from the proximity index by ignoring patch size. It is a simple measure of patch context (McGarigal et al. 2002) and has been used to describe fragmentation effects on martens (Hargis et al. 1999). The radius of gyration (GYRATE) is a measure of patch extent that describes patch configuration and shape by taking the mean distance (m) between each cell in the patch and the patch centroid; thus this metric is affected by both patch size and patch compaction (McGarigal et al. 2002).

Modeling Marten Occurrence as a Function of Environmental Covariates

I examined marten occurrence in relation to habitat variables using AIC modeling and logistic regression. I used three analyses to see if there were correlations between marten detections and change in habitat. In the first analysis I examined marten detections in 1983 as a function of the continuous and categorical environmental covariates that were primarily derived from the 1978 vegetation map. In the second analysis I explored marten detections in relation to environmental covariates derived from both the map and field surveys conducted in 2003–2004 and 2007–2008. My third analysis examined covariates in relation to the change in marten detections in the interval from 1983 to my study in 2007–2008 (Table 5). In the latter analysis I attempted an *ad hoc* evaluation of marten detections using change co-variates between 1983 and 2007. Stations with 1983 marten detections were paired with a 2008 station using the nearest neighbor tool in ArcMap (ESRI, Inc., Redlands, CA). The paired stations were 'subtracted' such that the response was marten detection loss (hereafter marten loss) represented by "1" versus marten still detected represented by "0". Marten loss was evaluated using AIC model selection with explanatory variables that depicted change, for example one variable (ddist_hab) was the distance of nearest

Table 5. Variables used in *a priori* models to evaluate effects on detection rates of martens in Sagehen Creek Experimental Forest, CA in 1983 and 2007–2008 and between the two time periods (Change).

Variables	Code	Description	Analysis
Aspect	aspect	N, NE, E, SE, S, SW, W, NW	1983
California wildlife habitat relationships vegetation class	veg	RFR, WFR, SMC, SCN, JPN, RPN, WMW	1983, 2008
California wildlife habitat relationships size class	size	1, 2, 3, 4, 5	1983, 2008
California wildlife habitat relationships canopy cover class	CC	dense, moderate, open, sparse	1983, 2008
Disturbance type	dist_type	Thin, shelterwood, clear-cut, salvage	2008, Change
Elevation	elev	In feet	1983, 2008, Change
Distance from the station to predicted habitat	dist_hab	In meters	1983, 2008
Predicted patch size	p_size	In meters	1983, 2008
Predicted patch edge	p_edge	In meters	1983, 2008
Slope	slope	In degrees	1983, 2008
Aspect	aspect	Degrees/360	2008
Distance from station to nearest road	distroad	In meters	1983, 2008
Distance from station to nearest stream	distwater	In meters	1983, 2008
Station location	xcoord, ycoord	UTM coordinate system	1983, 2008, Change
Amount of large woody material	CWD	Volume	2008
Live basal area	BA_live	Volume	2008
Total basal area	BA_total	Volume	2008
Distance to any forest disturbance	dist_dist	In meters	2008
Size of disturbance	dist_size	In meters	2008
Change in annual precipitation	dpAnn	In cm	Change
Change in annual mean maximum daily temperature	dMax	In ^{o}C	Change
Change in annual mean minimum daily temperature	dMin	In ^{o}C	Change
Change in distance to predicted habitat patch	ddist_hab	In meters	Change
Change in patch size	dp_size	In meters	Change
Difference in predicted quality	dquality	Between -5 and 5.	Change

predicted habitat in 1983 subtracted from the distance from the same point in 2008. I evaluated climatic changes of annual precipitation, annual mean maximum temperature (max) and annual mean minimum temperature (min) temperature based on estimates from the Parameter-elevation Regressions on Independent Slopes Model (PRISM) dataset (http://www.prism.oregonstate.edu). This is a topographically sensitive dataset with a precipitation and temperature grid at a resolution of 4 km. Values used from each of these variables were calculated by subtracting the 2007 values from the 1983 values because PRISM data for 2008 were not available at the time of analysis. Potentially meaningful environmental variables like elevation and distance to water were included in some models even though they did not reflect change between the periods.

In all analyses, models were developed *a priori* to explore relationships between selected explanatory variables and marten detections. Models were ranked according to AIC corrected for small sample size (AIC_c). The model with the lowest AIC_c value and highest AIC_c weight was considered the "best" model (Burnham and Anderson 2002). Models with AIC_c values that differed by < 2.0 from the top model (ΔAIC_c, < 2.0) were considered competitive with the top model. I used Wald's 95% confidence intervals on slope coefficients and a deviance goodness-of-fit test to determine the strength of specific effects (Ramsey and Schafer 2002). Beta regression coefficients and 95% confidence intervals were evaluated in relation to the top model in each analysis using logistic regression. If the top model contained only continuous variables, I assessed spatial autocorrelation with program Spatial Analyses in Macroecology (SAM). I used a moving-average autoregressive model that accounted for spatial autocorrelation within the ordinary least squares logistic regression analysis. The spatial autoregressive parameter (ρ) represented an increase in autocorrelation when it approached its maximum limits of -1 and 1 (Fortin and Dale 2005, Rangel et al. 2006).

I used different *a priori* models for each of the three analyses (1983, 2007, and Change; Appendix 3) as the same variables were not available for both 1983 and 2007. However, the explanatory variables elevation (elev) and the interaction between distance to habitat and patch size (dist_hab*p_size) were included in all three analyses because I predicted that they would have the most impact on marten detections based on published literature (Table 5). *A priori* models were evaluated using SAS 9.1 and PROC GENMOD.

RESULTS

Marten Detections

Estimated site occupancy ($\hat{\psi}$) did not differ significantly from the naïve detection percentage in any of the surveys conducted at SCEF in 1991–1993 or 2007–2008 (Table 6). Since the estimated and naïve estimates did not differ in the individual surveys, I assumed that the naïve detection percentage would also

Table 6. Results of AIC model selection based on *a priori* models that included constant occupancy ($\psi(.)$) and detection probabilities that were either constant (p(.)) or variable (p(t)) among sampling visits during four studies of martens at Sagehen Creek Experimental Forest, CA.

Survey	Model	AIC[a]	ΔAIC[b]	*w*[c]	Model Likelihood	K	Naïve est. [d]	$\hat{\psi}$	SE($\hat{\psi}$)	$\hat{p}$ [e]	SE($\hat{p}$)[f]	$1-(1-p)^k$
$1991_{\text{Snow-free}}$	$\psi(.)p(.)$	157.55	0.00	0.95	1.00	2	0.258	0.258	0.056	0.78	0.04	1.00
	$\psi(.)p(t)$	163.61	6.06	0.05	0.05	6		0.258	0.056			
1992_{Snow}	$\psi(.)p(.)$	115.06	0.00	0.87	1.00	2	0.145	0.148	0.046	0.45	2803.80	0.95
	$\psi(.)p(t)$	119.40	4.32	0.10	0.12	6		0.167	0.054			
$1993_{\text{Snow-free}}$	$\psi(.)p(.)$	99.64	0.00	0.93	1.00	2	0.241	0.242	0.054	0.83	0.06	1.00
	$\psi(.)p(t)$	104.71	5.01	0.07	0.07	6		0.248	0.056			
2008_{Snow}	$\psi(.)p(.)$	139.00	0.00	0.99	1.00	2	0.104	0.128	0.041	0.24	0.06	0.75
	$\psi(.)p(t)$	142.29	10.29	0.01	0.01	9		0.122	0.056			

[a] Akaike's Information Criterion (AIC) evaluates model fit

[b] The relative difference in AIC values compared with the top ranked model

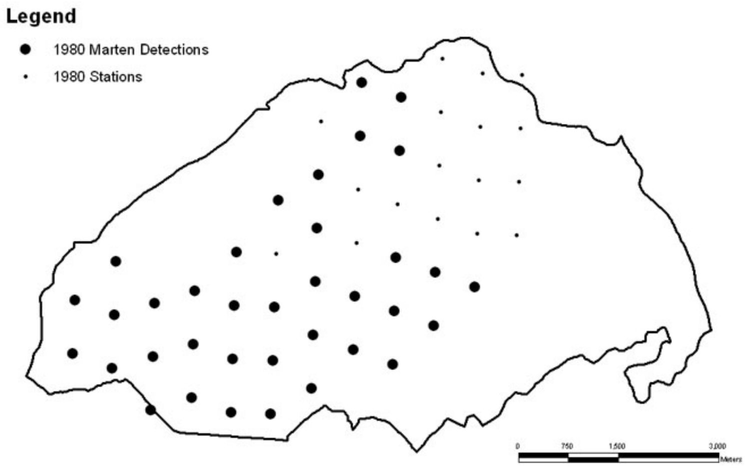
[c] Model weight

[d] Number of station detections divided by the total number of stations (*n*)

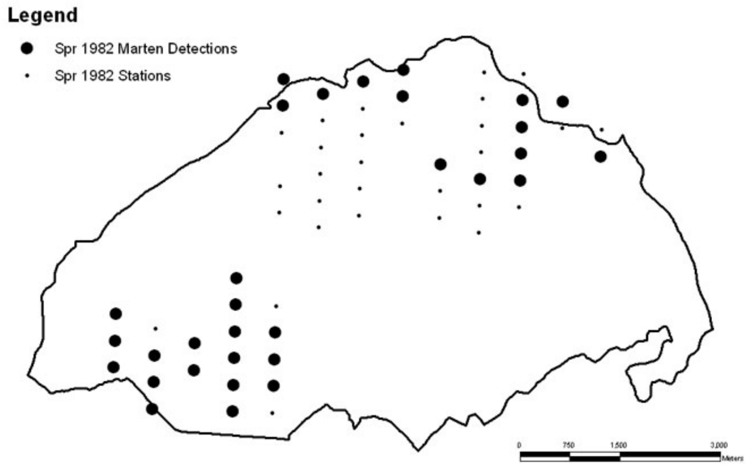
[e] Estimated probability of detection

[f] Standard error is high for the 1992 survey due to a difference in survey methods. Stations were pulled after a marten detect ion occurred.

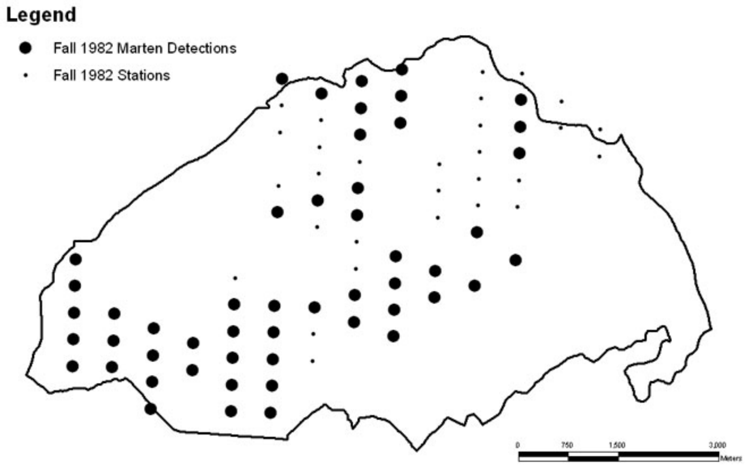
A. Spencer (01 Jan - 01 Jun 1980); n = 53; duration = 180 days; 72% detection rate



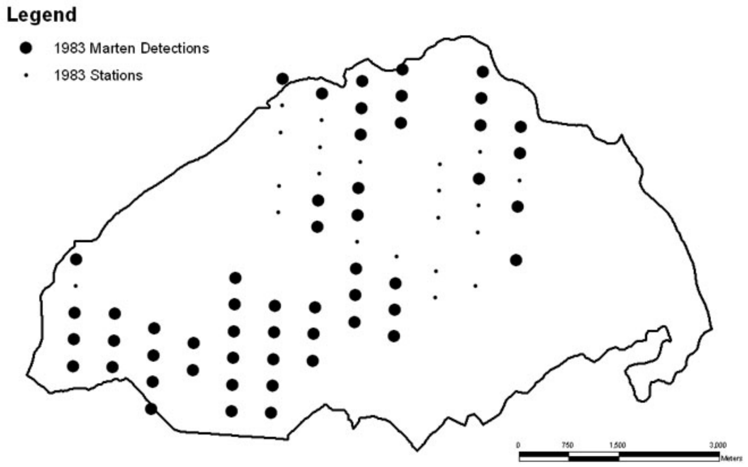
B. Martin (15 Apr - 24 Jun 1982); n = 60; duration = 69 days; 52% detection rate



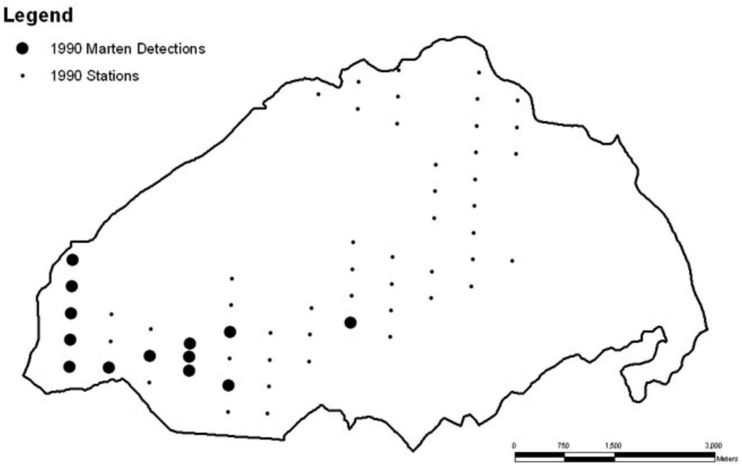
C. Martin (21 Oct - 19 Nov 1982); n = 80; duration = 27 days; 64% detection rate



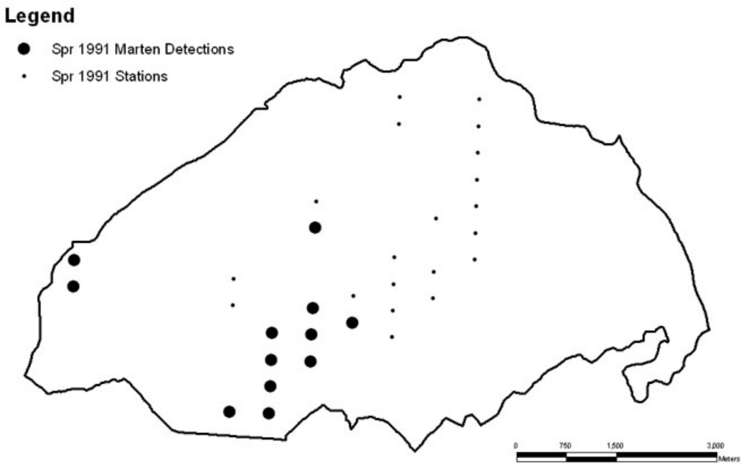
D. Martin (01 Aug - 27 Aug 1983); n = 74; duration = 25 days; 72% detection rate



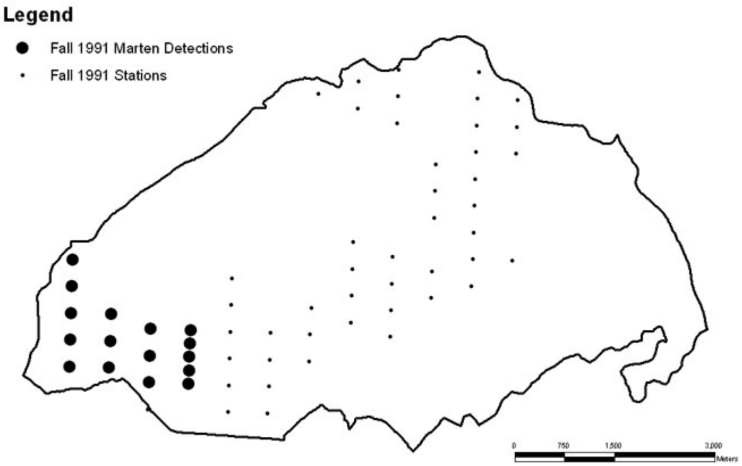
E. Martin (15 Oct - 23 Nov 1990); n = 59; duration = 38 days; 22% detection rate



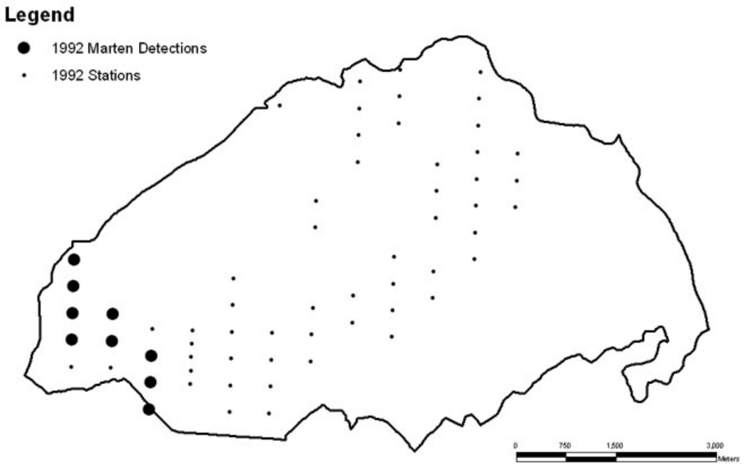
F. Martin (27 Feb - 11 Apr 1991); n = 32; duration = 41 days; 38% detection rate



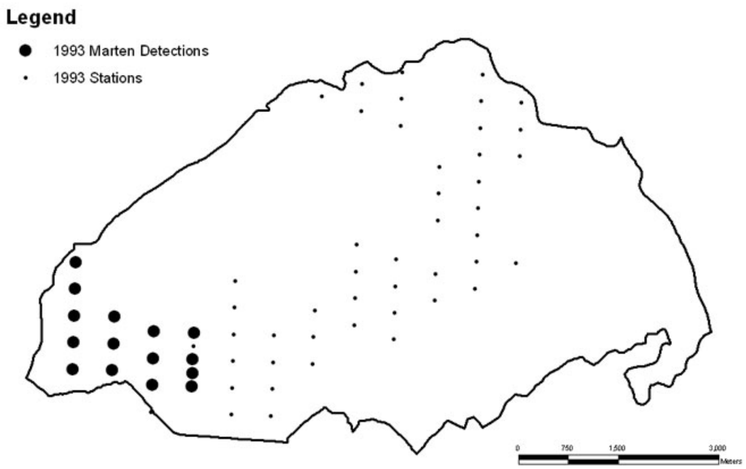
G. Martin (11 Oct - 14 Nov 1991); n = 62; duration = 22 days; 26% detection rate



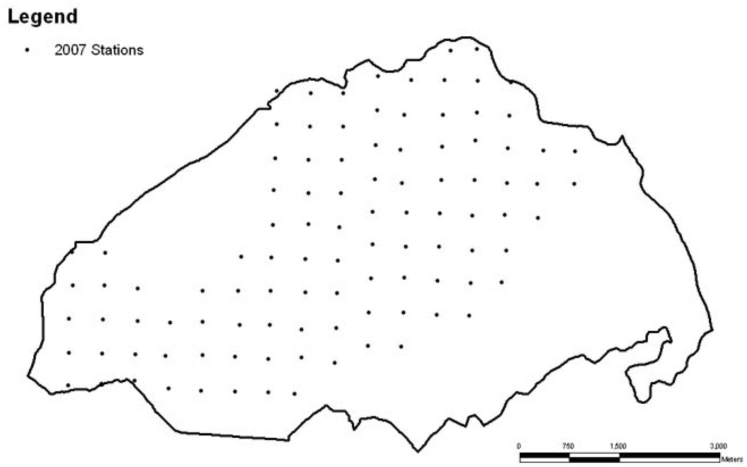
H. Martin (02 Mar - 07 Apr 1992); n = 62; duration = 40 days; 16% detection rate



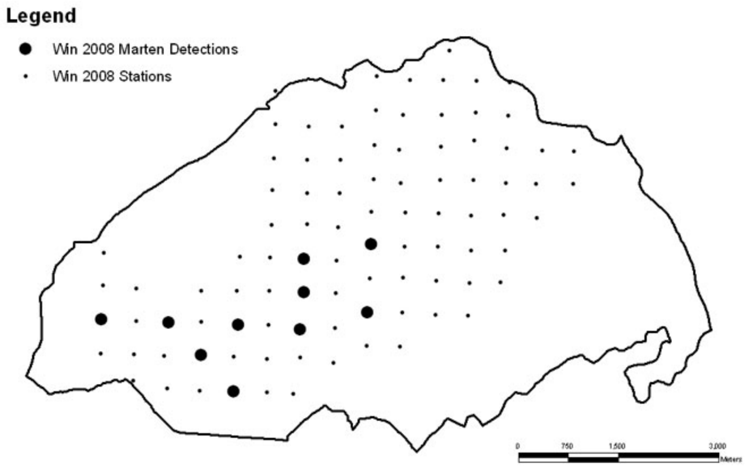
I. Martin (18 May - 26 Jun 1993); n = 62; duration = 38 days; 24% detection rate



J. Moriarty (20 Jun - 03 Sep 2007); n = 104; duration = 35 days; 0% detection rate



K. Moriarty (10 Jan - 23 Mar 2008); n = 94; duration = 40 days; 11% detection rate



L. Moriarty (26 Jul - 27 Aug 2008); n = 10; duration = 35 days; 0% detection rate

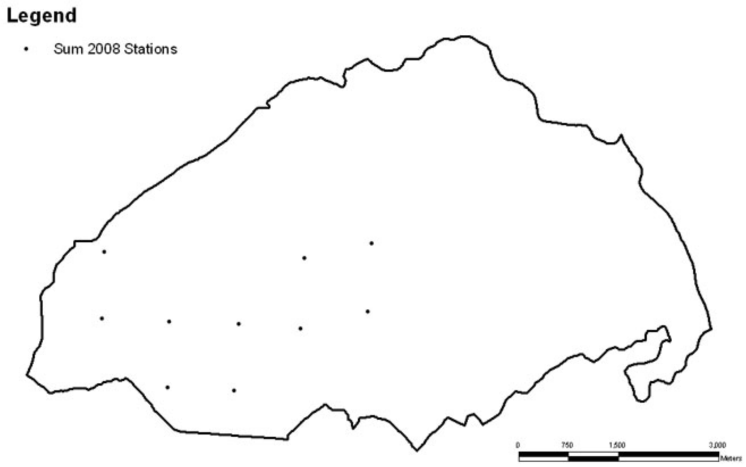


Figure 4. Marten detections in Sagehen Creek Experimental Forest, CA, during nine previous survey periods (Spencer 1981, Zielinski 1981, Martin 1987, 1995) and my surveys in 2007–2008). Stations with and without marten detections are indicated by large and small solid circles, respectively.

be similar to estimated occupancy among the surveys that were missing detection histories (1980–1983).

The distribution of marten detections changed spatially from a semi-uniform distribution in the upper and lower basins in the 1980s to detections that were clustered in the southwest corner of the upper basin by the 1990's (Figure 4). In the four surveys conducted in 1980–1983 (Table 2) the average percent of stations with marten detections was 65% (SE = 0.047, 95% C.I. = 49.7–79.7%), and the average percentage of stations with marten detections in the upper and lower basins was 77% and 43%, respectively. The odds ratio of a marten being detected in the upper basin in 1980–1983 was 4 times more likely relative to the lower basin.

In the five surveys completed in 1990–1993 the overall average percent of stations with marten detected was 25% (SE = 0.034, 95% C.I. = 15.4 to 34.9%). The average percent of stations with detections greatly contrasted between the upper and lower basin (36% and 2%, respectively), making the odds ratio of martens being detected in the upper basin 650 times more likely than in the lower basin.

I detected no martens in summer 2007 or summer 2008. In winter 2007–2008, I detected martens at 10 stations. The average percent of stations with at least one marten detection among the three surveys was 4% (SE = 0.061, 95% C.I. = -16.0 to 23.0%). Because of the low proportion of detections at any stations, the contrast between detection rates in the upper and lower basins (8% vs. 1%)

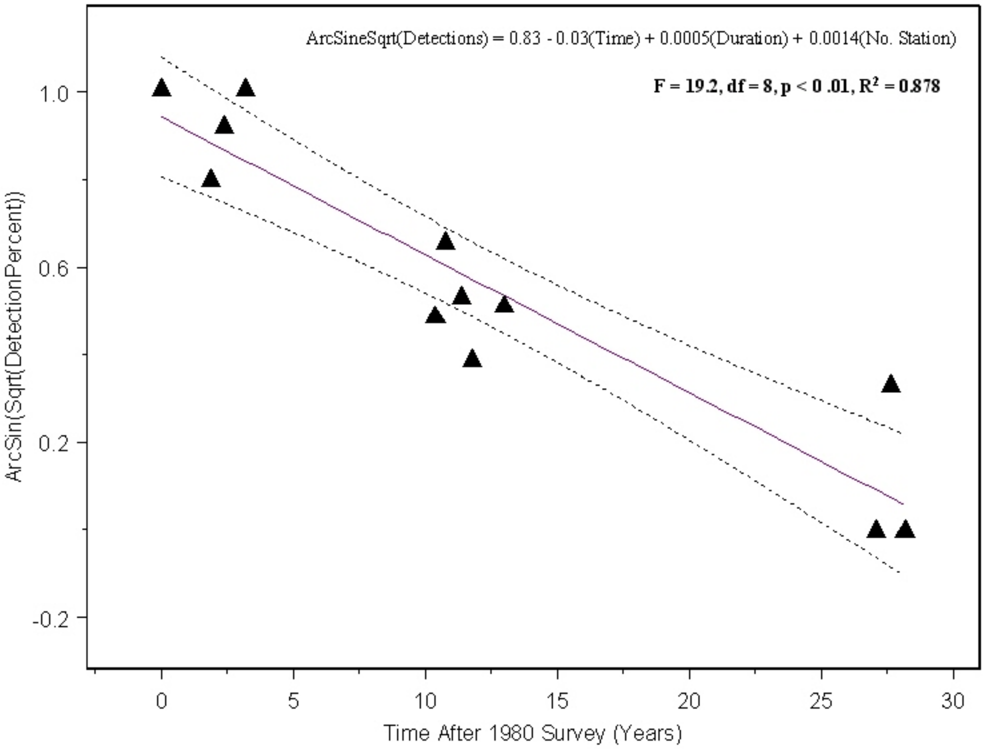


Figure 5. Relationship between time after the first survey of martens in Sagehen Creek Experimental Forest, CA in 1980, and the naïve transformed percentages of marten detections in subsequent surveys (ArcSine (√ (number of stations with marten/total stations). Second order polynomial line of fit and 95% confidence interval shown.

was less dramatic than in earlier surveys. However, the odds ratio of detecting a marten in the upper basin was still 9 times more likely than in the lower basin.

In winter 2007–2008, martens were detected in the southwest portion of the upper basin (n = 8 camera detections, including 6 with tracks, 1 snow track only, and 1 genetic hair sample only). Hair snare devices were deployed for > 1 week at each of the 10 stations where martens were detected, and 12 marten hair samples were collected. Of these, 5 were from 3 individuals (2 females, 1 male), and the other 7 samples either did not have enough DNA or were from the same individuals (Appendix 2, Table A2.5).

Marten detections declined significantly at SCEF between 1980 and 2008 while accounting for season, survey duration, number of stations, and time since survey (Figure 5). Time since the 1980 survey was the only significant explanatory variable in this model ($\beta = -0.033$, SE = 0.076, 95% C.I. = -0.037 to -0.028, $p < 0.001$).

Habitat Configuration and Composition

The percent cover of predicted marten habitat in SCEF declined from 27.0% (10.73 km^2) in 1978 to 20.1% (8.0 km^2) in 2007 (Figure 6, Table 7). In 1978, a single large, contiguous patch of marten habitat covered 17.8% of the area (7.08 km^2). By 2007 the largest contiguous patch of marten habitat comprised only 8.21% (3.27 km^2) of the total area. A 6.9% reduction in marten habitat from 1978 to 2007 seems small, but is misleading without additional context. For

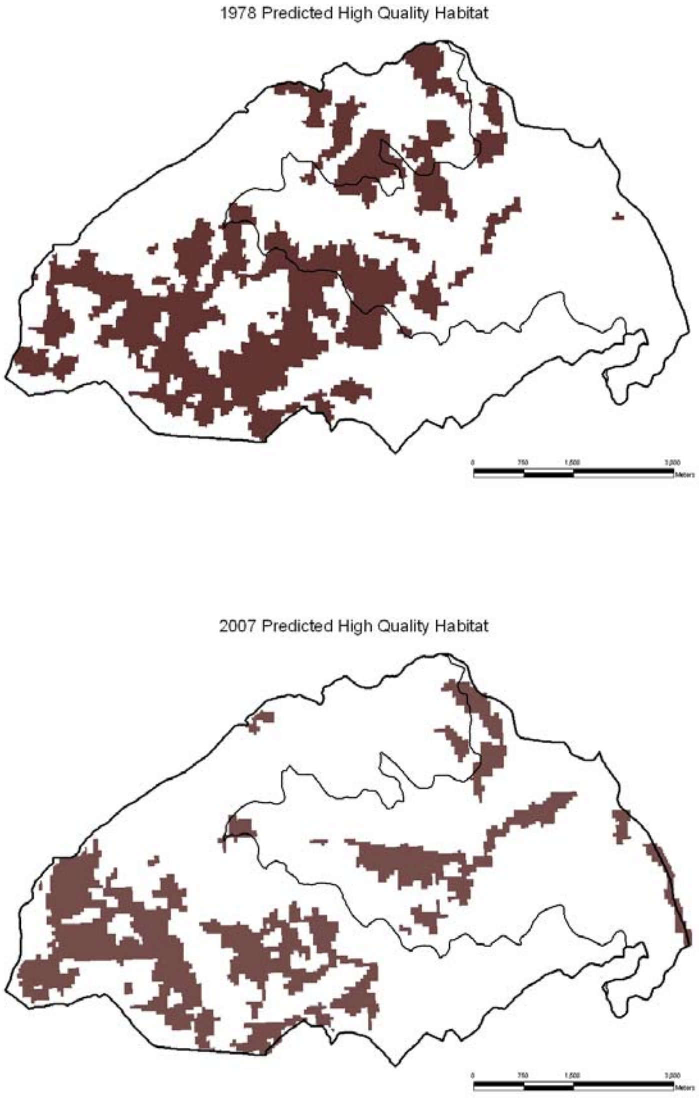


Figure 6. Predicted high quality marten habitat at Sagehen Creek Experimental Forest in 1978 (upper) and 2007 (lower), based on habitat definitions in the California Wildlife Habitat Relationship model (CWHR 2006). The upper basin is west of the 2,050m contour line inside the study area outline.

Table 7. Estimated amount and configuration of high quality marten habitat in Sagehen Creek Experimental Forest, CA in 1978 versus 2007. Data are presented separately for areas below and above the 2,050 m elevation contour (lower and upper basins, respectively). Standard errors for patch metrics are in parentheses.

	Lower basin		Upper basin	
Variable Name	1978	2007	1978	2007
Landscape metrics				
Percentage of landscape (PLAND)	16.81	15.19	32.93	23.13
Number of Patches (NP)	15	9	17	15
Largest Patch Index (LPI)	6.63	8.7	22.58	13.26
Percent cover of core areas (CPLAND)	3.6	2.53	10.51	6.22
Number of Distinct Core Areas (NDCA)	9	9	24	15
Patch metrics				
Mean patch area (AREA_MN) in ha	16.50 (3.0)	24.68 (6.3)	48.67 (32.6)	38.1 (23.5)
Area-weighted core area (CORE_AM) in ha	15.67 (13.9)	18.75 (17.5)	146.25 (143.7)	76.68 (66.3)
Area-weighted distinct core area (DCORE_AM) in ha	22.30 (14.1)	18.19 (13.2)	62.11 (58.1)	39.47 (36.4)
Proximity mean index (PROX_MN)	42.24 (27.6)	20.34 (7.8)	326.09* (101.6)	92.63* (35.2)
Area-weighted gyration (GYRATE_AM)	348.41 (23.4)	614.49 (31.7)	932.01 (70.4)	785.88 (45.8)
Mean nearest neighbor distance (ENN)	254.71 (84.1)	236.51 (82.2)	144.73 (21.4)	208.82 (78.1)

* Statistically significant with $P < 0.05$.

Table 8. Estimated amount and configuration of high quality marten habitat in Sagehen Creek Experimental Forest, CA in 1978 versus 2007. Data are presented separately for the entire SCEF and the predicted habitat gain as well as predicted habitat loss between the two time periods (1978, 2007). Standard errors for patch metrics are in parentheses.

Variable Name	1978	2007	Gain	Loss
Landscape metrics				
Percentage of landscape (PLAND)	26.95	20.13	8.94	15.78
Number of Patches (NP)	19	18	29	46
Largest Patch Index (LPI)	17.8	8.21	1.83	6.83
Percent cover of core areas (CPLAND)	9.1	4.92	0.85	4
Number of Distinct Core Areas (NDCA)	25	24	12	19
Patch metrics				
Mean patch area (AREA_MN) in ha	56.46 (36.5)	44.54 (19.2)	12.27 (3.0)	13.65 (6.6)
Area-weighted core area (CORE_AM) in ha	189.99 (9.8)	60.12 (2.6)	4.09 (0.5)	50.00 (2.3)
Area-weighted distinct core area (DCORE_AM) in ha	96.05 (0.2)	34.53(0.2)	6.79 (1.4)	43.38 (1.5)
Proximity mean index (PROX_MN)	*283.16*(95.7)*	*83.51* (29.4)*	11.09 (4.2)	46.27 (14.6)
Area-weighted gyration (GYRATE_AM)	1045.65 (49.5)	746.58 (23.2)	308.91 (12.4)	635.63 (18.3)
Mean nearest neighbor distance (ENN)	194.38 (68.3)	240.50 (71.5)	302.43 (59.0)	221.15 (34.5)

* Statistically significant with $P < 0.05$.

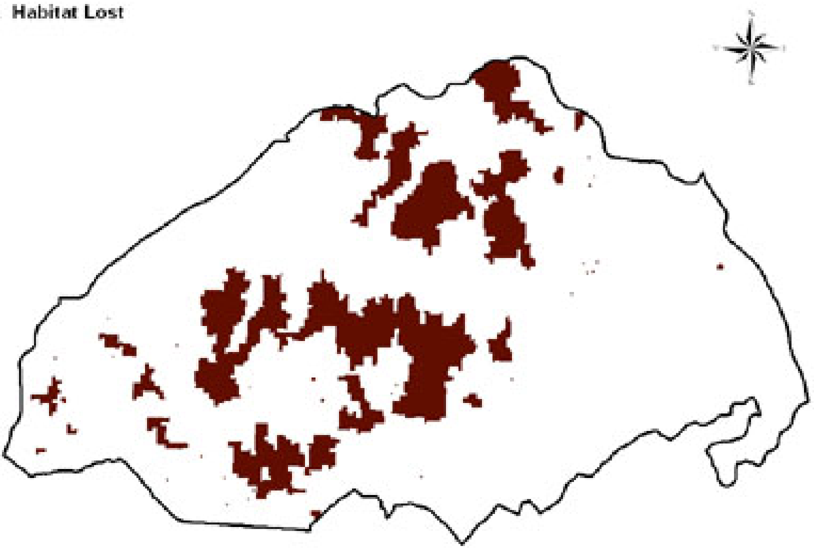
example, the total amount of high quality marten habitat decreased by 15.8% (6.28 km^2) from 1978 to 2007. Although 8.9% (3.6 km^2) of the area changed from the 'moderate' to the 'high' quality class; a large portion of this habitat gain was in riparian zones (52%) and not in the conifer types that characterize typical marten reproductive habitat (Figure 7). The total amount of habitat, number of habitat patches, core area, proximity mean index, and patch quality (area weighted gyration) was much less for habitat gained than habitat loss (Figure 7, Table 8).

Mean habitat patch area (AREA_MN) changed from 56.46 ha in 1978 to 44.54 ha in 2007 (Table 8). Although these estimates were not different statistically (Wilcoxon-rank sum, Z = 0.562, p = 0.574), there was high variation between the largest patches in both time periods (Figure 6). The Area-weighted core area (CORE_AM) did not differ between 1978 and 2007 (Wilcoxon-rank sum Z = 0.304, p = 0.761), even though the mean point estimate in 1978 was over three times as large as in 2007 (189 ha vs. 60 ha, respectively; Table 8).

After accounting for area, the mean distance between patches of marten habitat (PROX_MN) was greater in 2007 than in 1978 (Wilcoxon-rank sum, Z = 2.234, p = 0.028; Table 8). However, the Euclidean nearest neighbor distance between patch centroids (ENN) did not differ between 1978 and 2007 (Wilcoxon-rank sum, Z = -0.473, p = 0.636; Table 8).

Mean patch area, core area, and gyration increased in the lower basin and declined in the upper basin between 1978 and 2007 (Table 7). For example, the largest habitat patch in the lower basin increased by 1.1% (29.6 ha gain) while the

A. Habitat Lost



A. Habitat Gained

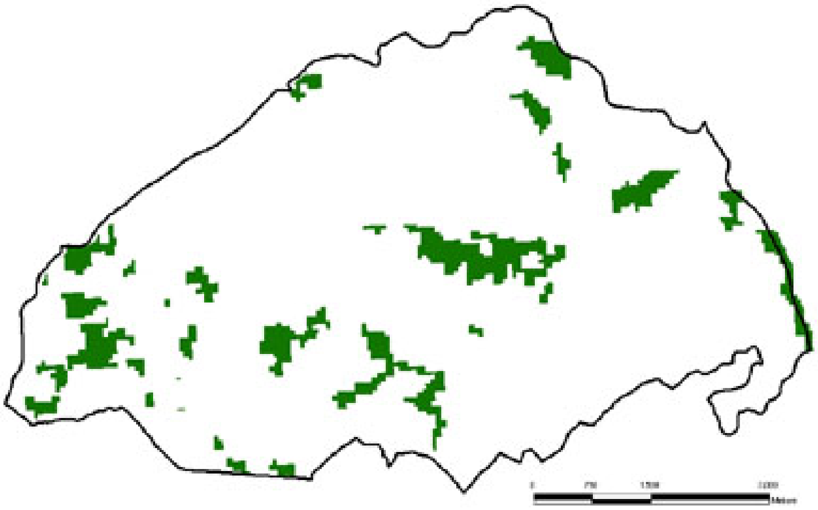


Figure 7. Estimated amount of high quality marten habitat (A) lost (15.8% and (B) gained (8.9%) during the period 1978–2007 on the Sagehen Creek Experimental Forest, CA.

largest patch in the upper basin decreased by 41% (239.8 ha reduction). The upper basin also had a 41% reduction in the total percent cover of core area of marten habitat (CPLAND), a 48% reduction in area-weighted core area, and a 72% decline in the mean proximity index (Table 7). Area-weighted measurements exhibited large variation due to the differences in area within the single large patches (Table 7).

Modeling Marten Occurrence as a Function of Environmental Covariates

1983 *a priori* models

The best model from 1983 included a positive relation between marten detections and elevation ($\beta = 0.0093$, S.E. = 0.003, $p < 0.001$; Table 9, Figure A3.1). There were no competitive models. After accounting for spatial autocorrelation of marten stations, elevation still explained a notable amount of the variation in marten detections ($n = 74$, $\rho = 0.449$, $r^2 = 0.114$, $F = 11.831$, $p < 0.001$).

2007–2008 *a priori* models

Of the 23 *a priori* models tested with the winter 2007–2008 data, four were competitive (Table 9; Appendix 3, Table A3.3). The best model included distance to a forest road, distance to high quality habitat, patch size, and an interaction between patch size and distance to the nearest high quality habitat. Surprisingly, this model suggested that martens were more likely to be detected when stations were closer to forest roads when accounting for all other variables ($\beta = -5.933$, S.E. = 3.278, 95% C.I. = -12.360 to 0.4931, $p = 0.07$). Martens were

Table 9. Competitive a priori models from the analysis of habitat effects on the detection of martens at Sagehen Creek Experimental Forest, CA. The response for the 1983 and 2008 analyses was a marten detection at a station. The response for the Change analysis was the lack of marten detected in 2007 in the vicinity of a 1983 marten detection (marten loss).

Analysis	Competitive Models[a]	Regression coefficient	K	AIC_c	ΔAIC_c	w_i
1983	elev	+[b]	2	78.62	0.00	0.40
2008	Distroad + dist_hab + p_size + dist_hab*p_size	0, 0, 0, 0[c]	5	65.26	0.00	0.22
2008	elev + dist_hab + p_edge + dist_hab*p_edge	0, 0, 0, 0	5	65.72	0.46	0.17
2008	dist_hab	+	2	66.13	0.86	0.14
2008	dist_hab + p_size + dist_hab*p_size	-[d], +, 0	2	66.13	0.86	0.14
Change	elev + distroad + dpann	0, +, 0	4	41.78	0.00	0.34
Change	distroad + distwater	+, 0	3	42.49	0.71	0.24
Change	elev + distwater + distroad + dp_size + dp_edge + dp_size*dp_edge	0, 0, 0, +, -, +	10	42.72	0.95	0.21

[a] Models with a ΔAIC_c value <2

[b] + indicates a positive beta coefficient with a 95% confidence interval that was > 0.

[c] 0 indicates a beta coefficient with a 95% confidence interval that included 0.

[d] – indicates a negative beta coefficient with a 95% confidence interval that was < 0.

Figure 8. Boxplots of the elevation covariate included in the most parsimonious AIC model describing marten occurrence on Sagehen Creek Experimental Forest in 1983. The 0 and 1 on the x-axis indicate stations without and with marten detections, respectively

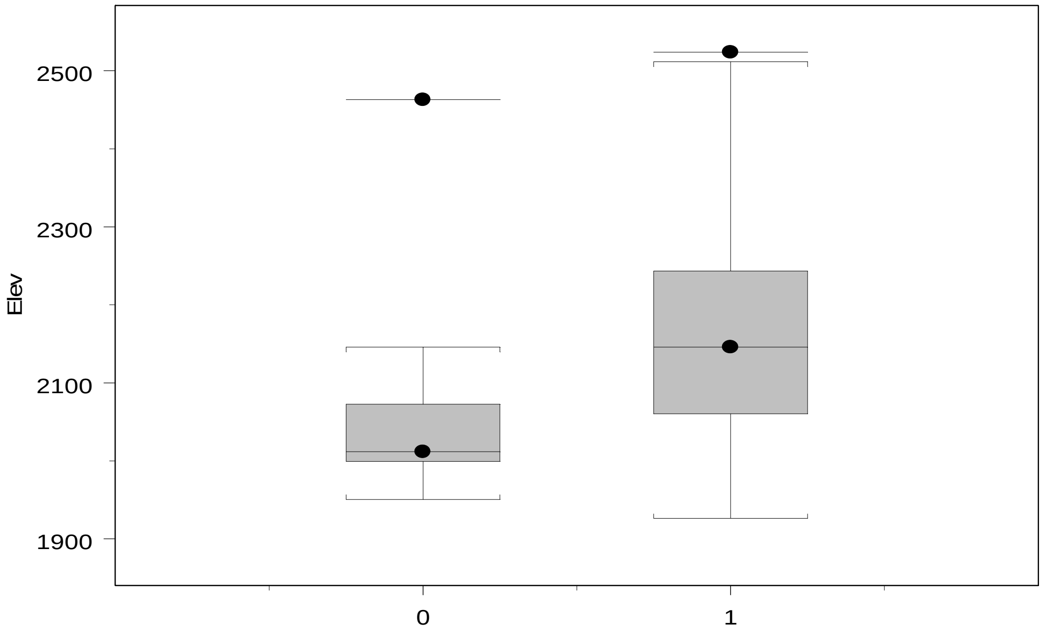


Figure 9. Boxplots of three covariates (distance to road, distance to predicted marten habitat, predicted habitat patch size) included in the most parsimonious AIC model describing marten occurrence on Sagehen Creek Experimental Forest in winter 2007-2008. The 0 and 1 on the x–axis indicate stations without and with marten detections, respectively.

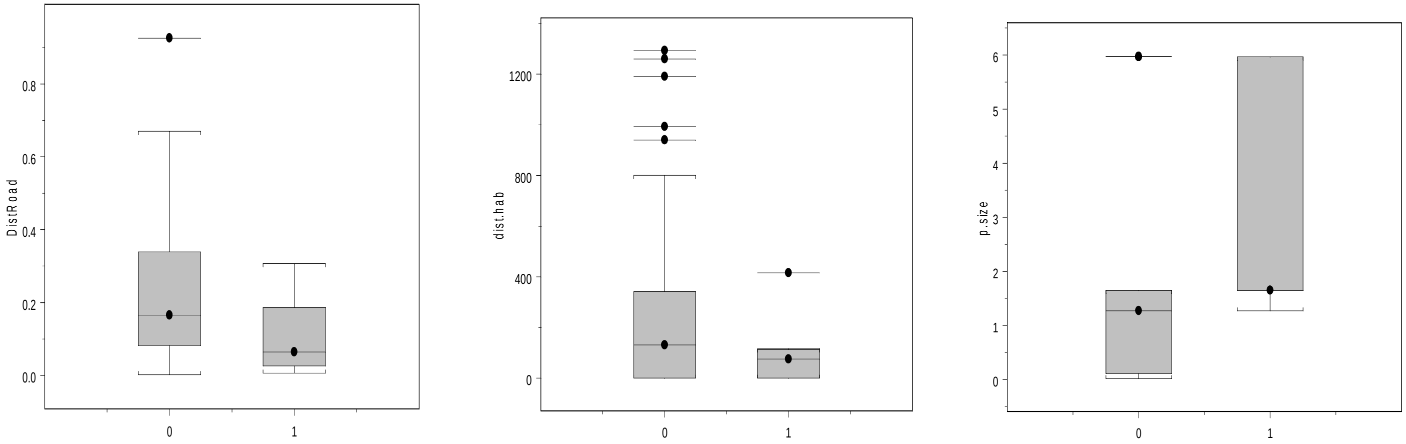
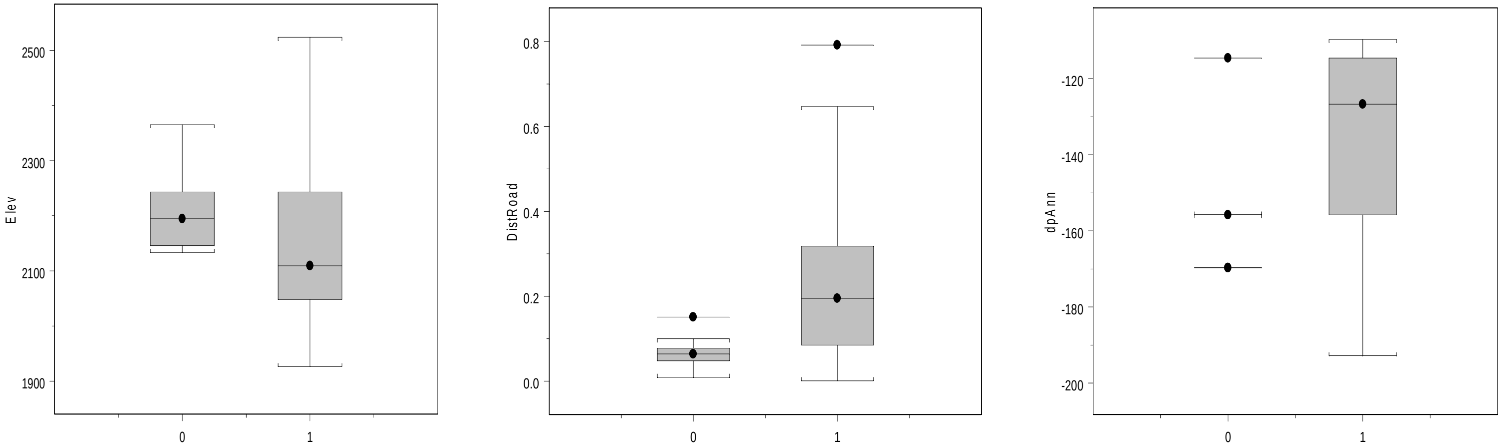


Figure 10. Boxplots of covariates included in the most parsimonious AIC model describing the change in marten detections on Sagehen Creek Experimental Forest during 1983–2008. On the x-axis a 0 indicates stations with marten detections both in 1983 and 2008 (no change), and a 1 indicates stations in which martens were detected in 1983 but not in 2007.



less likely to be detected when stations were distant from high quality habitat when accounting for all other factors (β = -0.0029, S.E. = 0.0031, 95% C.I. = -0.0089 to 0.0031, $p = 0.35$). Patch size was positively associated with detections after accounting for all other factors (β = 0.1607, S.E. = 0.1764, 95% C.I. = -0.1851 to 0.5064, $p = 0.36$). Lastly, this model indicated the strength of the interaction between patch size and distance to the nearest high quality habitat was weak as indicated by the small beta estimate and the fact that the 95% confidence interval overlaped zero after accounting for all other explanatory variables (β = 0.0009, S.E. = 0.0014, 95% C.I. = -0.0019 to 0.0037, $p = 0.53$). The best model explained little of the variation in marten detections ($n = 103$, $\rho = 0.145$, $r^2 = 0.078$, $F = 3.163$, $p = 0.03$).

Change Analysis

The most parsimonious of the 19 *a priori* models tested in the analysis of change indicated that the decline in marten detections was best explained by detections at lower elevations (β = -0.0032, S.E. = 0.0050, 95% C.I. = -0.0130 to 0.0066, $p = 0.53$), increasing distance from a road (β = 19.880, S.E. = 9.189, 95% C.I. = 1.8707 to 37.8909, $p = 0.03$), and a slight positive association with increased annual precipitation (β = 0.0241, S.E. = 0.0255, 95% C.I. = -0.0026 to 0.0741, $p = 0.34$; Table 9). After accounting for the spatial autocorrelation of stations, this model explained a small proportion of the variation in predictive marten loss ($n = 52$, $\rho = 0.216$, $r^2 = 0.134$, $F = 2.433$, $p = 0.08$). There were two competitive models (Table 9, Appendix 3, Table A3.5). Elevation was a significant explanatory variable in two of the top three models, both suggesting that increasing elevation was weakly associated with the decline in marten detections (Table 9, Appendix 3).

In the 28 years since the first marten surveys at SCEF, the annual mean minimum daily temperature increased by 4˚C ($\beta = 6.28$, $r^2 = 0.66$, $p < 0.001$), the annual mean maximum daily temperature increased by 0.43 ˚C ($\beta = 0.05$, $r^2 = 0.21$, $p = 0.01$), and total annual precipitation decreased by 55 cm ($\beta = -1.38$, $r^2 = 0.10$, $p = 0.09$; Appendix 4).

DISCUSSION

The results of this study suggest a decline in the abundance of martens at Sagehen Creek Experimental Forest during 1980–2008. Similar declines have been documented at other locations in the Sierra Nevada and Cascade ranges of California (Zielinski et al. 2005, Kirk and Zielinski 2009). The decline at SCEF is of particular concern considering that this area was historically considered a marten stronghold by trappers (Grinnell et al. 1937) and was chosen as a study site for several research projects because of the high density of martens (Spencer 1981, Zielinski 1981, Martin 1987). The average detection rate of 4% in my study is markedly less than the average detection rate of 65% in the 1980s, and does not bode well for the persistence of martens at SCEF. There are a number of possible explanations for the apparent decline of martens in SCEF including habitat loss, increases in habitat fragmentation, and other effects that compound the relationship between marten occurrence and habitat.

The definition of marten habitat that I used in my study was conservative compared to studies in which other biologists explored marten populations in relation to the amount of clear-cut and forested vegetation (e.g. Hargis et al 1999, Potvin et al. 1999). My results are likely more sensitive to partial cuts and thinning treatments. These results indicate habitat change between 1978 and 2007 at SCEF and can be compared among other studies that similarly defined predicted marten habitat (e.g. Green 2007, Kirk and Zielinski 2009).

Because martens tend to avoid openings and fragmented landscapes (Drew 1995, Hargis et al. 1999, Potvin et al. 2000, Andruskiw et al. 2008, Webb and Boyce 2009), I expected to observe a decline in marten occurrence as a result of fragmentation of habitat in the study area. Although the total amount of predicted habitat did not significantly differ between 1978 and 2007, the combination of known timber harvest activities and the loss of predicted habitat similarly correspond with a decline in marten detections between 1983 and 1990. During the period from 1984–1990 more than 30% of the forested habitat in SCEF was impacted by salvage cuts, selective tree cutting, thinning, clear-cuts, or shelterwood cuts. When a previously contiguous forest is fragmented by clear-cuts, martens may either relocate (Potvin et al. 1999), expand their home ranges (Potvin and Breton 1997, Fuller and Harrison 2005), or abandon the area (Chapin et al. 1998). Depending on geographic area, there appears to be a threshold such that marten populations are extirpated after 33-55% of forested habitat is removed (Hargis et al. 1999, Potvin et al. 2000, Fuller 2006, Webb and Boyce 2009). I was not able to create a vegetation map that would represent marten habitat availability in 1990; however, with the dramatic differences in detections I suspect the number and spatial distribution of martens changed during the period between 1983 and 1990.

Marten detections were high during the early surveys at SCEF, and the overall percentage of predicted habitat at SCEF did not significantly change from 1978 to 2007. Thus, the total amount of habitat may not be the most important variable affecting marten occurrence. Instead, it is likely that the size of patch core areas, distance between patches, spatial configuration of patches, and microhabitat features within patches may be more important for marten persistence within this geographic region than the total amount of habitat (Hargis et al. 1999, Minta et al. 1999). I suspect that the reduction of core habitat and the increase of patch distance exceeded the threshold for martens to persist in the lower basin and limited the marten population at SCEF. Both the percent core area and largest patch size declined between 1978 and 2007. Between 1978 and the 1990s most of the predicted high quality marten habitat was eliminated from the lower basin, which directly correlated with the shift of marten detections to the upper basin (Martin 1995). In the upper basin, patch size and core areas decreased, and the distance between patches increased. Even though a disproportionate amount of habitat was removed from the upper basin, the matrix of suitable habitat was likely still large enough to provide some habitat for martens.

Another possible explanation for the declining abundance of marten on SCEF is that selective logging and salvage logging of dead and dying trees may have reduced the availability of denning and resting structures. I did not measure changes in the abundance of denning and resting structures, but some researchers have suggested that those structures can be limiting factors for martens (Martin 1987, Spencer 1987). Cavities, mistletoe brooms, epicormic branches, large woody material, and large standing snags are preferred denning structures for martens (Martin and Barrett 1991, Buskirk and Powell 1994); however, these types of structures were often removed in traditional silvicultural treatments (Smith et al. 1997). Thus, it is likely that the combination of the 1988 Golden Sale and the 1990 Salvage Sale reduced the availability of trees with these structural attributes while also decreasing the recruitment of structurally diverse trees in subsequent years. The 1990 Salvage was designed to remove dead and dying trees following a large scale tree die-off that occurred in the 1980s (J. Roubique, Truckee Ranger District, District Ranger, personal communication). Following these two events, marten detections declined by an average of 40%, and marten detections were primarily limited to high elevation areas in the southwest portion of the basin. Although I did not directly assess snag and cavity abundance, it has been suggested that previous snag retention practices in Forest Service timber sales in SCEF were inadequate for persistence of cavity nesting birds (Morrison et al. 1986). A reduction in snags and associated den cavities could have a bioenergetic cost to martens at SCEF as martens behaviorally thermoregulate by using cavities in trees, snags, and logs as resting and denning sites (Taylor and Buskirk 1994). The loss of microhabitat features such as cavities in living and dead trees likely compromised martens at SCEF.

Alternative Explanations for Marten Decline

The causal ecological processes leading to the apparent decline of martens at SCEF are complex and almost certainly extend beyond the scope of my data. The evidence points to timber harvest as a major contributing factor, but it is possible that competition, predation, prey abundance and distribution, disease, and a changing climate regime may also have synergistically affected marten occurrence over the 28-year period of my analysis.

In addition to directly reducing marten habitat, timber harvest can affect habitat for marten prey and reduce the ability of martens to effectively forage. Prey numbers and biomass are often similar in harvested and non-harvested stands (Hargis et al. 1999, Andruskiw et al. 2008), but may not be equally available to martens in all seasons in all cover types. For example, martens use shelterwood stands to forage on ground squirrels (*Spermophilus* sp.) and chipmunks (*Tamias* sp.) during summer (Ellis 1998), but during winter they forage heavily on northern flying squirrels (*Glaucomys sabrinus*) and Douglas squirrels (*Tamiasciurus douglasii*), which are associated with mature and late-seral forest (Zabel and Waters 1992, Weigl 2007). In addition, snowshoe hare

(*Lepus americanus*), which are winter prey of martens at SCEF, occur at highest densities in areas with dense understory cover that can be used for predator avoidance and browse (Litvaitis et al. 1985). Considering the habitat requirements of the principal prey used by martens in winter at SCEF, it is likely that forest thinning reduces prey biomass available to martens in winter when thermoregulation requires high energetic and metabolic input (Taylor and Buskirk 1994). Futhermore, recent thinning projects and previous management within SCEF removed much of the downed woody debris and foraging success may be lower in cut and regenerating forests lacking structural characteristics that martens use as hunting cues (Andruskiw et al. 2008). I did not collect data on small mammals and these hypotheses require further investigation.

Increased risk of predation on martens may be an indirect effect of timber harvest when the harvest increases marten visibility and decreases available escape cover (Drew 1995). Potential marten predators detected within SCEF include mountain lion, (*Puma concolor*), bobcat (*Lynx rufus)*, coyote (*Canis latrans)*, great horned owl (*Bubo virgianus*), northern goshawk (*Accipiter gentilis*), and red-tailed hawk (*Buteo jamaicensis*) (Drew 1995, Bull and Heater 2001b). In Lassen National Forest, marten predation was only documented in shelterwood stands (n = 5), which suggested that predation risk may have been higher in areas with limited cover (Ellis 1998). Martens behave cautiously when coyote scat is present (Drew 1995). The upper basin likely restricted terrestrial predators like coyotes and bobcats in winter with deep snow pack providing some refuge from these predators (Krohn et al. 2004). Although I did not attempt to test hypotheses regarding the effects of habitat structure on predation on martens, such hypotheses need to be tested in the future.

An alternative hypothesis for the declining marten population at SCEF may be that climate change is altering vegetation structure and associated mammal populations. It is unlikely that climate change affected vegetation or marten numbers between 1983 and 1990. In this region, the time frame between 1961 and 1990 is considered a reference period for climate modeling (Hayhoe et al. 2004, Lawler et al. 2009) and as such change in climate during that period is unexpected.

Changing weather patterns may affect the flora and fauna in this region (Kelly and Goulden 2008, Moritz et al. 2008, Lutz et al. 2009, vanMatgem et al. 2009). At SCEF the annual mean minimum temperature increased during the mid to late 1990s (Appendix 5, Figure A5.3). Warming rates have been shown to increase tree mortality by changing typical hydrologic cycles as well as making trees more susceptible to disease and insect attacks (vanMatgem et al. 2009). Red fir is recognized as preferred marten habitat in this area (Spencer et al. 1983, Mayer and Laudenslayer 1988), and the evidence suggests that large scale red fir die-offs are likely due to the synergistic effects of insects (*Dendroctonus* sp., *Ips* sp., *Scolytus* sp.), dwarf mistletoe (*Arceuthobium* sp.), Annosum root rot (*Heterobasidium annosum*), and other forest diseases at SCEF that may be exacerbated by changing climate (Bulaon and MacKenzie 2007). Large-diameter red fir are not declining more than expected with changing climate, but there may be a uniform decrease in large-diameter white fir and lodgepole pine (Lutz et al. 2009), which are also preferred habitat for marten. While dead trees and other structural defects in trees resulting from forest diseases may be temporarily beneficial for marten dens and rest sites, accelerated mortality and range contractions of species such as red fir may result in the decline of marten habitat in the future.

In addition to vegetation change there have been notable range shifts in mammals correlated with climate change in the last century with additional changes expected (Moritz et al. 2008, Lawler et al. 2009). I did not measure the abundance of other mammals at SCEF, but I did note that some mammals, including yellow-bellied marmot (*Marmota flaviventris*), Belding's ground squirrel (*Spermophilus beldingi*), and pika (*Ochotona princeps*), were not observed during my field work despite their previous abundance in the area (Nee 1967, Taylor 1970, Docekal 1978, Woodard 1994). Pikas and marmots are sensitive to the effects of global warming (Krajick 2004, Moritz et al. 2008). The cause of suspected mammal declines at SCEF is unknown; these declines may reflect increased environmental stress.

Data Considerations

It is possible that variation in survey methods over the 28-year period in my analysis may have influenced the results. One difference between my study and previous studies at SCEF was that previous researchers used track plates in trees, whereas I placed track plates on the ground. I did this because it is logistically difficult to set and maintain track plates in trees (Zielinski 1995, Long et al. 2008), and because I thought it was more important to be consistent with current methods being used in other mesocarnivore studies in which researchers used track plates on the ground (Ray and Zielinski 2008). There is little reason to suggest that placement of track plates had any affect because of the high probability of detection during this study (Table 6).

When martens were not detected in summer 2007, I switched to a combination of methods during winter 2007–2008 in an effort to increase my odds of detecting martens. This could have biased my results in favor of detecting more martens than in previous studies in which researchers used live-trapping, track plates, or snow tracking during winter (Spencer 1981, Martin 1987). If anything, however, this makes the low detection rate of martens in my study even more suggestive of a population decline relative to previous studies.

Results from previous years did not suggest large differences in detection between the snow and snow-free seasons. In fact there were fewer detections per unit effort in the snow seasons in 1992 and 2008 compared to the snow-free seasons of 1991 and 1993, the only years for which detection histories were available (Table 5). This suggests that the likelihood of detecting martens was similar among seasons or at least not consistently greater in one season than another. However, my surveys suggested a marked difference in marten detections between the snow and snow-free seasons in 2007–2008. This could be because martens were not present in the summer or because detection probabilities differed between seasons. It is also possible that the martens that I detected in winter were dispersing individuals and not residents, as dispersal normally occurs in the fall and early winter (Bull and Heater 2001a, Broquet et al. 2006). This possibility, and seasonal differences in detection rates, need to be investigated with radio-collared martens before inferences are made from the lack of detections during summer in 2007 and 2008.

The 1978 and 2007 habitat maps were created using identical methods, but I was unable to quantify the error in these maps and thus it is possible that they had inaccuracies that were relevant to my hypotheses regarding marten habitat. A qualified aerial photograph interpreter compared 235 reference points on the vegetation maps to minimize classification error, so I expect that accuracy of my maps was >80% based from other remote sensing standards (Broham and Bryant 2005). Under-classification of red fir, one of the primary vegetation types linked to marten occurrence, may have implications for the predicted habitat model in that it would reduce the total amount of predicted habitat. I compensated in part by including large and dense mixed-conifer fir in the high quality marten habitat category, which increased the predicted habitat in 1978 to a level expected by locations from Spencer (1981) and Martin (1987) (Table 3). The inclusion of large-diameter and dense canopy cover mixed-conifer fir and the combination of habitat into dichotomous categories (predicted high quality and not predicted high quality) likely provides a reasonable representation of true marten habitat. In future studies I would randomly ground check a large sample of reference points to specifically address map classification accuracy.

I considered four potential problems while using the data for model selection and logistic regression to assess changes in microhabitat. The first is that this process assumes the primary response, marten detection, is synonymous with marten habitat selection. Because stations were baited with food and lure, the motivation of a marten to visit these stations may not be representative of habitat that a marten would otherwise use. Second, the analysis of marten locations in 1983 was based on the vegetation map created in 1978. It is possible that the map did not completely reflect changes that occurred between 1978 and the 1983 survey; however I did not consider this a problem because no management activity was reflected in the TNFESDL. Third, many of the covariates were extracted from previously modeled vegetation and climate data, which may have compounded error due to the imprecision of modeling (Glenn and Ripple 2004). Lastly, the number of detections was highly skewed in 2007-2008 and in the change analysis. Because of these potential problems, I was concerned that inference from logistic regression models might be weak. Nonetheless, with the available series of data, the change analysis seemed to be the only direct method to assess changes in marten detection in relation to environmental covariates.

The 1983 model selection results differed from conclusions made by Spencer (1981) and Martin (1987) who based their assessment of habitat selection on radio telemetry locations. Spencer (1981) suggested that differences in results from track plates and telemetry were due to the use of bait and lure at track plate stations. As such, it was not completely unexpected that the change analysis did not explain much of the variation in marten detections at SCEF. The climate covariates of annual mean minimum temperature, annual mean maximum temperature, and total annual precipitation were not included in the most parsimonious change model. Nonetheless, even small changes in the climate may affect species distributions (Moritz et al. 2008). My results cannot be used as a predictive model for habitat selection because my data were not collected using methods to evaluate habitat selection. Future studies should use a tight experimental design with replication along with unbaited marten locations. Explanatory variables extrapolated from the vegetation maps and climate models should also be examined at a finer spatial resolution and in a way that reduces bias and decreases random error.

MANAGEMENT IMPLICATIONS AND CONCLUSIONS

The distribution and detection rate of martens have declined at SCEF over the past 28 years. Although my study was observational, I suspect that the changes in vegetation are at least partly responsible for the observed decline. Due to the apparent shift in marten occurrence both in location and numbers at SCEF, I recommend that managers carefully plan for the future conservation of martens on this landscape. Martens either persist as a small population in the southwest portion of SCEF or are functionally extirpated from the basin. The objective should be to integrate treatments designed to maintain the natural disturbance regime with treatments designed to maintain habitat for sensitive species such as martens (Forman and Collinge 1996, North et al. 2009). Suppression of disturbance, such as fire, can lead to large-scale high-severity fires (VanWagtendonk and Fites-Kaufman 2006). To reduce the risk of such fires, the U. S. Forest Service has proposed the use of Strategically Placed Area Treatments (SPLATs) on SCEF and surrounding areas (Battles and Stephens 2001, Vaillant 2008). If SPLATs are the chosen method for treatment, there are at least five strategies that should increase the likelihood of marten persistence within SCEF. First, managers should strive to retain the remaining contiguous large patches of predicted marten reproductive habitat, especially red fir in the upper basin. Second, additional thinning should be implemented only if the pattern of fuel heterogeneity clearly indicates it is necessary. The natural red fir fire regime widely varies and fuel accumulation at SCEF may be within expected levels (Taylor 2000, Bekker and Taylor 2001, Taylor and Solem 2001). Third, corridors of dense, late-seral vegetation should be retained in thinned areas. Heinemeyer (2002) recommended a width: length ratio of 1:2.5 for effective connectivity of marten habitat. Adjacent thinned areas should still retain escape routes in the form of remaining trees and varied amounts of canopy and shrub cover for visual camouflage between habitat patches. Forth, efforts to reduce the number of cleared forest gaps >80 m across (Heinemeyer 2002) should be beneficial for martens. Drew (1995) found that martens were more likely to cross an area with residual trees for escape cover, even if those trees were defoliated. Lastly, striving for a silvicultural paradigm that retains large snags, diverse tree structure, and patches of decadent trees is crucial to maintaining resting and denning habitat for martens (Franklin et al. 2002). Previous timber harvests at SCEF apparently have created an environment with diminishing benefits to martens. Thus, any additional management actions should consider the balance between additional negative effects on marten habitat and the predicted effects of fire behavior.

Future research should investigate synergistic effects that may influence marten abundance and distribution, including relationships between inter-specific competition and predation, the abundance of prey relative to changes in habitat structure and composition, long-term changes in small mammal composition, and forest composition due to shifting climatic regimes. Hopefully, the rich data set on marten abundance at SCEF will provide encouragement for such studies in the future.

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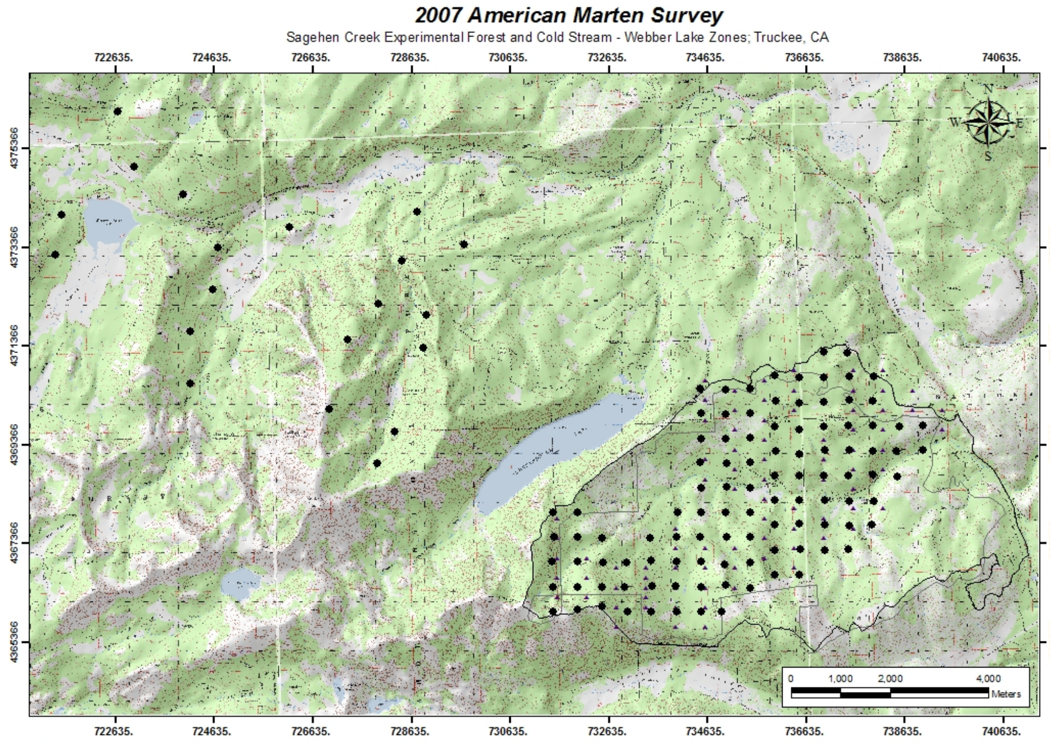
APPENDIX 1: DETAILED SURVEY METHODS

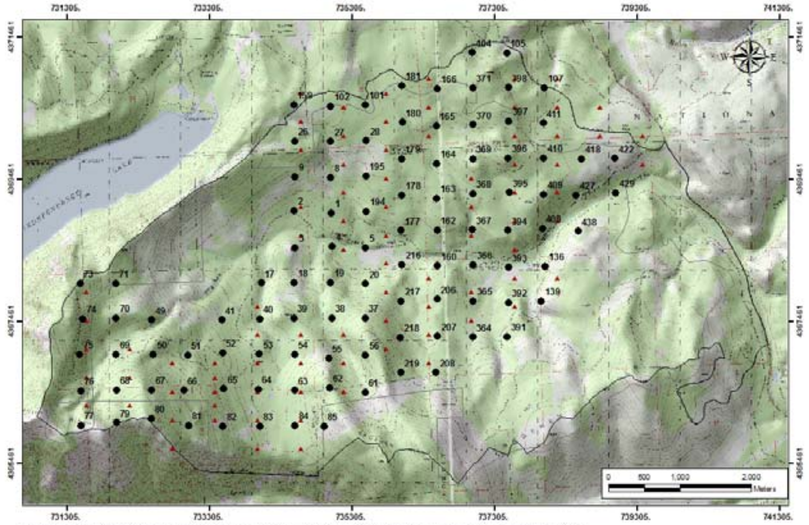


SCEF grid a subcomponent of the UC Berkeley fire modeling grid. Boundary provided by D. Saah. Plot locations provided by G. Roller.
North American Datum of 1983 (NAD83), Conic Alberts Projection
Map created by K. Moriarty - 01 Oct 07

Figure A.1 1. Survey points completed for marten surveys in summer 2007; Sagehen Creek Experimental Forest and to the northwest in the Webber Lake, Perazzo Meadow, and Cold Stream Canyon area, Tahoe National Forest, CA.

2007 American Marten Survey

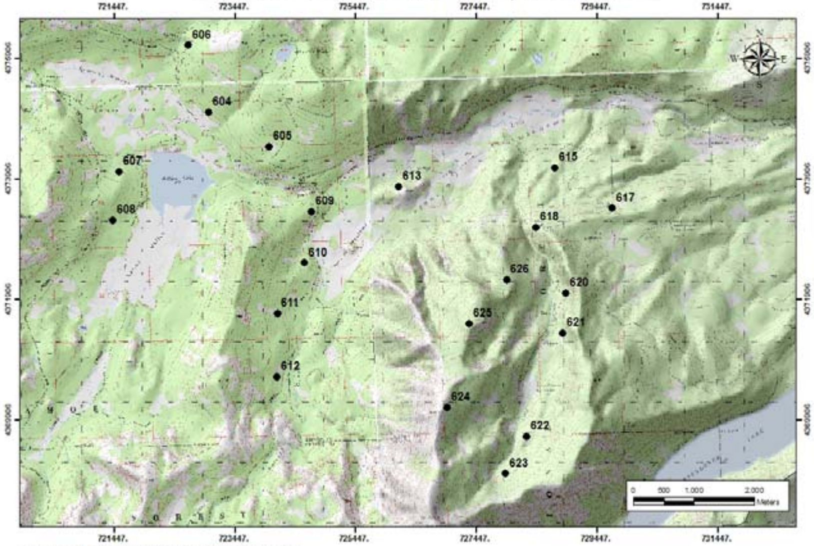
Sagehen Creek Experimental Forest; Truckee, CA



SCEF grid a subcomponent of the UC Berkeley fire modeling grid. Boundary provided by D. Saah. Plot locations provided by G. Roller.
North American Datum of 1983 (NAD83), Conic Alberts Projection
Map created by K. Moriarty - 01 Oct 07

2007 American Marten Survey

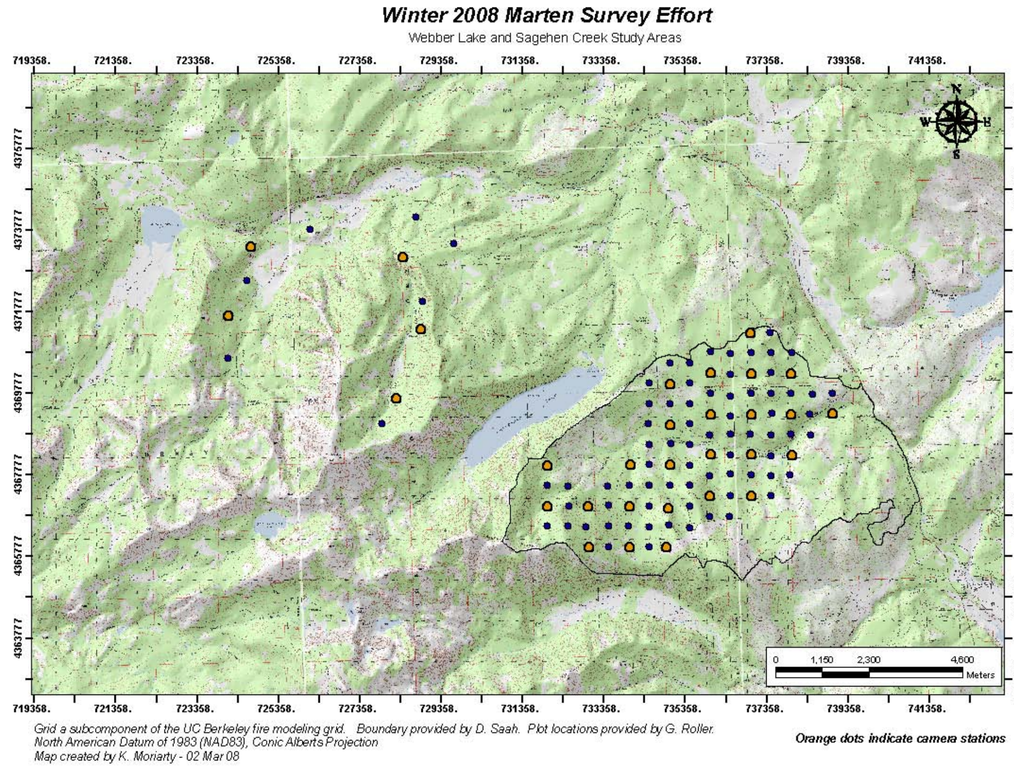
Webber Lake (northwest), Perazzo Meadows, and Cold Stream Canyon; Tahoe National Forest, CA



North American Datum of 1983 (NAD83), Conic Alberts Projection
Map created by K. Moriarty - 01 Oct 07

Figure A.1 2. Marten survey stations sampled in summer 2007 at Sagehen Creek Experimental Forest, and to the northwest in the Webber Lake, Perazzo Meadow, and Cold Stream Canyon area, Tahoe National Forest, CA

Figure A.1 3. Track plate hair snare used to detect martens in summer 2007 at Sagehen Creek Experimental Forest, CA.



Winter 2008 Marten Survey Effort

Webber Lake and Sagehen Creek Study Areas

Grid a subcomponent of the UC Berkeley fire modeling grid. Boundary provided by D. Saah. Plot locations provided by G. Roller.
North American Datum of 1983 (NAD83), Conic Alberts Projection
Map created by K. Moriarty - 02 Mar 08

Orange dots indicate camera stations

Figure A.1 4. Marten survey stations sampled in winter 2007–2008 in Sagehen Creek Experimental Forest, CA. Orange circles indicate locations of remote sensor cameras; filled black circles represent bait stations.

Figure A.1 5. Digital cameras (Cuddeback, model Excite) with an insulated jacket were used to detect martens at Sagehen Creek Experimental Forest, CA winter 2007–2008.

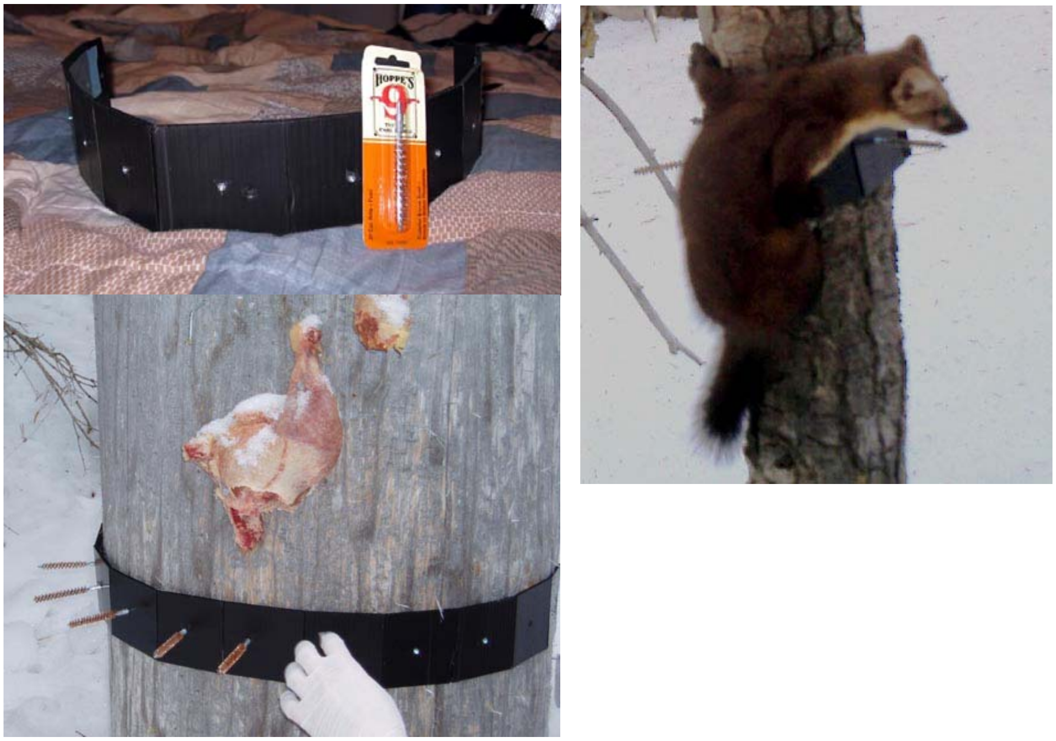


Figure A.1 6. Marten hair snare devices used in the winter consisted of an 8cm wide Coroplast strip with 38 caliber gun cleaning brushes mounted 10 cm apart and projecting outward from the trunk. Snare developed by P. Figura and L. Knox, California Department of Fish and Game.

Table A.1 1. Historical marten surveys northwest of Sagehen Creek Experimental Forest in the Webber Lake, Perazzo Meadows, and Cold Stream Canyon basins, CA. Data extracted from Simon (1980:46).

Surveyor	Survey Start	Date End	Trap nights	Traps set off	Marten captures	Marten recaptures
Simon	Sept-78	Dec-78	678	152	12	7
Simon	Jan-79	May-79	150	19	11	6
Simon	Jun-79	Oct-79	738	198	22	14

APPENDIX 2: CONTEMPORARY SURVEY RESULTS

Table A.2 1. Marten survey effort from summer 2007 at Sagehen Creek Experimental Forest (SCEF) and to the northwest in three watersheds (Cold Stream-Webber). Surveys were completed using track plates in two study areas over a 10 week period. These were broken down into two survey bouts or "runs". Run 1 had two routes (A&B) that were set up at different times.

	No. stations	No. checks	Station visits[a]	Trap nights	Start	Stop	Nights
SCEF							
Run 1 - A	28	5	140	980	20-22 Jun	25-27 Jul	35
Run 1 - B	25	4	100	700	27-29 Jun	25-27 Jul	28
Run 2	51	5	255	1785	8-10 Aug	12-13 Sep	35
Cold Stream- Webber	20	5	77	539	8-18 Aug	11 Sep	Varies
Totals	124		572	2324			

[a] Number of cumulative visits at set stations

Table A.2 2. Marten survey effort during winter 2008 season at Sagehen Creek Experimental Forest and to the northwest in two watersheds (Cold Stream, Perazzo Meadows).

	No. stations		No. checks		No. station visits[a]	No. survey nights		Duration (nights)[b]		Aprx. effective nights	
	Camera	Bait	Camera	Bait		Camera	Bait	Camera	Bait	Camera	Bait
Sagehen											
Run 1	13	40	9-12	6	450	878	1930	66-68	45-49	35-40	35
Run 2	12	29	5	5	300	585	1475	35	35	35	35
Cold Stream-Perazzo	5	8	3	3	39	145	261	29	29	29	35
Totals	30	77			789	1608	3666				

[a] The number of checks with survey effort, reflects an approximation of possible detection opportunity.

[b] Durations varied due to camera flash malfunctions in Run 1.

Table A.2 3. Species detected during summer 2007 track plate surveys at Sagehen Creek Experimental Forest (SCEF) and within a zone to the northwest including Cold Stream Canyon, Perazzo Meadows, and Webber Lake watersheds (Cold Stream-Webber). The number of boxes (n) varied between runs and location (see Table 2.1).

Common name	Species	SCEF (n = 53)	Cold Stream-Webber (n = 20)	Total detected	Percent of detections
Unknown chipmunk	*Tamias sp.*	214	12	226	33.8%
Black bear	*Ursus americana*	188	22	169	25.3%
California ground squirrel	*Spermophilus beecheyi*	50	15	106	15.8%
Golden-mantled ground squirrel	*Spermophilus lateralis*	70	15	85	12.7%
Unknown small rodents	*Mice*	34	4	36	5.4%
Douglas' squirrel	*Tamiasciurus douglasii*	27	16	34	5.1%
Raccoon	*Procyon lotor*	3	0	4	0.6%
American marten	*Martes americana*	0	3	3	0.4%
Northern flying squirrel	*Glaucomys sabrinus*	2	0	2	0.3%
Lizard	*Lizard*	1	0	1	0.1%
North American porcupine	*Erithizon dorsatum*	1	0	1	0.1%
Striped skunk	*Mephitis mephitis*	1	0	1	0.1%
Western spotted skunk	*Spilogale gracilis*	1	0	1	0.1%
Totals	*13 species*			669	100%

Table A.2 4. Species detected during winter 2007–2008 surveys at Sagehen Creek Experimental Forest, CA and to the northwest in two watersheds (Cold Stream, Perazzo Meadows). Snow-tracking was not evaluated except for the two key mustelid species (American marten and wolverine) because the reliability of the detection method differed by snow condition and observer.

Common Name	Species	No. stations	SCEF	Cold Stream	Total detected	Percent of detections
Common raven	*Corvus corax*	14	28	0	28	26.9%
Coyote	*Canis latrans*	9	12	0	12	11.5%
American marten	*Martes americana*	10	8	4	12	21.2%
Weasels (long and short–tailed)	*Mustela species*	5	8	6	14	13.5%
Stellar's jay	*Cyanocitta stelleri*	2	5	0	5	4.8%
Western spotted skunk	*Spilogale gracilis*	1	4	0	4	3.8%
Douglas' squirrel	*Tamiasciurus douglasii*	4	4	0	4	3.8%
Snowshoe hare	*Lepus americana*	4	3	2	5	4.8%
Wolverine	*Gulo gulo*	2	2	1	6	5.8%
Unknown small rodents	*Mice*	?	1	1	2	1.9%
Black bear	*Ursus americana*	1	1	0	1	1.0%
Bobcat	*Felis rufus*	1	1	0	1	1.0%
Totals	*12 species*				104	100%

Table A.2 5. Individual and gender results from marten hair samples at Sagehen Creek Experimental Forest, CA 2007-2008. .

Individual	Station	Date collected	Gender	Sample number
1	055	4-Mar-08	F	SC2008016
poor DNA	055	4-Mar-08	poor DNA	SC2008014
poor DNA	055	4-Mar-08	poor DNA	SC2008015
2	069	9-Mar-08	M	SC2008028
2	069	9-Mar-08	M	SC2008024
3	Near W622	19-Feb-08	M	SC2008323
4	051	18-Mar-08	F	SC2008058
4	051	18-Mar-08	F	SC2008059
4	051	18-Mar-08	F	SC2008049
4	051	18-Mar-08	F	SC2008050
4	051	23-Mar-08	F	SC2008165
5	W622	19-Mar-08	M	SC2008085
5	W622	19-Mar-08	M	SC2008086
5	W622	19-Mar-08	M	SC2008083
5	W622	19-Mar-08	M	SC2008089

* ‘W’ indicates a station at the Cold Stream-Webber Lake drainages.

APPENDIX 3: AIC MODELS AND CORRELATION TABLES

Table A3 1. 19 *a priori* models examined to determine which environmental covariates best explained marten detections in Sagehen Experimental Forest, CA in 1983.

Model	Deviance	Log-likelihood	k	AICc	ΔAICc	w
elev	74.45	-37.22	2	78.61	0.00	0.39
veg + elev	67.48	-33.74	6	80.73	2.11	0.13
elev + dist_hab + p_edge + dist_hab*p_edge	69.95	-34.97	5	80.84	2.22	0.13
elev + dist_hab + p_size + dist_hab*p_size	69.96	-34.98	5	80.84	2.23	0.13
elev + dist_hab + p_size + dist_hab*p_size distwater	67.93	-33.96	6	81.18	2.56	0.11
elev + dist_hab + p_size + dist_hab*p_size + distwater + distroad	67.89	-33.94	7	83.58	4.97	0.03
dist_hab + p_size + dist_hab*p_size + distroad + distwater	72.12	-36.06	6	85.37	6.75	0.01
size + distwater + dist_hab + p_size dist_hab*p_size	64.82	-32.41	9	85.63	7.02	0.01
dist_hab + p_size + dist_hab*p_size	77.76	-38.88	4	86.34	7.72	0.00
Distwater	82.33	-41.16	2	86.49	7.88	0.00
veg + size + cc + distwater	57.49	-28.74	12	86.61	7.99	0.00
veg + dist_hab + p_size + dist_hab*p_size + distroad	67.32	-33.66	9	88.13	9.51	0.00
size + distwater	75.13	-37.56	6	88.38	9.77	0.00
dist_hab + p_size + dist_hab*p_size + distroad	77.72	-38.86	5	88.60	9.99	0.00
dist_hab	84.60	-42.30	2	88.77	10.15	0.00
veg size + dist_hab + p_size + dist_hab*p_size + distroad	61.13	-30.56	12	90.24	11.62	0.00
aspect + distwater + dist_hab + p_size + dist_hab*p_size	65.57	-32.78	12	94.69	16.07	0.00

aspect + size + distwater + dist_hab + p_size + dist_hab*p_size	59.82	-29.91	16	101.36	22.74	0.00
veg + aspect + dist_hab + p_size + dist_hab*p_size + distroad	62.59	-31.29	16	104.13	25.51	0.00

Table A3 2. Pearson correlation coefficients for 1983 AIC model covariates describing marten detections in Sagehen Creek Experimental Forest, CA. There were no statistically significant correlations with 83 degrees of freedom, correlations >|0.70| are in italics.

	Elevation	Distance to habitat	Patch size	Patch edge	Slope	Distance to road	Distance to water
Elevation	1.000	-0.137	0.430	0.430	0.501	0.129	0.418
Distance to habitat		1.000	-0.306	-0.302	-0.114	0.105	0.063
Patch size			1.000	*1.000*	0.213	-0.238	0.133
Patch edge				1.000	0.213	-0.242	0.131
Slope					1.000	0.061	0.313
Distance to road						1.000	0.257
Distance to water							1.000

Table A3 3. 26 *a priori* models used in analysis to determine which environmental covariates most parsimoniously explained marten detections within Sagehen Experimental Forest, CA in 2008.

Model	Deviance	Log-likelihood	k	AICc	ΔAICc	w
Distroad + dist_hab + p_size + dist_hab*p_size	54.64	-27.32	5	65.26	0.00	0.21
elev + dist_hab + p_edge + dist_hab*p_edge	55.09	-27.55	5	65.71	0.45	0.17
dist_hab	62.00	-31.00	2	66.12	0.86	0.14
dist_hab + p_size dist_hab*p_size	62.00	-31.00	2	66.12	0.86	0.14
distroad + distwater + dist_hab + p_size dist_hab*p_size	54.47	-27.23	6	67.34	2.08	0.07
elev + distwater + distroad + dist_hab + p_size dist_hab*p_size	53.12	-26.56	7	68.30	3.04	0.04
elev + dist_hab + p_size + dist_hab*p_size	57.80	-28.90	5	68.42	3.16	0.04
elev	65.18	-32.59	2	69.30	4.04	0.02
distwater	65.32	-32.66	2	69.44	4.18	0.02
elev + dist_hab + slope	61.39	-30.69	4	69.80	4.54	0.02
elev + BA_total + CWD	61.39	-30.69	4	69.80	4.54	0.02
elev + BA_total + CWD + dist_hab + p_size dist_hab*p_size	61.39	-30.69	4	69.80	4.54	0.02
elev + distwater + dist_hab + p_size dist_hab*p_size	57.22	-28.61	6	70.10	4.84	0.01
elev + distwater	64.53	-32.26	3	70.77	5.51	0.01
elev + slope + distwater	64.17	-32.08	4	72.58	7.32	0.00
size + distwater	64.09	-32.04	5	74.71	9.45	0.00
size + distwater + dist_hab + p_size + dist_hab*p_size	57.79	-28.89	8	75.33	10.07	0.00
veg + dist_hab + p_size + dist_hab*p_size + distroad	51.09	-25.54	12	78.55	13.29	0.00
Veg + size + distroad + dist_hab + p_size + dist_hab*p_size	50.90	-25.45	13	80.99	15.73	0.00
veg + size + distroad + BA_total + dist_hab + p_size + dist_hab*p_size	50.90	-25.45	13	80.99	15.73	0.00
veg + dist_type + dist_hab + p_size + dist_hab*p_size distroad	46.92	-23.46	15	82.44	17.18	0.00
Veg + elev	62.73	-31.37	9	82.67	17.41	0.00
veg + size + cc + distwater	57.31	-28.65	14	90.08	24.82	0.00
Aspect + distwater + dist_hab + p_size + dist_hab*p_size	0.00	0.00	79	707.56	642.30	0.00
aspect + size + distwater + dist_hab + p_size + dist_hab*p_size	0.00	0.00	82	844.60	779.34	0.00
veg + aspect + dist_hab + p_size + dist_hab*p_size distroad	0.00	0.00	84	961.33	896.07	0.00

Table A3 4. Pearson correlation coefficients for 2008 AIC model covariates describing marten detections in Sagehen Creek Experimental Forest, CA. There were no statistically significant correlations with 93 degrees of freedom, correlations >|0.70| are italic.

	Elev.	Dist. to habitat	Patch size	Patch edge	Slope	Dist. to road	Dist. to water	Dist. to disturb.	Harvest year	Disturb. size	CWD	BA_live	BA_all	Aspect
Elevation	1.00	-0.25	0.74	0.71	0.45	0.15	0.32	-0.37	0.47	-0.23	-0.08	-0.08	-0.11	-0.08
Distance to habitat			-0.39	-0.41	-0.26	0.20	-0.06	-0.17	-0.05	0.21	0.06	0.12	0.14	0.07
Patch size			1.00	0.99	0.37	-0.04	0.15	-0.13	0.25	-0.17	-0.05	-0.05	-0.091	-0.17
Patch edge				1.00	0.36	-0.09	0.12	-0.12	0.25	-0.16	-0.03	-0.01	-0.04	-0.16
Slope					1.00	-0.07	0.10	-0.08	0.17	-0.18	-0.02	-0.10	-0.11	-0.09
Distance to road						1.00	0.18	0.01	0.14	0.17	-0.11	-0.24	-0.19	-0.08
Distance to water							1.00	-0.31	0.22	0.08	0.12	0.00	0.01	-0.08
Distance to disturbance								1.00	-0.10	-0.08	0.01	-0.09	-0.08	0.17
Harvest year									1.00	-0.21	0.06	0.03	0.03	0.06
Disturbance size										1.00	0.09	0.10	0.12	-0.05
Coarse woody debris (CWD)											1.00	0.51	0.57	-0.01
Live basal area (BA_live)												1.00	*0.96*	-0.00
All basal area (BA_all)													1.00	-0.04
Aspect														1.00

Table A3 5. 19 *a priori* models examined to determine which environmental covariates most parsimoniously explained marten loss within Sagehen Experimental Forest during 1983-2008.

Model	Deviance	Log-likelihood	k	AICc	ΔAICc	w
elev + distroad + dpann	32.927	-16.463	4	41.778	0.000	0.341
distroad + distwater	35.991	-17.995	3	42.491	0.713	0.239
elev + distwater + distroad + dp_size + dp_edge + dp_size*dp_edge	17.359	-8.679	10	42.725	0.947	0.213
dist_type + distroad	34.344	-17.172	5	45.648	3.870	0.049
dist_type + h_year + dp_size + dp_edge + dp_size*dp_edge	26.591	-13.295	8	45.940	4.162	0.043
distroad	32.478	-16.239	6	46.345	4.567	0.035
dist_type + distroad + distwater	33.137	-16.569	6	47.004	5.226	0.025
distroad + distwater + dpann + dmax + dmin	25.591	-12.796	9	47.877	6.099	0.016
dpann + dmax + dmin	39.356	-19.678	4	48.207	6.429	0.014
elev + h_year	42.844	-21.422	3	49.344	7.567	0.008
dist_type + dpann	39.680	-19.840	5	50.985	9.207	0.003
elev + dist_dist + dpann	42.223	-21.111	4	51.074	9.296	0.003
dist_dist	46.860	-23.430	2	51.105	9.327	0.003
Elev	47.193	-23.596	2	51.438	9.660	0.003
dist_type + elev	40.527	-20.264	5	51.831	10.054	0.002
Ddist_hab + dp_size + ddist_hab*dp_size	44.151	-22.076	4	53.002	11.224	0.001
elev + dist_type + dist_dist + dpann	37.609	-18.805	7	54.155	12.377	0.001
elev + ddist_hab + dp_size + ddist_hab*dp_size	43.476	-21.738	5	54.780	13.002	0.001
elev + dp_size + ddist_+ hab dp + size*ddist_hab	43.476	-21.738	5	54.780	13.002	0.001

Table A3 6. Pearson correlation coefficients for AIC model covariates describing the change in marten detections between 1983 and 2008 in Sagehen Creek Experimental Forest, CA. There were no statistically significant correlations with 51 degrees of freedom, correlations >|0.70| are italic.

	Elevation	Δ Max temp.	Δ Min temp.	Δ Annual precip.	Δ Distance hab.	Δ Patch size	Harvest year	Disturbance distance	Δ Patch edge	Distance to road	Distance to water
Elevation	1.00	0.29	0.74	-0.77	-0.25	0.25	0.38	-0.23	0.26	0.12	0.28
Δ Max temp.		1.00	0.08	-0.48	-0.08	-0.04	0.14	0.07	-0.04	-0.10	-0.20
Δ Min temp.			1.00	-0.71	-0.40	0.11	0.23	0.01	0.10	-0.07	0.25
Δ Annual Precip.				1.00	0.31	-0.03	-0.29	0.04	-0.05	0.13	0.05
Δ Distance hab.					1.00	0.08	-0.24	-0.28	0.05	0.25	-0.15
Δ Patch size						1.00	0.22	0.04	*0.99*	0.33	0.17
Harvest year							1.00	0.28	0.30	0.25	0.13
Disturbance distance								1.00	0.07	-0.16	-0.14
Δ Patch edge									1.00	0.32	0.16
Distance to road										1.00	0.22
Distance to water											1.00

APPENDIX 4: SAS CODE USED FOR AIC MODELS

Code was modified by Tim Lawes and Katie Moriarty, Department of Fisheries and Wildlife.

```
quit;

* Marten Habitat Comparison 1983*;

OPTIONS LS=95 NONUMBER  DTRESET PS=1000 FORMDLIM='*';
LIBNAME Analysis "E:\11SASME";
TITLE 'Marten83 Habitat Logistic Regression';

* Import data from an Excel worksheet using the Import GUI *;
Proc Import Out = Work.sites
 DATAFILE= "E:\11SASME\1983a.xls"
 DBMS=xls REPLACE;
 Getnames=yes;
Run;
proc print data=sites;
run;
/*proc sort data=sites;
by ASPECT QUALITY VEG size CC;
run;*/
proc freq data=sites;
run;
proc means data=sites MEAN MEDIAN STDDEV LCLM UCLM MAX MIN CV;
class maam;
var elev dist_hab p_size p_edge slope distroad distwater ;
run;

/*PROC DATASETS MEMTYPE=ALL;
delete marten_aic;
run; */

Data N_eff(keep=n_eff);
       Set sites end=lastobs;
       if maam=0 then n_eff+1;
       else if maam=1 then n_eff+1;
       if lastobs;
      run;
        proc print data=n_eff;
        run;

%MACRO GENMOD (MODEL, CLASSVARS, XVARS);
*SPECIFIY TITLE FOR EACH ITERATION-- THE TITLE WILL HAVE THE
MODEL NAME AND LIST OF EXPL. VAR.;
TITLE "&XVARS";
*SPECIFY GENERAL STRUCTURE OF LOGISTIC REGR. MODEL OUTPUTING
RELEVANT METRICS—MACRO REPLACES & WITH
SPECIFIED VARIABLES WHEN CALLING MACRO ;
```

```
PROC GENMOD DATA=sites DESCENDING ORDER=DATA;
CLASS &CLASSVARS (REF=FIRST) / PARAM=REF;
MODEL MAAM = &CLASSVARS &XVARS  / LINK=logit Dist=bin type3
obstats scale=1 CL xVARS;
ODS output modelfit=modelfit modelinfo=modelinfo
ParameterEstimates=ParameterEstimates NOBS=NUMOBS;

RUN;

%Mend Genmod;

%MACRO GENMOD2 (MODEL, XVARS);
*SPECIFIY TITLE FOR EACH ITERATION-- THE TITLE WILL HAVE THE
MODEL NAME AND LIST OF EXPL. VAR.;
TITLE "&XVARS";
PROC GENMOD DATA=sites DESCENDING ORDER=DATA;
MODEL MAAM =  &XVARS  / LINK=logit Dist=bin type3 obstats scale=1
CL xVARS;
ODS output modelfit=modelfit modelinfo=modelinfo
ParameterEstimates=ParameterEstimates NOBS=NUMOBS;
RUN;

%Mend Genmod2;

/*****************************************************************
******************************/
/*
*/
/* aic_macro.sas
*/
/*
*/
/* SAS macro for computing aic and aicc from PROC GENMOD output.
Results from multiple        */
/* runs of GENMOD are accumulated in a dataset named by the user.
To use the macro, first     */
/* run PROC GENMOD and include the following statements after the
model statement:             */
/*
*/
/*     ODS output modelfit=modelfit;
*/
/*     ODS output modelinfo=modelinfo;
*/
/*     ODS output ParameterEstimates=ParameterEstimates;
*/
/*
*/
/* These statements invoke the Output Delivery System to create
SAS datasets containing        */
/* GENMOD output.  Next, invoke the macro:
*/
```

```
/*
*/
/*     %AICC(dsn=chat_aic,estdsn=estimate,model=sex age date**2
avgprecip,model_dimension=1);  */
/*
*/
/* The macro has 4 parameters.  Values are assigned by the user.
Parameters are as follows:    */
/*     DSN names a dataset in which AIC results are accumulated
*/
/*     ESTDSN names a dataset in which parameter estimates from
the model are stored           */
/*     MODEL is a label used to identify the model
*/
/*     MODEL_DIMENSION takes on an integer value that identifies
the highest order interaction */
/*        term (involving only CLASS variables) that is specified
in ANY model in the candidate*/
/*        set, not just the current model.  For example, suppose
the candidate set of models   */
/*        includes two CLASS variables (variables that are names
in a CLASS statement), say    */
/*        YEAR and SEX. If the candidate set includes models that
contain YEAR*SEX interaction */
/*        terms, then MODEL_DIMENSION=2.  If the candidate set
includes terms for SEX and AGE  */
/*        that involve only main effects or interactions with
non-CLASS variables, then        */
/*        MODEL_DIMENSION=1.
*/
/*
*/
/* IMPORTANT: This macro calls a 1-observation dataset named
"N_eff" that contains a variable  */
/*            named "N_eff."  The value of that variable is the
effective sample size for      */
/*            computing AICc.  This data set must be created by
the user prior to calling      */
/*            the aicc macro.  Sample code for creating the data
set appears below:            */
/*
*/
/*            The data set Nests contains one observation for
each observation interval.       */
/*            The variable t is the length of the interval.
*/
/*            Surv=1 if the clutch survived the interval, Surv=0
if it did not.                */
/*
*/
/*       Data N_eff(keep=n_eff);
*/
```

```
/*         Set Nests end=lastobs;
*/
/*         if surv=0 then n_eff+1;
*/
/*         else if surv=1 then n_eff+t;
*/
/*         if lastobs;
*/
/*       run;
*/
/*
*/
/* NOTE:  Missing values for one or more explantory variables can
result in different subsets  */
/*        of the data being used for different models.  Before
running analyses (and before    */
/*        creating the N_eff data set) I strongly recommend that
any observation with missing  */
/*        values for any explanatory variable in the canadidate
set be deleted.                */
/*
*/
/*****************************************************************
******************************/

%Macro aicc(dsn=,estdsn=,model=,model_dimension=);

      /* Obtain dfg (number of observations or intervals used in
the analysis minus */
      /* the number of parameters estimated), loglike (maximized
value of the       */
      /* Log-likelihood function), and the model deviance.
*/

      data temp;
         retain dfg deviance loglike;
         set modelfit;
         if _n_=1 then dfg=df;
         if criterion='Log Likelihood' then loglike=value;
         if criterion='Deviance' then deviance=value;
         if criterion='Log Likelihood' then output;
         keep dfg loglike deviance;
      run;

      /* obsused is the number of observations (intervals) used
in the analysis. */
      /* ness is the effective sample size used in AICc
claculations            */
      /* model is a label that is assigned by the user.
*/

      data temp2;
         retain N_eff;
```

```
         if _n_=1 then set N_eff;
         set numobs;
         length model $ 60;
         model="&model";
         if label='Number of Observations Used';
         Obsused=n;
         keep obsused model n_eff;
      run;
      *proc print data=modelinfo;run;
      *proc print data=numobs;run;
      *proc print data=temp;run;
      *proc print data=parameterEstimates;run;
      /* param2 is the parameter name for continuous covariates,
and the parameter */
      /* name concatenated with level for variables named in a
class statement.    */
      /* estimate is the estimated value of the parameter.
*/
      /* StdErr is the estimated standard error for the parameter
named by param2. */

      data temp4(keep=param2 estimate) temp4a(keep=param2 StdErr)
           temp4b(keep=level1-level&model_dimension df parameter
estimate StdErr);
          length Param2 $24 parameter $16 level1-
level&model_dimension $16;
            retain level1-level&model_dimension ' ';
          Set ParameterEstimates;
          if parameter='Scale' then delete;
          if parameter='Intercept' then level1=' ';
          if level1= '.' then param2=trim(parameter);
          else param2=trim(parameter)||trim(level1);
      run;

      data temp6;
         retain model obsused n_eff;
         if _n_=1 then set temp2;
         set temp4b;
      run;

      /* Compute AIC (Burnham and Anderson 2002:p.61) and  */
      /* AICC (Burnham and Anderson 2002:p.66.             */

      data temp3;
         merge temp temp2;
         n=n_eff;
         k=obsused-dfg;
         aic = -2*loglike + 2*K;
         aicc = aic +(2*K*(K+1))/(n-k-1);
      run;

      /* Save the values of AIC and AICC for this particular
model to a dataset that    */
```

```
      /* that will hold the results from all models.  It is
important that the dataset  */
      /* named in the base= statement be an empty data set when
the first model is run. */


      Proc append base=&dsn data=temp3 force;
      run;
      *proc print data=&dsn; run;

      /* Save the parameter estimates for this particular model
*/

    Proc append base=&estdsn data = temp6 force;
      run;
      *proc print data=&estdsn; run;

%Mend aicc;

/* MODELS WITH CLASS VARIABLES ARE "%GENMOD" MACRO AND MODELS
WITH JUST CONTINUOUS VARIABLES ARE "%GEMMOD2" MACROS.*/
/* FORMAT FOR "%GENMOD" IS ( , CLASS1 CLASS2 ECT, CONTINUOUS1
CONTINUOUS2 ECT) */
/* FORMAT FOR "%GEMMOD2" IS ( , CONTINUOUS1 CONTINUOUS2 ECT) */
/* NO NEED TO CHANGE THE "%AICC" MACRO UNLESS YOU ARE INCLUDING
INTERACTIONS – THEN "MODEL_DIMENSION=HIGHEST ORDER INTERACTION"
*/



%GENMOD( , veg, elev);
%AICC(dsn=marten_aic, estdsn=estimate, model=veg elev,
model_dimension=1);

%GENMOD( , veg, dist_hab p_size dist_hab*p_size distroad);
%AICC(dsn=marten_aic, estdsn=estimate, model=veg dist_hab p_size
dist_hab*p_size distroad, model_dimension=2);

%GENMOD( , veg aspect, dist_hab p_size dist_hab*p_size distroad);
%AICC(dsn=marten_aic, estdsn=estimate, model=veg aspect dist_hab
p_size dist_hab*p_size distroad, model_dimension=2);

%GENMOD( , veg size, dist_hab p_size dist_hab*p_size distroad);
%AICC(dsn=marten_aic, estdsn=estimate, model=veg size dist_hab
p_size dist_hab*p_size distroad, model_dimension=2);

%GENMOD( , size , distwater dist_hab p_size dist_hab*p_size);
%AICC(dsn=marten_aic, estdsn=estimate, model=size distwater
dist_hab p_size dist_hab*p_size, model_dimension=2);

%GENMOD( , aspect, distwater dist_hab p_size dist_hab*p_size);
%AICC(dsn=marten_aic, estdsn=estimate, model= aspect distwater
dist_hab p_size dist_hab*p_size, model_dimension=2);
```

```
%GENMOD( , aspect size , distwater dist_hab p_size
dist_hab*p_size);
%AICC(dsn=marten_aic, estdsn=estimate, model= aspect size
distwater dist_hab p_size dist_hab*p_size, model_dimension=2);

%GENMOD( , veg size cc, distwater);
%AICC(dsn=marten_aic, estdsn=estimate, model= veg size cc
distwater, model_dimension=1);

%GENMOD( , size , distwater);
%AICC(dsn=marten_aic, estdsn=estimate, model= size distwater,
model_dimension=1);

%GENMOD2( , dist_hab);
%AICC(dsn=marten_aic, estdsn=estimate, model= dist_hab,
model_dimension=1);

%GENMOD2( , dist_hab p_size dist_hab*p_size);
%AICC(dsn=marten_aic, estdsn=estimate, model= dist_hab p_size
dist_hab*p_size, model_dimension=2);

%GENMOD2( , dist_hab p_size dist_hab*p_size distroad);
%AICC(dsn=marten_aic, estdsn=estimate, model= dist_hab p_size
dist_hab*p_size distroad, model_dimension=2);

%GENMOD2( , dist_hab p_size dist_hab*p_size distroad distwater);
%AICC(dsn=marten_aic, estdsn=estimate, model= dist_hab p_size
dist_hab*p_size distroad distwater, model_dimension=2);

%GENMOD2( , distwater);
%AICC(dsn=marten_aic, estdsn=estimate, model= distwater,
model_dimension=1);

%GENMOD2( , elev);
%AICC(dsn=marten_aic, estdsn=estimate, model= elev,
model_dimension=1);

%GENMOD2( , elev dist_hab p_size dist_hab*p_size);
%AICC(dsn=marten_aic, estdsn=estimate, model= elev dist_hab
p_size dist_hab*p_size, model_dimension=2);

%GENMOD2( , elev dist_hab p_size dist_hab*p_size distwater);
%AICC(dsn=marten_aic, estdsn=estimate, model= elev dist_hab
p_size dist_hab*p_size distwater, model_dimension=2);

%GENMOD2( , elev dist_hab p_edge dist_hab*p_edge);
%AICC(dsn=marten_aic, estdsn=estimate, model= elev dist_hab
p_edge dist_hab*p_edge, model_dimension=2);

%GENMOD2( , elev dist_hab p_size dist_hab*p_size distwater
distroad);
```

```
%AICC(dsn=marten_aic, estdsn=estimate, model= elev dist_hab
p_size dist_hab*p_size distwater distroad, model_dimension=2);

proc sort data=MARTEN_AIC;
by aicc;
TITLE '83 MARTEN HABITAT AIC MODELS';
run;

proc print data=marten_aic; run;
PROC SORT DATA=ESTIMATE;
BY MODEL;
RUN;

proc print data=ESTIMATE;run;

PROC GENMOD DATA=sites DESCENDING ORDER=DATA;
*CLASS aspect (REF=FIRST) quality (REF=FIRST) VEG (REF=FIRST) CC
(REF=FIRST)SIZE (REF=FIRST)  / PARAM=REF;
CLASS VEG (REF=FIRST)  / PARAM=REF;
MODEL  maam = veg dist_hab p_size distroad pedge  /
 LINK=logit Dist=bin type3 obstats scale=1 CL xVARS;
 ods output modelfit=modelfit
PARAMETERESTIMATES=ParameterEstimates modelinfo=modelinfo
NOBS=NUMOBS ;
 OUTPUT OUT=OBSTATS PRED=PREDICT P=PHAT LOWER=LCI UPPER=UPL;
 ods output obstats=resids;
 *lsmeans VEG / Diff CL E alpha=0.05;
Run;
PROC PRINT DATA=OBSTATS;
RUN;
PROC PRINT DATA=FITSTAT;
RUN;
PROC PRINT DATA=PARMS;
RUN;

quit;


* Marten Habitat Comparison 2008*;
* Models only


%GENMOD( , veg, elev);
%AICC(dsn=marten_aic, estdsn=estimate, model=veg elev,
model_dimension=1);

%GENMOD( , veg, dist_hab p_size dist_hab*p_size distroad);
%AICC(dsn=marten_aic, estdsn=estimate, model=veg dist_hab p_size
dist_hab*p_size distroad, model_dimension=2);

%GENMOD( , veg dist_type, dist_hab p_size dist_hab*p_size
distroad);
```

```
%AICC(dsn=marten_aic, estdsn=estimate, model=veg dist_type
dist_hab p_size dist_hab*p_size distroad, model_dimension=2);

%GENMOD( , veg aspect, dist_hab p_size dist_hab*p_size distroad);
%AICC(dsn=marten_aic, estdsn=estimate, model=veg aspect dist_hab
p_size dist_hab*p_size distroad, model_dimension=2);

%GENMOD( , veg size, distroad dist_hab p_size dist_hab*p_size);
%AICC(dsn=marten_aic, estdsn=estimate, model=veg size distroad
dist_hab p_size dist_hab*p_size, model_dimension=2);

%GENMOD( , veg size, distroad BA_total dist_hab p_size
dist_hab*p_size);
%AICC(dsn=marten_aic, estdsn=estimate, model=veg size distroad
BA_total dist_hab p_size dist_hab*p_size, model_dimension=2);

%GENMOD( , size , distwater dist_hab p_size dist_hab*p_size);
%AICC(dsn=marten_aic, estdsn=estimate, model=size distwater
dist_hab p_size dist_hab*p_size, model_dimension=2);

%GENMOD( , aspect, distwater dist_hab p_size dist_hab*p_size);
%AICC(dsn=marten_aic, estdsn=estimate, model= aspect distwater
dist_hab p_size dist_hab*p_size, model_dimension=2);

%GENMOD( , aspect size , distwater dist_hab p_size
dist_hab*p_size);
%AICC(dsn=marten_aic, estdsn=estimate, model= aspect size
distwater dist_hab p_size dist_hab*p_size, model_dimension=2);

%GENMOD( , veg size cc, distwater);
%AICC(dsn=marten_aic, estdsn=estimate, model= veg size cc
distwater, model_dimension=1);

%GENMOD( , size , distwater);
%AICC(dsn=marten_aic, estdsn=estimate, model= size distwater,
model_dimension=1);

%GENMOD2( , dist_hab);
%AICC(dsn=marten_aic, estdsn=estimate, model= dist_hab,
model_dimension=1);

%GENMOD2( , dist_habp_size dist_hab*p_size);
%AICC(dsn=marten_aic, estdsn=estimate, model=dist_hab p_size
dist_hab*p_size, model_dimension=2);

%GENMOD2( , distroad dist_hab p_size dist_hab*p_size);
%AICC(dsn=marten_aic, estdsn=estimate, model= distroad dist_hab
p_size dist_hab*p_size, model_dimension=2);

%GENMOD2( , distroad distwater dist_hab p_size dist_hab*p_size);
%AICC(dsn=marten_aic, estdsn=estimate, model= distroad distwater
dist_hab p_size dist_hab*p_size, model_dimension=2);
```

```
%GENMOD2( , distwater);
%AICC(dsn=marten_aic, estdsn=estimate, model= distwater,
model_dimension=1);

%GENMOD2( , elev);
%AICC(dsn=marten_aic, estdsn=estimate, model= elev,
model_dimension=1);

%GENMOD2( , elev dist_hab p_size dist_hab*p_size);
%AICC(dsn=marten_aic, estdsn=estimate, model= elev dist_hab
p_size dist_hab*p_size, model_dimension=2);

%GENMOD2( , elev distwater dist_hab p_size dist_hab*p_size);
%AICC(dsn=marten_aic, estdsn=estimate, model= elev distwater
dist_hab p_size dist_hab*p_size, model_dimension=2);

%GENMOD2( , elev dist_hab p_edge dist_hab*p_edge);
%AICC(dsn=marten_aic, estdsn=estimate, model= elev dist_hab
p_edge dist_hab*p_edge, model_dimension=2);

%GENMOD2( , elev distwater distroad dist_hab p_size
dist_hab*p_size);
%AICC(dsn=marten_aic, estdsn=estimate, model= elev distwater
distroad dist_hab p_size dist_hab*p_size, model_dimension=2);

%GENMOD2( , elev distwater);
%AICC(dsn=marten_aic, estdsn=estimate, model= elev distwater,
model_dimension=1);

%GENMOD2( , elev p_edge distwater);
%AICC(dsn=marten_aic, estdsn=estimate, model= elev p_edge
distwater, model_dimension=1);

%GENMOD2( , elev slope distwater);
%AICC(dsn=marten_aic, estdsn=estimate, model= elev slope
distwater, model_dimension=1);

%GENMOD2( , elev dist_hab slope);
%AICC(dsn=marten_aic, estdsn=estimate, model= elev dist_hab
slope, model_dimension=1);

%GENMOD2( , elev BA_total CWD);
%AICC(dsn=marten_aic, estdsn=estimate, model= elev BA_total CWD,
model_dimension=1);

%GENMOD2( , elev BA_total CWD dist_hab p_size dist_hab*p_size);
%AICC(dsn=marten_aic, estdsn=estimate, model= elev BA_total CWD
dist_hab p_size dist_hab*p_size, model_dimension=2);


* Marten Habitat Comparison 83v08*;

%GENMOD( , dist_type , distroad);
```

```
%AICC(dsn=marten_aic, estdsn=estimate, model= dist_type distroad,
model_dimension=1);

%GENMOD( , dist_type, dquality distroad);
%AICC(dsn=marten_aic, estdsn=estimate, model= dquality dquality
distroad, model_dimension=1);

%GENMOD( , dist_type, distroad distwater);
%AICC(dsn=marten_aic, estdsn=estimate, model= dist_type distroad
distwater, model_dimension=1);

%GENMOD( , dist_type , elev);
%AICC(dsn=marten_aic, estdsn=estimate, model= dist_type elev,
model_dimension=1);

%GENMOD( , dist_type , h_year dp_size dp_edge dp_size*dp_edge);
%AICC(dsn=marten_aic, estdsn=estimate, model= dist_type h_year
dp_size dp_edge dp_size*dp_edge, model_dimension=2);

%GENMOD( , dist_type , elev distwater distroad dp_size dp_edge
dp_size*dp_edge);
%AICC(dsn=marten_aic, estdsn=estimate, model= elev distwater
distroad dp_size dp_edge dp_size*dp_edge, model_dimension=2);

%GENMOD( , dist_type , dpann);
%AICC(dsn=marten_aic, estdsn=estimate, model= dist_type dpann,
model_dimension=1);

%GENMOD( , dist_type, distroad distwater dpann dmax dmin);
%AICC(dsn=marten_aic, estdsn=estimate, model= distroad distwater
dpann dmax dmin, model_dimension=1);

%GENMOD( , dist_type , elev dist_dist dpann);
%AICC(dsn=marten_aic, estdsn=estimate, model= elev dist_type
dist_dist dpann, model_dimension=1);

%GENMOD( , dist_type , h_year dpann dmax dmin dp_size dp_edge
dp_size*dp_edge);
%AICC(dsn=marten_aic, estdsn=estimate, model= dist_type h_year
dpann dmax dmin dp_size dp_edge dp_size*dp_edge,
model_dimension=1);

%GENMOD2( , elev);
%AICC(dsn=marten_aic, estdsn=estimate, model= elev,
model_dimension=1);

%GENMOD2( , distroad distwater);
%AICC(dsn=marten_aic, estdsn=estimate, model= distroad distwater,
model_dimension=1);

%GENMOD2( , dist_dist);
%AICC(dsn=marten_aic, estdsn=estimate, model= dist_dist,
model_dimension=1);
```

```
%GENMOD2( , elev ddist_hab dp_size ddist_hab*dp_size);
%AICC(dsn=marten_aic, estdsn=estimate, model= elev ddist_hab
dp_size ddist_hab*dp_size, model_dimension=2);

%GENMOD2( , ddist_hab dp_size ddist_hab*dp_size);
%AICC(dsn=marten_aic, estdsn=estimate, model= ddist_hab dp_size
ddist_hab*dp_size, model_dimension=2);

%GENMOD2( , elev h_year);
%AICC(dsn=marten_aic, estdsn=estimate, model= elev h_year,
model_dimension=1);

%GENMOD2( , elev dp_size ddist_hab dp_size*ddist_hab );
%AICC(dsn=marten_aic, estdsn=estimate, model= elev dp_size
ddist_hab dp_size*ddist_hab, model_dimension=2);

%GENMOD2( , elev dist_dist distwater distroad dp_size dp_edge
dp_size*dp_edge);
%AICC(dsn=marten_aic, estdsn=estimate, model= elev dist_dist
distwater distroad dp_size dp_edge dp_size*dp_edge,
model_dimension=2);

%GENMOD2( , dpann dmax dmin);
%AICC(dsn=marten_aic, estdsn=estimate, model= dpann dmax dmin,
model_dimension=1);

%GENMOD2( , elev distroad dpann);
%AICC(dsn=marten_aic, estdsn=estimate, model= elev distroad
dpann, model_dimension=1);

%GENMOD2( , elev dist_dist dpann);
%AICC(dsn=marten_aic, estdsn=estimate, model= elev dist_dist
dpann, model_dimension=1);
```

APPENDIX 5: PRISM DATA

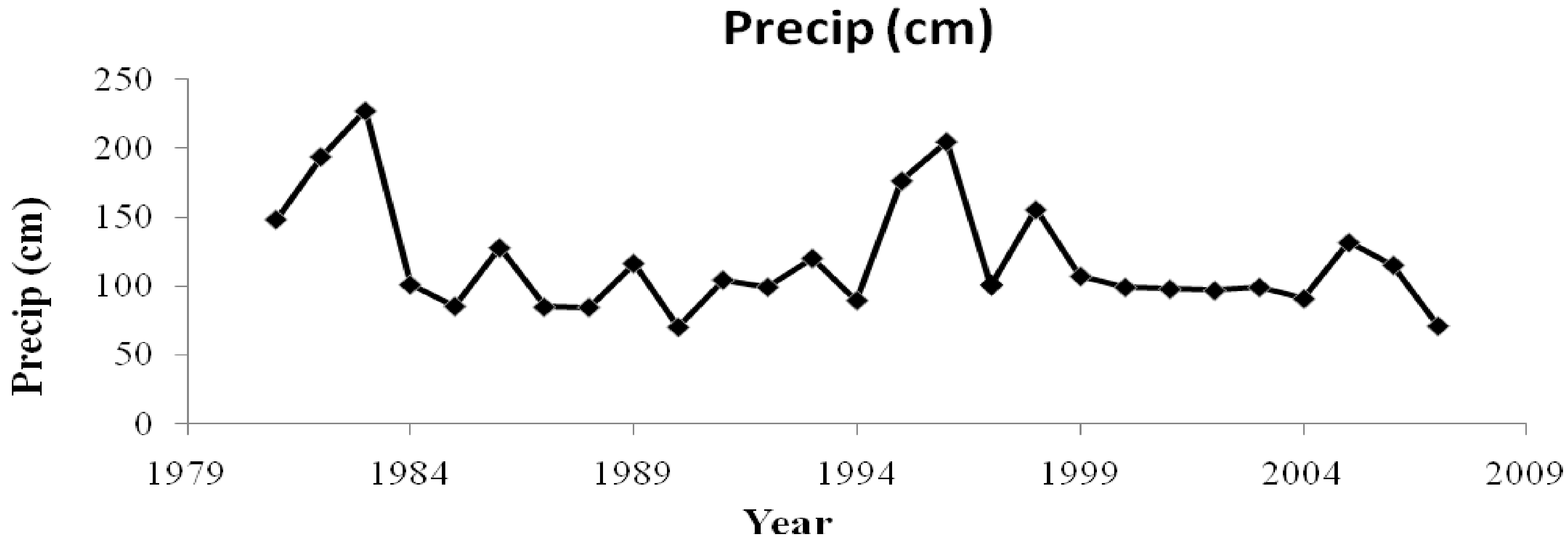


Figure A.5 1. Total annual precipitation (cm) at Sagehen Creek Experimental Forest, CA between 1980 and 2007 as estimated by the PRISM climate model.

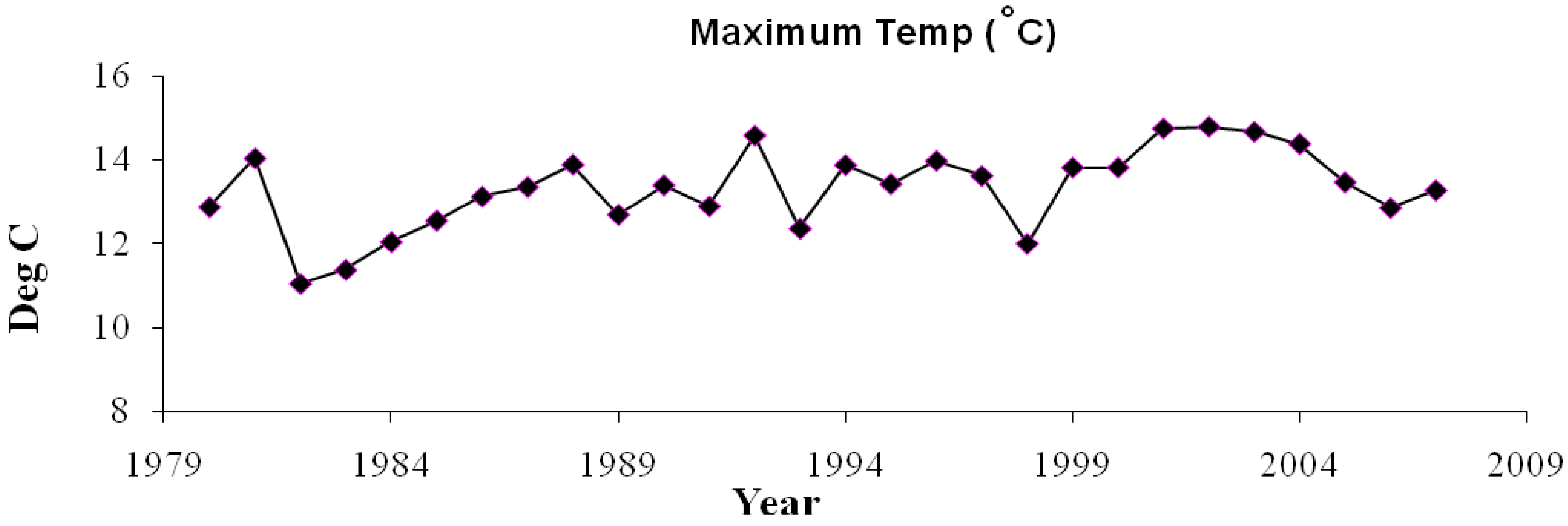


Figure A.5 2. Annual mean maximum temperature (°C) at Sagehen Creek Experimental Forest, CA from 1980 to 2007 as estimated by the PRISM climate model.

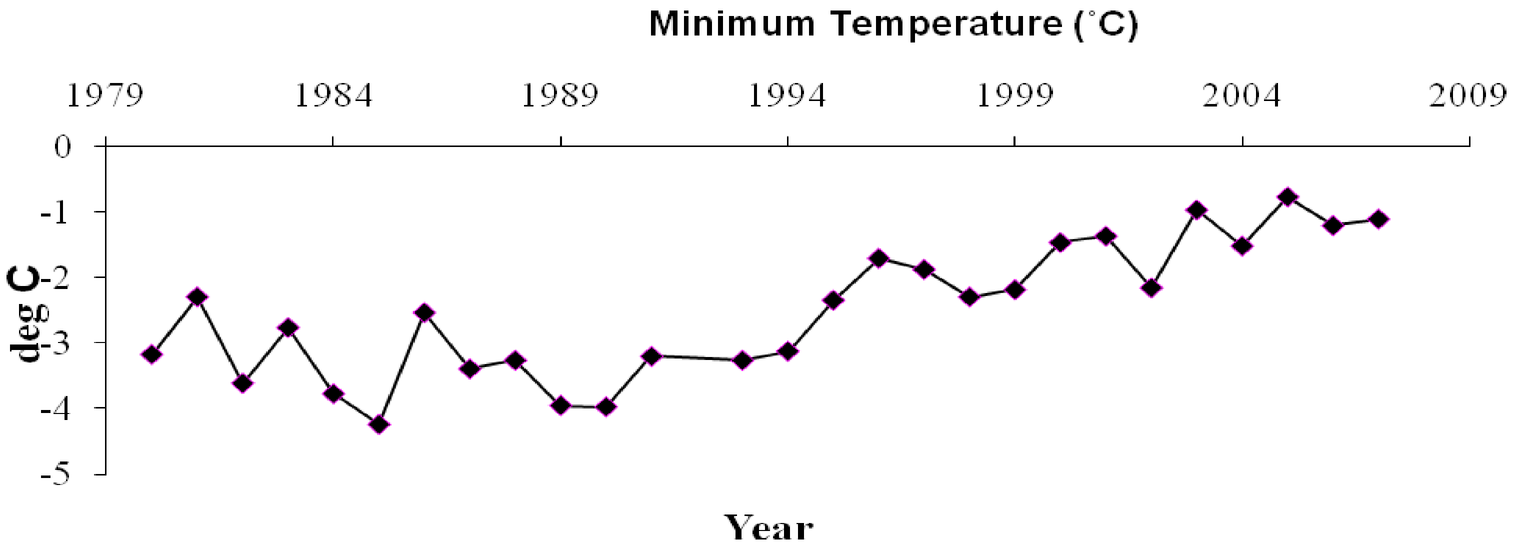


Figure A.5 3. Annual mean minimum temperature (°C) at Sagehen Creek Experimental Forest, CA from 1980 to 2007 as estimated by the PRISM climate model