Effects of Off-Highway Vehicle Use on the American Marten

Author(s): William J. Zielinski, Keith M. Slauson, Ann E. Bowles
Source: Journal of Wildlife Management, 72(7):1558-1571.
Published By: The Wildlife Society
DOI: http://dx.doi.org/10.2193/2007-397
URL: http://www.bioone.org/doi/full/10.2193/2007-397

Management and Conservation Article

Effects of Off-Highway Vehicle Use on the American Marten

WILLIAM J. ZIELINSKI,[1] *United States Department of Agriculture Forest Service, Pacific Southwest Research Station, Redwood Sciences Laboratory, Arcata, CA 95521, USA*

KEITH M. SLAUSON, *United States Department of Agriculture Forest Service, Pacific Southwest Research Station, Redwood Sciences Laboratory, Arcata, CA 95521, USA*

ANN E. BOWLES, *Hubbs–Sea World Research Institute, San Diego, CA 92109, USA*

ABSTRACT Motorized recreation in North American wildlands is increasing, and technological developments in the power and range of vehicles has increased access to high-elevation habitats. The American marten (*Martes americana*) is vulnerable to this disturbance because martens, like other residents of high-elevation forests, are associated with remote wilderness conditions where the presence of motorized vehicles is a recent phenomenon. We evaluated the effects of vehicles at 2 study sites in California, USA, by comparing marten occupancy rates and probabilities of detection in areas where recreational vehicle use is legal and encouraged (use areas) with wilderness areas where vehicles are prohibited (non-use areas). We sampled vehicle occurrence in nearby use and non-use areas using sound level meters and determined marten occurrence using track and camera stations. We also included 2 secondary measures of potential effects of vehicles on martens: sex ratio and circadian pattern of activity. Martens were ubiquitous in use and non-use areas in both study sites, and there was no effect of vehicle use on marten occupancy or probability of detection. We predicted that females might be less common and martens more nocturnal in use than in non-use areas, but neither occurred. Martens were exposed to low levels of disturbance in our study sites. We estimated that a marten might be exposed to 0.5 vehicle passes/hour and that this exposure had the greatest effect on <20% of a typical home range area. Furthermore, vehicle use usually occurred when martens were inactive. We did not measure behavioral, physiological, or demographic responses, so it is possible that vehicles may have effects, alone or in concert with other threats (e.g., timber harvest), that we did not quantify. We encourage additional studies to determine whether other montane species that are year-round residents demonstrate the same response to motorized vehicles. (JOURNAL OF WILDLIFE MANAGEMENT 72(7):1558–1571; 2008)

DOI: 10.2193/2007-397

KEY WORDS American marten, California, disturbance, *Martes americana*, noise, off-highway vehicles, Sierra Nevada.

The use of off-highway vehicles and over-snow vehicles (hereafter OHVs) for recreation in California, USA, is growing along with the burgeoning population of the state. From 1976 to 2002, the number of registered OHVs has increased statewide by 108% and snowmobile use has increased 8% per year (California Department of State Parks and Recreation 2002). In 2004, almost 10% of all visits to national forests in the United States were for the purpose of OHV use (U.S. Department of Agriculture [USDA] Forest Service, Recreation, Heritage and Wilderness Program 2005). From 1982 to 2001, driving motor vehicles off road became one of the fastest growing activities in the United States (Cordell et al. 2005).

Managing this growth in a manner that is consistent with multiple land management objectives poses a mounting challenge to land managers and OHV recreation communities. Although there are a number of reviews of the effects of recreation and OHVs on wildlife (e.g., Boyle and Samson 1985, Gutzwiller 1991, Knight and Gutzwiller 1995, Joslin and Youmans 1999), there have been few studies directed at the effects of OHVs on top predators (e.g., White et al. 1999, Creel et al. 2002, Nevin and Gilbert 2005, Bunnell et al. 2006, Kolbe et al. 2007) and none addressing American martens (*Martes americana*) specifically. Joslin and Youmans (1999), in a review of potential impacts of motorized recreation on wildlife in Montana, USA, hypothesized that the large home range requirements, specialized habitat needs, low reproductive potential, and inability to disperse across areas of unacceptable habitat predispose martens to habitat fragmentation and population isolation and that recreational activities may contribute to these impacts.

Martens are carnivorous mammals that occupy late-seral conifer forests at high elevations in the Sierra Nevada of California (Spencer et al. 1983, Hargis and McCullough 1984, Zielinski et al. 2005). Because their habitats occur in some of the highest-elevation forests in California, martens have been relatively isolated from most human disturbance, which predominates at lower-elevation environments. Moreover, before the popularity of winter motorized recreation in California, martens were virtually undisturbed by humans during winter. The growth of the human population in California, the increase in recreation, and advances in OHV technology have combined over the last few decades to make many previously undisturbed high-elevation habitats accessible to OHVs. The recent increase in recreational activity in high-elevation forest habitats has created concern in some conservationists that martens may respond negatively to year-round disturbance by OHVs. In addition to the direct effects humans and vehicles may have on martens, OHVs may also affect marten prey populations. Moreover, snowmobiles can change the physical environment by compacting snow, permitting other predators that compete with, or prey on, martens (e.g., coyotes [*Canis latrans*]) access to areas that they would normally be restricted from by deep snow (Bunnell et al. 2006, but see also Kolbe et al. 2007).

[1] *E-mail: bzielinski@fs.fed.us*

To address the need for information on the effects that OHVs may have on American marten populations, we initiated a study in the Sierra Nevada of California. Most studies of the effects of a disturbance on wildlife rely on behavioral or physiological measures (Knight and Cole 1995), and many studies have demonstrated that a variety of wildlife species avoid places where noise of human origin is the greatest (Bowles 1995). However, behavioral measures may not be the best indication of the effect of disturbance (Gill et al. 2001). Also, for small, uncommon, and nocturnal species such as the marten, behavior may not be the most practical response variable to measure. We instead examined the effect of OHV disturbance on the spatial distribution and occurrence, rather than behavioral responses, of martens. We predicted that if OHV use was perceived as a threat, martens would disproportionately occur in areas where OHV use was low relative to areas where it was high.

We also considered 2 additional potential responses to OHV use: change in activity pattern and change in sex ratio in affected populations. Mammalian predators can become more nocturnal in the presence of human activity (e.g., Van Dyke et al. 1986, Riley et al. 2003) and we hypothesized that martens would do the same if OHV use was perceived as a disturbance. Thus, we also evaluated whether marten activity differed between low and high OHV use areas. In addition, we assumed that female martens, like females of other species of carnivores (e.g., bobcats [*Lynx rufus*]; Riley et al. 2003), would be more selective of habitats than males and, therefore, would place a greater premium on locating their home ranges away from disturbance. Thus, we also evaluated the effect of OHV use on the sex ratio of martens.

STUDY AREA

We replicated our study in 2 areas in the Sierra Nevada, the Lake Tahoe Basin Management Unit and High Sierra Ranger District of the Sierra National Forest, both administered by the United States Forest Service. The Lake Tahoe study site was located in the central Sierra Nevada, on the west shore of Lake Tahoe (Fig. 1), and we collected data from summer 2003 through summer 2004. The study area was composed of nearly equivalent portions of the Desolation Wilderness and adjacent non-wilderness areas to the north. Elevations ranged from 2,100 m to 3,100 m, and the area was composed largely of forested habitats dominated by red fir (*Abies magnifica*), lodgepole pine (*Pinus contorta*), white fir (*Abies concolor*), western white pine (*Pinus monticola*), mountain hemlock (*Tsuga mertensiana*), and Jeffrey pine (*Pinus jeffreyi*). The Lake Tahoe study area was largely managed for recreation in recent decades but had a low density of roads and trails. Historically, overgrazing and clear-cut timber practices characterized the exploitation of natural resources in the Lake Tahoe Basin (Lindström et al. 2000). More recently, however, harvest was significantly reduced and focused on single-tree selection, salvage logging, and fuels reduction (Lindström et al. 2000).

The High Sierra study area was located in the southern Sierra Nevada (Fig. 1). We collected data from fall 2004 through summer 2005. The study area was approximately 100 km^2 and was composed of nearly equivalent portions of the Dinky Lakes and John Muir Wilderness areas and adjacent non-wilderness area to the west. Elevations ranged from 2,400 m to 3,200 m, and the area was composed largely of forested habitats dominated by lodgepole pine, red fir, western white pine, mountain hemlock, and Jeffrey pine. The High Sierra study area also contained a number of meadow complexes, occurring largely in the wilderness areas. The non-wilderness portions of the High Sierra study area were largely managed for recreation, including winter grooming of designated snowmobile routes. The High Sierra study area was affected by the same timber harvest practices that affected the Sierra Nevada in general; early timber harvest was via selection of the biggest individual trees which then, in the 1980s, shifted to more clear-cutting (McKelvey and Johnston 1992).

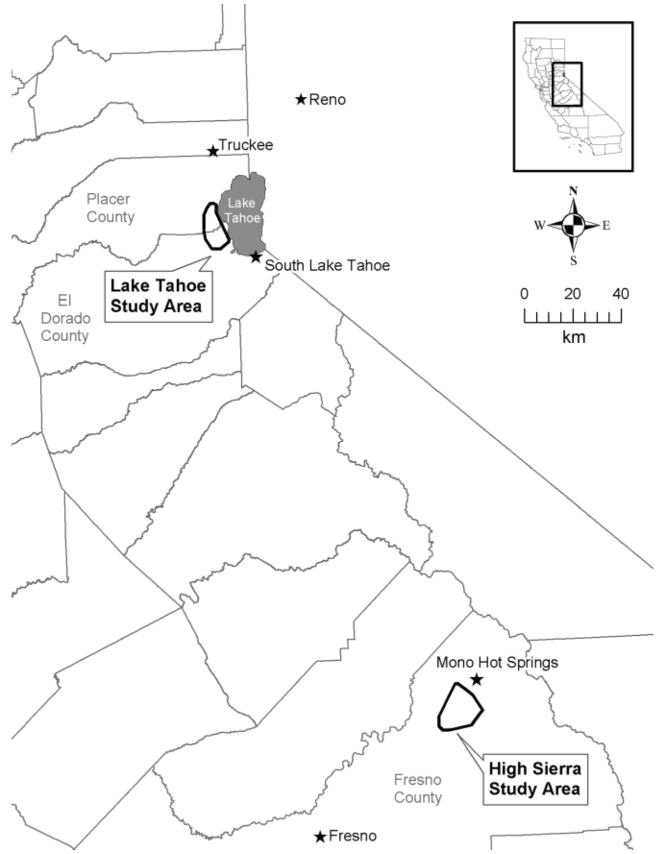

Figure 1. Location of the Lake Tahoe and High Sierra American marten study sites, California, USA, in 2003–2005.

METHODS

Sample Units

We divided each study area into 2 adjacent subunits, one area where OHV use was permitted and encouraged (hereafter use area) and one area where OHV use was prohibited (hereafter non-use area). Non-use areas were within congressionally designated wilderness areas immediately adjacent to areas where OHV use was encouraged on public lands throughout the year. Non-use areas were

Table 1. Proportion of use and non-use areas, in the Lake Tahoe and High Sierra marten study sites, California, USA, 2003–2005, in various categories of vegetation classes, as interpreted by the California Wildlife Habitat Relations model (Mayer and Laudenslayer 1988).

Vegetation characteristic	Lake Tahoe		High Sierra	
	Use area	Non-use area	Use area	Non-use area
Non-habitat[a]	22	24	28	12
High-quality habitat[b]	18	19	52	47
Canopy closure class				
Dense	7	3	30	13
Moderate	48	32	31	53
Open	20	31	14	25
Sparse	4	13	12	1
Less than sparse	21	21	13	8
Tree size class				
Seedling	0	0	0	0
Sapling	1	0	1	0
Pole	3	10	14	22
Small tree	58	65	69	70
Medium–large tree	16	4	6	0
Multilayered tree	0	0	0	0
Class other than those above	22	21	10	8

[a] Proportion of total area with combinations of vegetation type, canopy closure class, and tree size class that the California Wildlife Habitat Relations (CWHR) system (Mayer and Laudenslayer 1988) considers non-habitat for American martens.

[b] Proportion of total area that achieves a high suitability rating (CWHR system) based on attributes of vegetation.

designated as off-limits to OHVs since the 1960s, and use areas were formally or informally designated in the late 1970s. We selected boundaries of the 2 subunits to create similar-sized areas (approx. 50 km^2 each) that were also similar in respect to their predicted suitability as marten habitat. We did not want differences in habitat suitability to confound the potential effects of OHV use; thus, we used the California Wildlife Habitat Relations (CWHR) model for the American marten to select subunit areas that were equivalent in terms of marten habitat suitability (Mayer and Laudenslayer 1988). This model uses information from the literature and expert opinion to develop a relationship between each combination of 3 vegetation characteristics (vegetation type, canopy closure class, and tree size class) and the suitability of habitat for each vertebrate species in California. We selected the boundaries of each study site (Lake Tahoe and High Sierra) such that use and non-use areas had similar proportions of the CWHR vegetation characteristics and similar proportions of areas classified as high-suitability habitat and non-habitat (Table 1).

We divided each subunit (use and non-use areas) within each study site into a set of 2-km^2 hexagonal sample units, which is about one-half of the average size marten home range in California (Simon 1980, Spencer 1981); thus, although we sought complete spatial independence of sample units, this may not have been achieved, especially for males. We identified and attempted to sample $\geq$20 sample units in each subunit of the study area, for a total of 40 total sample units for each study site. We conducted sampling of marten occurrence and of OHV use and noise throughout the year, centered on each of 4 seasons (spring: 17 Apr–25 Jun; summer: 30 Jun–15 Sep; fall: 5 Oct–15 Dec; winter: 15 Jan–Mar). The OHV use was predicted to be greatest during the winter (snowmobiles) and summer (motorcycles, all-terrain vehicles, and 4-wheel-drive trucks) and least during the spring and fall.

Marten Sampling

Occurrence.—We determined marten occurrence in each sample unit using baited track plates, baited remote cameras, and snow-tracking (Halfpenny et al. 1995, Kucera et al. 1995, Zielinski 1995). We established 3 potential station locations in the center of each sample unit, each separated by 250 m and each 636 m from the edge of the sample unit and 1,272 m from the nearest station in an adjacent sample unit. During seasons without snow (i.e., summer and fall) we established a sooted track plate with track-receptive contact paper at each of the 3 stations within each sample unit. We baited each station with chicken and ran it for 12 consecutive days. We used a commercial trapping lure (Gusto; Minnesota Trapline Products, Pennock, MN) as an olfactory attractant that we placed at each station when we established it. We visited each station every third day (total of 4 visits) to collect tracks, replace bait, and replace track plates as needed.

During seasons with snow (i.e., winter and spring), we established a Trailmaster film camera system (Kucera et al. 1995) at 2 of the 3 stations in each sample unit. We deployed the systems on single trees with a plastic shield to shed snowfall without triggering photographs and to keep the system components free of snow and ice. We baited each camera station with chicken, installed trapping lure, and ran it for 15 consecutive days. We visited cameras every fifth day (total of 3 visits) to collect film and replace bait as needed. During winter and spring, we also conducted snow-tracking at each sample unit on 2 transects; the first transect occurred from the point where we entered the sample unit to the first station, and the second occurred from the first to the second station. A marten photograph or, in rare cases when a camera was inoperable, a marten track in the snow resulted in presence for the sample unit for the season in which it occurred.

Both study areas were above the typical elevational range for the occurrence of congeneric fishers (*Martes pennanti*; Zielinski et al. 2005); nonetheless, we detected one fisher via camera at one sample unit in the High Sierra site. We did not detect fishers via their tracks, which can be readily distinguished from the tracks of martens (Zielinski and Truex 1995).

The probability that a marten occupies a sample unit and the probability that it is detected there are separate phenomena (MacKenzie et al. 2006). Thus, it is possible that use and non-use areas could be equivalent in occupancy but that martens have different probabilities of detection in the 2 areas. To evaluate this possibility, we subjected the detection-history data at each sample unit to analysis to estimate probability of detection when present (MacKenzie et al. 2006), which we accomplished by first creating a detection history for each sample unit. We aggregated the detection outcome (0 = no detection, 1 = detection) for each visit across all stations during each visit to a sample unit (3 visits for camera stations, 4 visits for track-plate stations). We then input the data into Program PRESENCE (Version 2; J. Hines, United States Geological Survey, Laurel, MD) to estimate detection probability and confidence interval, for each study area subunit during each season. We compared detection probabilities between study area subunits, for each season, using *t*-tests.

Circadian activity and sex ratio.—We used cameras as the primary marten detection device in the fall and winter but also modified our protocol in the High Sierra study area to include cameras during all 4 seasons. Whenever we used cameras, we programmed them to print time of day on the photograph. Because martens readily return to a baited station after it is discovered, we could only consider the initial detection at the first camera station in a sample unit an unbiased sample of the time of day that martens were active. We used an index of diurnality (Halle and Weinert 2000) to compare the relative proportion of diurnal activity in the use areas compared to the non-use areas:

$$I_{\text{Diurnality}} = \left[\frac{\sum_{hL} cL}{\sum_{hL} cL + \sum_{hD} cD} \right] \times 2 - 1$$

where ΣcL and ΣcD are the number of activity records during the day and night, respectively, and hL and hD are day length and night length (which were different for each of the 4 seasons). I_D is positive when diurnal activity prevails (max.: +1 when exclusively active during daytime) and negative when nocturnal activity prevails (min.: −1 when exclusively active at night; Halle and Weinert 2000).

The use of track plates also provided us the opportunity to gather incidental information on the effects of OHV use on the sex ratio of animals that use each of the areas. Martens are sexually dimorphic and a study in Ontario determined that the tracks of males are significantly larger in specific dimensions compared to those of females (Routledge 2000). We developed a similar algorithm by evaluating the tracks from known-identity individuals from California, collected in other studies where martens were captured and released across track-receptive surfaces (Slauson et al., in press). Our single-variable algorithm used total length of the track impression of either front foot such that

$$\text{Sex} = \text{Total Length(mm)} - 30.75,$$

where Sex > 0 is male and Sex < 0 is female. This function correctly classified sex for each of 54 tracks of known identity (from 12 M:8 F of *M. a. sierrae*), including 100% correct classification of tracks from 4 subadult males (Slauson et al., in press).

For sample units where we collected marten tracks at track-plate stations, we classified to sex all forefoot impressions of suitable quality from each sheet of the track-receptive contact paper. Because we could not distinguish individuals, the possible result at each sample unit was either male, female, or both, regardless of how many different individual track impressions we classified as male or female at one sample unit. We compared sex ratios of classified impressions from the use and non-use areas using chi-square statistics.

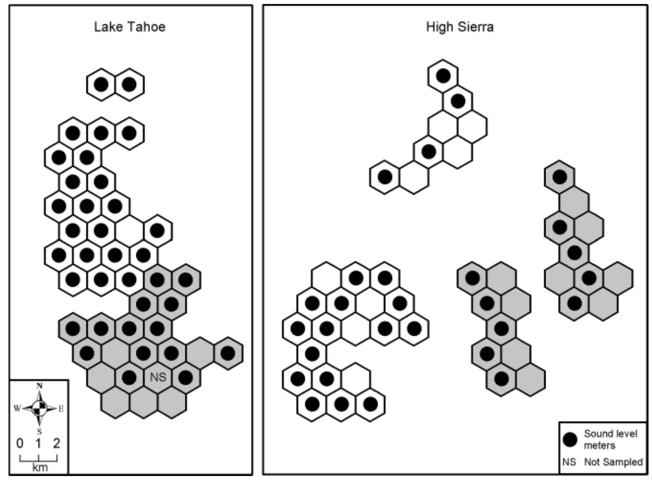

Figure 2. Sample units (hexagons) that included sound level recorders (with black circles) in the Lake Tahoe and the High Sierra American marten study sites, California, USA, in 2003–2005. Open and gray sample units are those in the use and non-use areas, respectively.

OHV Sampling

Acoustic sampling.—We sampled the frequency as well as the spatial and temporal patterns of OHV use on major roads and trails during each season using audio recording devices. We used Larson Davis 720 Type II sound level meters (SLMs; Larson Davis, Depew, NY) to collect A-weighted time-history sound data at 2-second intervals over periods of ≤4 days (2-sec L_{Aeq}). We collected the data to assess the incidence of OHV activity and to quantify the absolute level of all types of sounds that could occur. During almost all seasons, in both study sites, we placed SLMs within 10 m of the most highly used road or trail within the selected sample units. The exception was winter in the Lake Tahoe site, when we centered some SLMs in sample units and deployed others along roads. Because the number of available SLM devices was limited, we could not deploy them at all sample units and we sampled in proportion to the variation in sound expected. Thus, we deployed more SLMs in the use areas than in the non-use areas (Fig. 2). It was also unnecessary to sample all of a set of sample units that were bisected by the same road or trail, when opportunities to exit that road or trail were limited. We mounted SLM microphones 1.4 m above substrate level and covered them with 5-cm open-pore foam windscreens. We established each SLM concurrently with the marten sampling stations and ran SLMs for most of the 12-day (summer and fall) or 15-day (winter and spring) survey period for each season.

We reviewed time-history data using custom software developed by Wyle Laboratories, Inc. (Arlington, VA) to distinguish sound events produced by vehicles passing near the SLMs from all other sources. Vehicle sound events were distinguished by their acoustic signatures. We plotted sequences of 2-second equivalent continuous sound levels (L_{Aeq}) in 20-minute segments and examined profiles of events. Real-time recordings and observations collected on-site provided sample acoustic signatures for comparison with the data collected by SLMs. The OHV events at close range had characteristic time-history profiles that could be identified with high reliability. During snow-free seasons, there was a modest amount of non-recreational truck use in the study area. We did not attempt to distinguish time-history profiles for trucks used for non-recreational purposes from those used for recreational purposes; we assumed their effects on martens to be identical.

We could not determine from the vehicle's sound profile the distance between the OHV producing each event and the SLM. However, OHV events that had $\leq$2-second L_{Aeq} $>$60 dBA were very likely to be within a few hundred meters of the SLM. Based on measured source levels of known vehicles, we expected the distance vehicles exceeding the 60-dBA criterion to be $<$100 m under most conditions. Thus, it was likely that events exceeding the 60-dBA criterion occurred within the same sample unit where we deployed the SLM. We then used the vehicle sound events to generate temporal noise budgets for OHV noise (day, night, weekday, weekend, and seasonal) for each study site.

We applied A-weighting to eliminate low-frequency environmental noise such as wind that would have contaminated measurements of OHV noise. It is recognized that by A-weighting the noise, some sounds that martens might be able to hear could be eliminated. However, the available data on mustelid hearing suggest that the lower limits of the A-weighting filter would provide a conservative estimate of exposure, that is, that A-weighting admitted more energy at low frequencies than mustelids could hear (Heffner and Heffner 1985, Kelly et al. 1986). Most of the energy emitted by OHVs was of low to mid-frequency. Although martens could be expected to hear well above the limits of A-weighting, comparison of real-time measurements and SLM events showed that A-weighted levels recorded during OHV passes were highly correlated with broadband levels ($>$90%).

The parameters used to characterize the temporal noise budget were time $>$60 dBA, total count of events identified in the time-history data, and L_{Aeq}. We calculated L_{Aeq} in 3 ways: for the season as a whole, for ambient noise, and for vehicle events that could be identified in the time-history data. We calculated each L_{Aeq} metric for nocturnal and diurnal periods for each season for each sample unit where an SLM was deployed.

Observer sampling: walking and listening surveys.—During each visit to a sample unit, field personnel conducted surveys to detect vehicle use by detecting them visually, by their sound, or by their tracks. We conducted walking surveys from the point of entry into each sample unit to the first station and between all subsequent stations (1 or 2 depending on season) in that particular sample unit. We summarized data from walking surveys as OHV events per kilometer surveyed. In addition, we conducted a 3-minute listening survey when we checked each track plate or camera station. We reported all sounds heard and we reported those originating from OHVs as minutes per hour of survey time.

Route mapping.—We recorded abundance and density of potential OHV routes for each study area so that we could 1) report the density of routes relative to the typical home range size of martens and 2) report potential OHV access using a metric that could be generated by managers elsewhere who were interested in comparing access opportunities in other areas with those in our 2 study sites. We began with the base transportation coverage provided by the Lake Tahoe Basin Management Unit and Remote Sensing Laboratory (USDA Forest Service), which included all roads identified as such by cartographic feature codes. We then removed some of these because of information field observers provided about whether the road was accessible to OHVs. To each of the roads in the resulting coverage we added a 50-m buffer on each side, assuming that this included the area of maximum disturbance. We referred to these as standard routes and estimated their area in each of the 2-km^2 sample units.

To account for the fact that in winter, vehicles travel over the snow and are not limited by road or trail access, we created a second coverage that included additional routes used during the snow seasons. We created this coverage by adding to the standard routes coverage the additional routes used by snowmobiles during snow seasons. These routes were mapped by field personnel onto United States Geological Survey 7.5-minute topographic maps after each foray into the study area and then digitized for use in a Geographic Information System. We also buffered these routes by 50 m and referred to them as extended winter routes. We used each of the route coverages (standard and extended winter routes) to determine the proportion of each sample unit that received OHV use. In addition to reporting the proportions of a sample unit occupied by buffered routes, we also determined whether there was an association between marten and sex-specific occupancy and the proportion of the sample unit with snowmobile use.

RESULTS

OHV Use

The sampling design guaranteed that the use area would have greater disturbance by OHVs on average than the non-use area, and this difference was verified by our indices of OHV use. Sound level meters were maintained at 78.2% and 50.0% of the sample units in the use and non-use areas in the Lake Tahoe study site and 70.3% and 36.8% in the High Sierra study site, respectively. The number of OHV events per hour $>$60 dBA was greater in the use compared to the non-use area in both study sites (Lake Tahoe: $t_{52} = 3.67$, $P \leq 0.001$; High Sierra: $t_{71} = 3.77$, $P \leq 0.001$; Table 2; Fig. 3). The number of OHV events per hour $>$60 dBA was also greater during the day versus night in the use areas in both study areas (Lake Tahoe: $t_{66} = 2.93$, $P = 0.005$; High

Table 2. Mean rates per sample hour of >60-dBA off-highway vehicle events at the Lake Tahoe and High Sierra marten study sites, California, USA, in 2003–2004.

			Weekday				Weekend			
			Day		Night		Day		Night	
Study area	Season	Area	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Lake Tahoe	Winter	Use	0.15	0.05	<0.01	<0.01	0.25	0.09	0.07	0.06
	Winter	Non-use	0.10	0.06	0		0.05	0.03	<0.01	<0.01
	Spring	Use	0.28	0.14	0.09	0.04	0.25	0.01	0.06	0.02
	Spring	Non-use	0.04	0.01	<0.01	<0.01	0.07	0.03	<0.01	<0.01
	Summer	Use	0.30	0.14	0.12	0.04	0.46	0.21	0.22	0.13
	Summer	Non-use	0.05	0.02	<0.01	<0.01	0.04	0.02	0.02	0.01
High Sierra	Fall	Use	0.05	0.03	0.06	0.03	0.09	0.05	0.01	0.01
	Fall	Non-use	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0	
	Winter	Use	0.07	0.02	0.04	0.01	0.20	0.01	0.01	0.01
	Winter	Non-use	<0.01	<0.01	0		<0.01	<0.01	0	
	Spring	Use	0.02	0.01	0.01	0.01	0.03	0.02	<0.01	<0.01
	Spring	Non-use	0		0		0		0	
	Summer	Use	0.12	0.01	0.01	0.01	0.19	0.09	0.03	0.01
	Summer	Non-use	<0.01	<0.01	<0.01	<0.01	0.01	0.01	0	

Sierra: $t_{81} = 2.72$, $P = 0.008$; Table 2). Season did not affect distribution of >60 dBA OHV events for either study area (Lake Tahoe: $F_{2,49} = 0.33$, $P = 0.72$; High Sierra: $F_{3,68} = 2.07$, $P = 0.11$; Table 2; Fig. 3), nor was there a difference between weekends and weekdays, regardless of season (Lake Tahoe: $t_{93} = 0.56$, $P = 0.57$; High Sierra: $t_{130} = -0.22$, $P = 0.82$; Table 2; Fig. 3).

During the summer and winter, the highest mean (SE) number of vehicle events recorded by the sound meters was 0.46 (0.21) per hour and 0.25 (0.09) per hour, respectively. Both maxima occurred in the Lake Tahoe site during the weekends and during the daytime hours (Table 2). Vehicle use during spring and fall was not substantially lower than use during summer and winter. In the Lake Tahoe site, the mean number of vehicle events >60 dBA during spring was greater or equal to the mean number of events during the winter but less than the mean number of events during the summer (Table 2). This was not the case in the High Sierra site where the magnitude of winter and summer OHV events was similar, with pronounced dips in spring and fall.

The few OHV events that were recorded in the non-use area most likely originated from nearby sample units in the use area (especially in the Lake Tahoe study site, where a few sample units in the use and non-use areas were sometimes within 500 m). Alternatively, some of these events could have been from illegal OHV use, which was less likely, however, given that the field technicians witnessed very little OHV use in the wilderness areas (<6 occasions at each study site; primarily during the summer at Lake Tahoe and in both summer and winter in the High Sierra). In addition, SLMs recorded far fewer OHV events in the non-use area in the High Sierra study site because they were further from the use area. The patterns in the distribution of seasonal L_{Aeq} metrics produced results very similar to the event data, but L_{Aeq} varied greatly in both use and non-use areas (Appendix).

Observations from field technicians generally agreed with the patterns exhibited by the SLMs (Table 3). Measures of OHV use were significantly greater, or nearly so, in the use area compared to the non-use area in both study areas (Lake Tahoe listening: $t_3 = 2.96$, $P = 0.06$; High Sierra listening: $t_3 = 63.19$, $P \leq 0.001$; Lake Tahoe walking: $t_3 = 3.65$, $P = 0.03$; High Sierra walking: $t_3 = 4.18$, $P = 0.02$; Table 3). In contrast to the SLM data, however, the listening and walking surveys indicated that OHV use was affected by season (Lake Tahoe listening: $F_{3,353} = 6.75$, $P = 0.01$; High Sierra listening: $F_{3,899} = 9.89$, $P \leq 0.001$; Lake Tahoe walking: $F_{3,1116} = 24.76$, $P = 0.001$; High Sierra walking: $F_{3,920} = 4.83$, $P = 0.002$).

In the Lake Tahoe and High Sierra sites, summer and winter indices of use were greater than spring and fall use indices (linear contrast summer–winter > spring–fall; Lake Tahoe listening: $F_{1,355} = 6.42$, $P = 0.01$; Lake Tahoe walking: $F_{1,1118} = 10.95$, $P = 0.001$; High Sierra listening: $F_{1,901} = 15.72$, $P \leq 0.001$; High Sierra walking: $F_{1,922} = 9.44$, $P = 0.002$) and use during summer, as indexed by listening surveys, exceeded the average use recorded in the other seasons (Lake Tahoe listening: $F_{1,355} = 3.15$, $P = 0.07$; High Sierra listening: $F_{1,901} = 20.82$, $P \leq 0.001$; Table 3). Walking surveys, however, revealed greater use during winter (linear contrast winter > summer–fall–spring; Lake Tahoe walking: $F_{1,1118} = 16.81$, $P \leq 0.001$; High Sierra walking: $F_{1,922} = 13.43$, $P \leq 0.001$).

Route mapping revealed that the standard routes occupied similar mean proportions of sample units in each study site (Lake Tahoe: 14.45%; High Sierra: 17.28%; Fig. 4A). The maximum proportion of a sample unit that was occupied by buffered standard routes was 36.46% (on the Lake Tahoe study site). In the winter, however, buffered routes were more extensive given that snowmobiles could use roadless areas. The extended winter routes occupied a mean of 24.6% and 19.5% of sample units in the Lake Tahoe and High Sierra study sites, respectively (Fig. 4B).

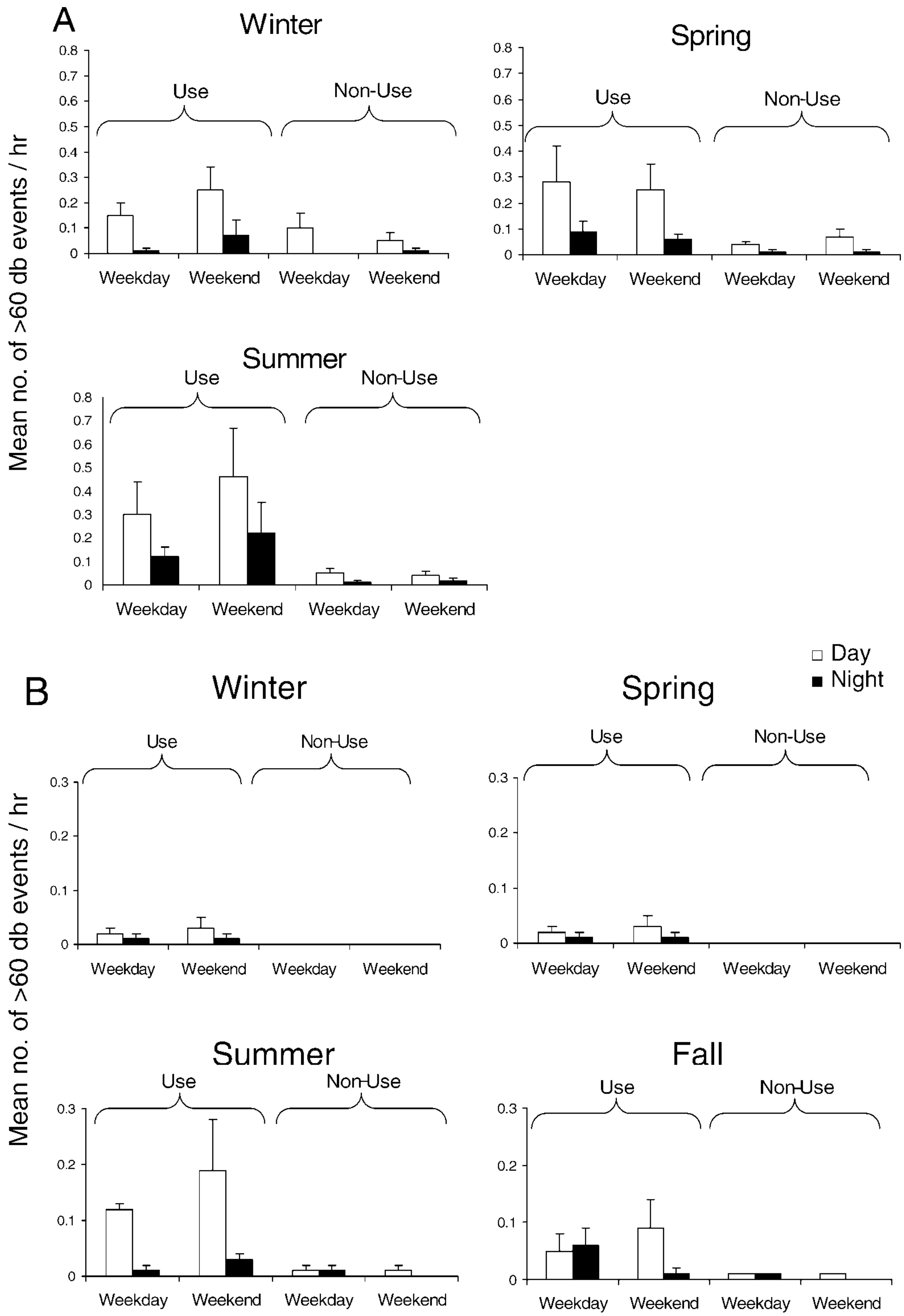

Figure 3. Mean number of >60 dBA off-highway vehicle events per hour, by period of week (weekend, weekday), time of day (open bars = day; closed bars = night) and season for use and non-use areas in the (A) Lake Tahoe and (B) High Sierra American marten study sites, California, USA, in 2003–2005. Bars represent 1 standard error. We collected no data for fall in the Lake Tahoe study site.

Marten Detections

Occurrence.—Martens were ubiquitous in both study sites and did not demonstrate a difference in occurrence in use and non-use areas (Fig. 5; Table 4). Detections occurred at 189 of 200 (94.5%) and 132 of 161 (82.0%) sample opportunities in use and non-use areas, respectively (combining data from both study sites). Occurrence did not appear to be affected by OHV use or by season. In addition, sample units in the highest quartile of values for buffered area of routes, in both study areas, were all occupied by martens. Marten detections were notably less common in the non-use area of the Lake Tahoe study site. Although this area was roughly equivalent to the non-use area in overall habitat suitability (Table 1), the sample units

Table 3. Number of motorized vehicles observed per hour of survey time (for listening surveys) or per kilometer of transect (for walking surveys) for the Lake Tahoe and High Sierra study sites, California, USA, in 2003–2004 (n = no. of listening or walking sessions).

	Summer			Fall			Winter			Spring		
Survey method	**No.**	**SE**	***n***	**No.**	**SE**	***n***	**No.**	**SE**	***n***	**No.**	**SE**	***n***
Listening												
Lake Tahoe												
Use	5.05	3.58	76	0.70	0.26	199	3.53	0.67	130	2.51	1.02	147
Non-use	0.77	3.88	63	0		181	0.41	0.29	97	1.01	0.40	118
High Sierra												
Use	4.02	0.48	348	0.83	0.25	242	2.59	0.55	162	1.67	0.63	155
Non-use	0		269	0.13	0.12	160	0		94	0		104
Walking												
Lake Tahoe												
Use	1.58	0.13	518	1.82	0.72	406	2.43	0.36	162	0.31	0.04	38
Non-use	0		339	0		285	0		66	0		154
High Sierra												
Use	1.02	0.14	365	0.93	0.43	245	2.27	0.47	162	0.35	0.08	156
Non-use	0		269	0.02	0.01	167	0		94	0.03	0.01	106

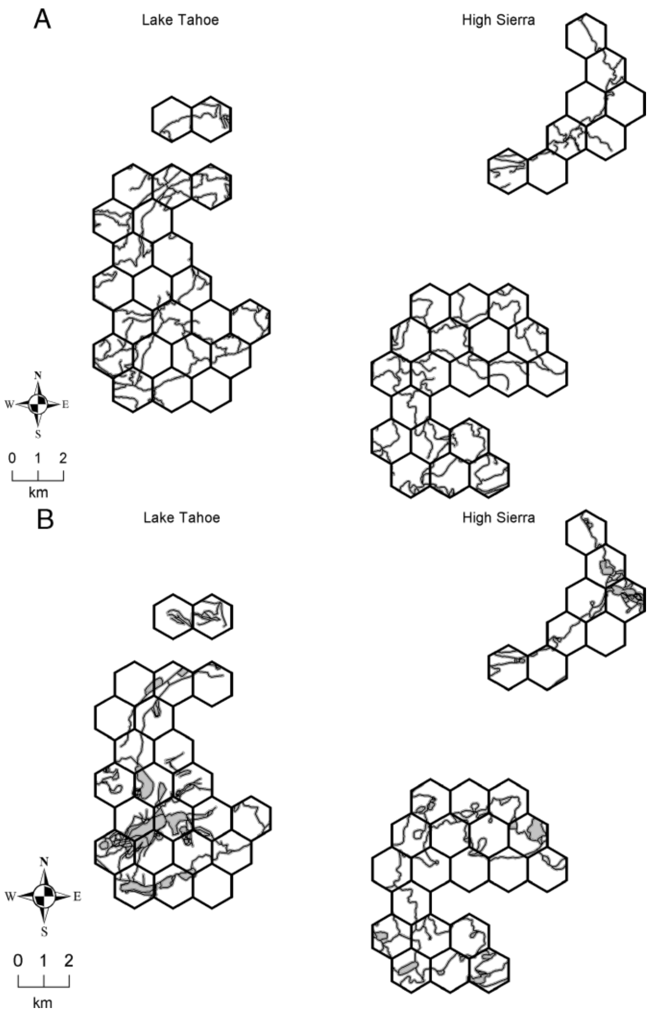

Figure 4. Use areas in the Lake Tahoe and High Sierra American marten study sites, California, USA, in 2003–2005, depicting the (A) standard off-highway vehicle (OHV) routes and (B) extended winter OHV routes, buffered by 50 m on each side.

with the fewest detections included large areas of non-habitat (i.e., exposed bedrock) or habitat that is only seasonally occupied (e.g., talus slopes).

Probability of detection.—We calculated probability of detection (p) over a 12-day (4-visit) survey period when we used track-plate stations and a 15-day (3-visit) period when we used cameras. Variable p was indistinguishable for the 2 areas, averaging 98.5% for the use areas and 97.8% for the non-use areas (across all seasons and both study sites; Table 5). Variable p exceeded 93% for each study site, for each season, and for use compared to non-use areas (Table 5). There was no discernable change in probability of detection with season. Thus, martens not only were ubiquitous in both use and non-use areas, but the protocol used to detect them assured an equally high confidence of detection during all 4 seasons when they were present.

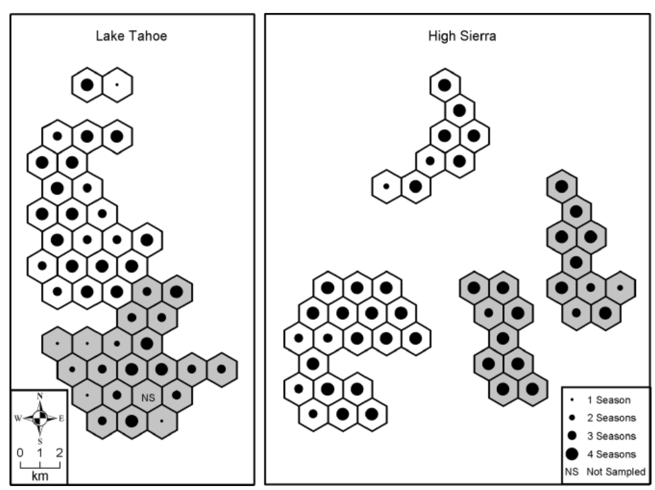

Figure 5. American marten detections in the Lake Tahoe and High Sierra American marten study sites, California, USA, in 2003–2005. Circle size represents the number of seasons (0–4) we detected martens in each sample unit (hexagon); open and gray sample units are those in use and non-use areas, respectively.

Table 4. Detections of American martens in use and non-use areas by study site (Lake Tahoe and High Sierra) and season, California, USA, in 2003–2004.

		Use area			Non-use area		
			Marten detections			Marten detections	
Study area	Season	No. SUs[a]	No.	%	No. SUs	No.	%
Lake Tahoe	Summer	23	19	82.6	23	13	56.5
	Fall	23	22	95.7	22	14	63.6
	Winter	23	22	95.7	20	19	95.0
	Spring	23	22	95.7	20	13	65.0
High Sierra	Fall	27	27	100	19	18	94.7
	Winter	27	27	100	19	19	100
	Spring	27	26	96.3	19	19	100
	Summer	27	24	88.9	19	17	89.5

[a] Sample units.

Circadian activity.—The index of diurnality was not substantially different for animals that were photographed at baited cameras in the use area compared to the non-use area (Table 6; Fig. 6). Marten activity occurred primarily during nighttime hours during all seasons and in both study sites. In a few instances, marten detections appeared to occur more frequently during the day in non-use areas (e.g., winter in High Sierra), but these were offset by most of the seasons when the opposite was true. Sample sizes for these comparisons were limited (i.e., approx. 40 for each season in each study area) because we used the time of only the first detection at any one camera in a sample unit for analysis, so inferences from the circadian activity data should be interpreted with caution. Including time of day for all marten detections substantially increased the sample size ($n = 2{,}357$) but did not affect the conclusion that marten circadian activity was not appreciably different in use and non-use areas. Interestingly, in the High Sierra study site, subsequent detections at camera stations in the use area appeared to occur more often in the daytime than the initial detections (Table 6).

Sex ratio.—The sex ratio in use and non-use areas did not differ in either study area (Table 7). The sex ratio favored males in all seasons in both study sites, which is not surprising given that male martens have larger home ranges and are also captured in live and kill traps more frequently than females (Buskirk and Lindstedt 1989). Males were especially overrepresented among detections in the non-use area in the Lake Tahoe study site (Table 7), a region that was also distinguished by the lower prevalence of martens compared to other areas. Probabilities of detection were also uniformly high and similar for both sexes (>93% for M and for F, regardless of study site or use vs. non-use area), which does not necessarily mean that males and females are equally abundant or detected at an equal number of sample units. Instead, of the males and females that we detected at least once, we regularly detected most on subsequent sampling occasions.

Table 5. Detection probability for martens in the Lake Tahoe and High Sierra study sites, for use and non-use areas, California, USA, in 2003–2004. We calculated summer and fall over a 12-day track-plate survey (4 3-day visits to 3 track plates); we calculated winter and spring results over a 15-day remote camera survey (3 5-day visits to cameras). Confidence intervals are 95%.

	Summer		Fall		Winter		Spring	
Study area	%	CI	%	CI	%	CI	%	CI
Lake Tahoe								
Use	97.5	93–99	97.3	92–99	99.7	99–100	99.5	98–100
Non-use	96.8	90–99	93.7	83–98	96.8	90–99	98.7	95–100
High Sierra								
Use	99.9	99–100	98.0	90–99	99.9	99–100	99.8	96–100
Non-use	99.5	98–99	97.5	91–99	100	100	99.6	97–100

DISCUSSION

None of the response variables we measured (occurrence, circadian activity, sex ratio) suggested martens were affected by the level of OHV use that occurred in our study sites. Our approach assumed that if increased OHV use had negative effects on martens we would have observed fewer occupied sample units, greater nocturnal behavior, or fewer females in the use areas. Although logistics and cost prevent studies of this nature from achieving great sample sizes, the fact that none of the 3 response variables supported the hypothesis of negative OHV effects, at either study site, suggests that the level of OHV use at the 2 locations did not produce substantial effects on marten populations.

We add, however, that our approach did not measure the potential direct effects of OHV on individual marten behavior and, thus, we do not know how they would react in the presence of OHVs or their sound or whether marten exposure to OHVs generated a stress response that could produce deleterious effects on reproduction or survival. A direct approach has been used with other species (e.g., Bright et al. 2003, Taylor and Knight 2003, Wisdom et al. 2004), but this is most effective for species that can be easily monitored during experimental treatments (either because their size make them conspicuous, they use open habitats, or they return reliably to one location [e.g., nest site]). Martens find daily refuge in inaccessible places, and extensive radiotelemetry studies would be required to discover these locations. Even if we used this approach, we could not have observed behavioral responses to noise directly. Sampling physiological end points (e.g., stress hormones) directly would require frequent recaptures or close monitoring to obtain fecal samples, introducing more disturbance than the OHV activity being studied.

Application of a study design requiring experimental OHV approaches, and measuring behavior or physiology directly, would be extremely challenging and limited to the involvement of only a few study animals. Furthermore, individuals can demonstrate a behavioral or physiological stress response to OHV that may not be reflected in population measures (e.g., Creel et al. 2002), such that the most useful responses to measure are those that affect populations, such as reproduction, mortality, and turnover rates (Gill et al. 2001). Without data on vital rates, we

Table 6. Comparison of the index of diurnality calculated using initial marten detections only and also including subsequent detections, for the Lake Tahoe and High Sierra study sites, California, USA, in 2003–2004. The index is positive (max.: +1) when diurnal activity prevails and negative (min.: −1) when nocturnal activity prevails.

	Summer		Fall		Winter		Spring	
Study area	**Use**	**Non-use**	**Use**	**Non-use**	**Use**	**Non-use**	**Use**	**Non-use**
Lake Tahoe								
Initial	−0.43	−0.56			−0.57	−0.82	−0.29	−0.33
Subsequent	0.15	0.38			−0.58	−0.74	−0.52	−0.03
High Sierra								
Initial	−0.02	−0.50	−0.50	−0.33	−0.85	−0.63	−0.59	−0.60
Subsequent	0.35	−0.29	−0.15	−0.40	−0.69	−0.72	−0.41	−0.70

cannot be sure that OHVs did not have negative effects on martens, even though we demonstrated none of the predicted changes in occupancy, sex ratio, or activity patterns. For example, it is possible few of the animals in the OHV areas were breeding and all the occupancy we recorded resulted from dispersal of young animals into the OHV areas from elsewhere. Although this was unlikely, because we photographed females with young in the OHV areas and we did not notice dramatic changes in numbers of detections in OHV areas during dispersal; effects of OHV use on demographic responses can only be excluded by conducting more detailed studies.

Despite our ignorance about the direct effects of OHVs on marten behavior, physiology, or the effects on vital rates, our results suggest the spatial and temporal frequency of stimuli from OHVs are not perceived by marten as significant threats. If this were the case, we would expect areas with otherwise suitable habitat to be unoccupied, either because animals abandoned their home ranges or because dispersing animals chose not to settle there. We would also expect greater nocturnal activity in the presence of diurnal OHV disturbance. The fact that we did not see these effects may be due to 1) the fact that the stimuli in each study area were not perceived as a threat or 2) a flexible response strategy, such as habituation to OHVs that do not pose a significant risk. Habituation is the persistent waning of a response that results from familiarity due to repeated exposure (Drickamer and Vessey 1982). Habituation is a variable phenomenon

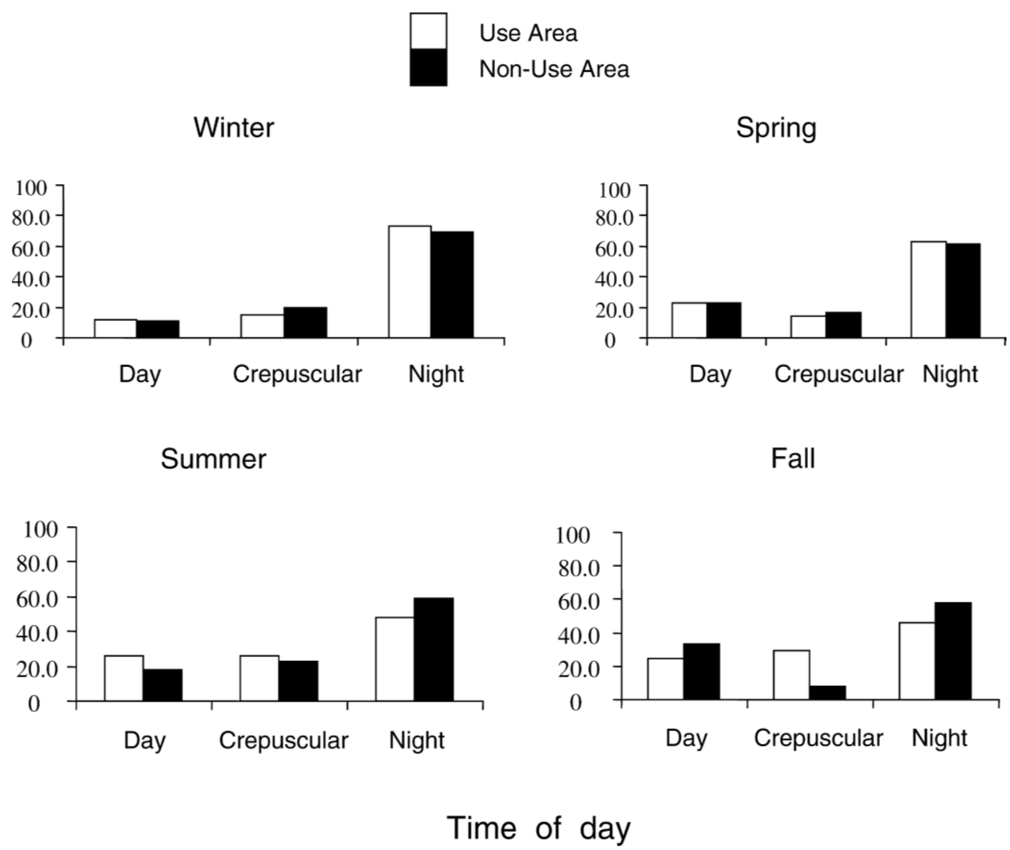

Figure 6. Proportion of initial American marten detections at sample units in the diurnal, crepuscular, and nocturnal periods in the Lake Tahoe and High Sierra study sites combined, California, USA, in 2003–2005. Open bars refer to use areas and black bars refer to the non-use areas. Temporal periods are defined using each seasonal average for sunrise and sunset. The crepuscular period includes an hour before and after sunrise and sunset.

Table 7. Number of track-plate sample units with detection of male and female American martens during the summer and fall seasons at the Lake Tahoe, High Sierra, and combined study sites, California, USA, in 2003–2004. We measured all tracks of suitable quality from the summer and fall seasons for both study sites.

	Lake Tahoe				High Sierra				Study areas pooled			
	Summer		Fall		Summer		Fall		Summer		Fall	
Metric	Use	Non-use	Use	Non-use	Use	Non-use	Use	Non-use	Use	Non-use	Use	Non-use
No. of sample units	23	23	23	22	27	19	14	14	50	42	37	36
M	18	13	18	12	19	15	8	11	37	28	26	33
F	10	4	10	5	19	14	2	7	29	18	12	12
Ratio M:F	1.8:1	3.3:1	1.8:1	2.4:1	1:1	1.1:1	4:1	1.6:1	1.2:1	1.5:1	2.1:1	2.75:1
χ^2		0.732		0.189		0.019		1.051		0.257		0.060
P		0.39		0.66		0.88		0.30		0.61		0.80

among wildlife species and individuals (Knight and Gutzwiller 1995); depending on the significance of the disturbance, individuals may avoid, ignore, or be attracted to noise (Dorrance et al. 1975, Richens and Lavigne 1978, Moen et al. 1982).

A spatial and temporally integrated view of potential OHV effects may explain why use areas were so fully occupied and, perhaps, why martens coexist with the disturbance. Consider the following equation as a method for characterizing the potential spatial and temporal effects of OHV exposure ($\hat{E}$):

$$\hat{E} = P_{\mathrm{HR}} \times N_{\mathrm{hour}} \times P_{\mathrm{diurnal}},$$

where P_{HR} is the proportion of home range affected most directly by OHVs, N_{hour} is number of OHV events per hour, and P_{diurnal} is the proportion of marten activity that occurs during the diurnal period (when OHVs are almost exclusively active). The buffered roads and trails (i.e., standard routes) occupied an average of about 16% of a sample unit, which means that if home ranges were randomly distributed, <20% of an average individual marten's home range area would receive the most acute level of disturbance from OHVs. Moreover, during the period of maximum OHV use (i.e., weekend days in summer), an average of one vehicle travels on these routes every 2 hours. The final component of the equation reflects the general nocturnal pattern of behavior (only 34% of initial detections at a camera were during the daytime). Thus, most OHV use occurs at a time when martens are inactive in sheltered rest sites in either cavities or, in winter, below the snow (Spencer 1987). Levels of exposure and the circadian activity we measured suggest an estimated relative summer exposure level of

$$\hat{E} = 0.16 \times 0.50 \times 0.34 = 0.027.$$

In winter the average maximum number of OHV events per hour was lower ($N_{\mathrm{hour}} \sim 0.25$), and although a larger proportion of the home range included buffered routes ($P_{\mathrm{HR}} \sim 0.22$), the composite exposure index was lower [$\hat{E} = 0.22 \times 0.25 \times 0.34 = 0.019$].

An understanding of marten biology and our findings suggest the exposure level experienced by martens in our study areas was low enough and the intrusions seemingly innocuous enough that martens did not benefit by relocating in response to this level of disturbance. Would relocating to an area with less disturbance be worth the risk, compared to tolerating one OHV pass every 2 hours, which occurs on <20% of the home range during the time of the day when martens are normally asleep or inactive? The probability that an individual marten will relocate appears even less likely if a vehicle has never posed a direct threat to its well-being. The trade-offs in this circumstance are conceptually similar to evaluating how animals respond to predation risk. The benefit of relocating in the presence of a predation risk depends on the risk of relocating and the availability and quality of alternative sites (Ydenberg and Dill 1986, Gill et al. 2001). Economically speaking, a marten should remain on its home range if the cost (or risk) of doing so is less than the cost (or risk) of relocating. Given what appears to be a relatively low exposure rate, and a risk that rarely includes probability of death (unlike predation), we do not find it surprising that, when habitat conditions are suitable, martens occupied OHV use areas in the same way they occupy areas of suitable habitat where OHVs were prohibited and did not occur.

We caution readers that our results apply only under OHV exposure rates that martens experienced at our 2 study sites. Although we found little evidence for negative effects of OHVs on martens, our results can be applied to other locations only if OHV use at the other locations is no greater than we measured. To conduct a comparison, others would need to sample OHV use using our methods, or, at a minimum, understand how our measure of OHV use relates to other standard approaches. Recommended methods to sample and estimate nonmotorized recreational use have been offered (Gregoire and Buhyoff 1999), but we are not aware of similar recommendations for standard methods for estimating motorized recreation or whether nonmotorized methods can be applied to OHVs. A standard method for estimating OHV use would allow us to determine how our results apply to other locations and should combine remote (SLM or camera) methods and data from human observers.

We also caution that the viability of any population is a function of habitat quality and the cumulative effects of threats. Off-highway vehicles are one of a number of potential threats to marten populations and the effect of OHVs may interact with other co-occurring threats. For example, neither of our study areas was subject to much timber harvest or vegetation management during our study. It is possible that, if marten habitat is being negatively affected, levels of OHV disturbance we recorded may have a negative effect on marten populations.

MANAGEMENT IMPLICATIONS

The USDA Forest Service is undergoing a nationwide process of officially designating OHV routes (USDA Forest Service, Recreation, Heritage and Wilderness Program 2005). Part of the process includes considering the effects of route location and density on wildlife. We did not find areas where OHV route location or density affected occupancy by individual martens and, therefore, cannot help define under what circumstances martens would be negatively affected by OHV use. We can, however, contribute to identifying circumstances where the designation of OHV routes would have the least effect on habitat occupancy and distribution. Martens had the greatest opportunity to interact with OHVs during summer, when diurnal activity increased. Because summer is the season when most OHV use is restricted to National Forest System and nonsystem routes, placing routes so they avoid high-quality marten habitat (late-successional conifer forests near meadows and riparian areas; Spencer et al. 1983) will minimize the possibility that martens encounter OHV stimuli when they are actively engaged in foraging or social behavior.

Joslin and Youmans (1999) concluded that martens may be negatively affected by motorized vehicles, because roads and trails add to fragmentation of habitat or populations. We agree but argue that the level of OHV use we witnessed did not affect occupancy and, therefore, did not appear to be contributing to fragmentation. Importantly, however, there are extensive areas of wilderness refugia in the vicinity of both areas where we studied martens. The maintenance of wilderness and nonmotorized areas, where motorized human impact is minimal, in close proximity of areas where martens are subjected to less benevolent conditions, may allow martens to persist in diverse landscapes.

ACKNOWLEDGMENTS

This work was supported by the California Department of Parks and Recreation Off-Highway Motor Vehicle Division and the California Off-Highway Motor Vehicle Commission, by the USDA Forest Service Pacific Southwest Regional Office, the USDA Forest Service Pacific Southwest Research Station (Redwood Sciences Laboratory), and Hubbs–SeaWorld Research Institute. We thank D. Craig and K. Mick for their assistance in administering the funds and their helpful comments and review of this report. We gratefully acknowledge the field assistance of T. Yack of Hubbs–SeaWorld, and K. Moriarty, A. Rogers, K. Gaudet, E. Shea, T. Dodson, B. Marckmann, R. Beane, M. Masten, K. Moughamer, P. Squires, R. Kussow, A. Stutz, W. Owens, and R. Schlexer of the USDA Forest Service Pacific Southwest Research Station. J. Werren assisted in developing maps and conducting spatial analysis. S. Denes and T. Yack conducted the analyses of SLM data. We gratefully acknowledge Wyle Laboratories for permission to use custom software to process SLM data. We conducted the work with the cooperation of the Lake Tahoe Basin Management Unit and the High Sierra Ranger District (Sierra National Forest) of the USDA Forest Service. Snowmobiles were loaned to the project by the Pacific Southwest Research Station (Sierra Nevada Research Center), Klamath National Forest, and Six Rivers National Forest, and the following national forests loaned us cameras: Eldorado, Modoc, Plumas, Sequoia, Six Rivers, and Stanislaus.

LITERATURE CITED

Bowles, A. E. 1995. Responses of wildlife to noise. Pages 109–156 *in* R. Knight and K. Gutzwiller, editors. Wildlife and recreationists: coexistence through management and research. Island Press, Washington, D.C., USA.

Boyle, S. A., and F. B. Samson. 1985. Effects of nonconsumptive recreation on wildlife: a review. Wildlife Society Bulletin 13:110–116.

Bright, A., G. R. Reynolds, J. Innes, and J. R. Waas. 2003. Effects of motorized boat passes on the time budgets of New Zealand dabchick, *Poliocephalus rufopectus*. Wildlife Research 30:237–244.

Bunnell, K. D., J. T. Flinders, and M. L. Wolfe. 2006. Potential impacts of coyotes and snowmobiles on lynx conservation in the Intermountain West. Wildlife Society Bulletin 34:828–838.

Buskirk, S. W., and S. L. Lindstedt. 1989. Sex biases in trapped samples of Mustelidae. Journal of Mammalogy 70:88–97.

California Department of State Parks and Recreation. 2002. Taking the high road: the future of California's off-highway vehicle recreation program. California Department of State Parks and Recreation, Sacramento, USA.

Cordell, H. K., C. J. Betz, G. Green, and M. Owens. 2005. Off-highway vehicle recreation in the United States: a national report from the national survey on recreation and the environment. U.S. Department of Agriculture, Forest Service, Southern Research Station, Athens, Georgia, USA.

Creel, S., J. E. Fox, A. Hardy, J. Sands, B. Garrott, and R. O. Peterson. 2002. Snowmobile activity and glucocorticoid stress responses in wolves and elk. Conservation Biology 16:809–814.

Dorrance, M. J., P. J. Savage, and D. E. Huff. 1975. Effects of snowmobiles on white-tailed deer. Journal of Wildlife Management 39:563–569.

Drickamer, L. C., and S. H. Vessey. 1982. Animal behavior: concepts, processes, and methods. Willard Grant Press, Boston, Massachusetts, USA.

Gill, J. A., K. Norris, and W. J. Sutherland. 2001. Why behavioural responses may not reflect the population consequences of human disturbance. Biological Conservation 97:265–268.

Gregoire, T. G., and G. J. Buhyoff. 1999. Sampling and estimating recreational use. U.S. Department of Agriculture Forest Service PNW-GTR-456, Pacific Northwest Research Station, Portland, Oregon, USA.

Gutzwiller, K. J. 1991. Assessing recreational impacts on wildlife: the value and design of experiments. North American Wildlife and Natural Resources Conference 56:248–255.

Halfpenny, J. C., R. W. Thompson, S. C. Morse, T. Holden, and P. Rezendes. 1995. Snow tracking. Pages 91–163 *in* W. J. Zielinski and T. E. Kucera, editors. A detection manual for wolverine, fisher, lynx and marten in the western United States. U.S. Department of Agriculture General Technical Report PSW-GTR-157, Pacific Southwest Experiment Station, Albany, California, USA.

Halle, S., and D. Weinert. 2000. Measuring and analysing activity of small mammals in the laboratory and in the field. Pages 285–312 *in* S. Halle and N. C. Stenseth, editors. Activity patterns in small mammals. Springer-Verlag, Berlin, Germany.

Hargis, C., and D. McCullough. 1984. Winter diet and habitat selection of

marten in Yosemite National Park. Journal of Wildlife Management 48: 140–146.
Heffner, R. S., and H. E. Heffner. 1985. Hearing in mammals: the least weasel. Journal of Mammalogy 66:745–755.
Joslin, G., and H. Youmans. 1999. Effects of recreation on Rocky Mountain wildlife: a review for Montana. Committee on Effects of Recreation on Wildlife, Montana Chapter of The Wildlife Society, Missoula, USA.
Kelly, J. B., G. L. Kavanagh, and J. C. Dalton. 1986. Hearing in the ferret (*Mustela putorious*): thresholds for pure tone detection. Hearing Research 24:269–275.
Knight, R. L., and D. N. Cole. 1995. Wildlife responses to recreationalists. Pages 51–69 *in* R. Knight and K. Gutzwiller, editors. Wildlife and recreationists: coexistence through management and research. Island Press, Washington, D.C., USA.
Knight, R. L., and K. J. Gutzwiller, editors. 1995. Wildlife and recreationists: coexistence through management and research. Island Press, Washington, D.C., USA.
Kolbe, J. A., J. R. Squires, D. H. Pletscher, and L. F. Ruggiero. 2007. The effect of snowmobile trails on coyote movements within lynx home ranges. Journal of Wildlife Management 71:1409–1418.
Kucera, T. E., A. Soukkala, and W. J. Zielinski. 1995. Photographic bait stations. Pages 25–65 *in* W. J. Zielinski and T. E. Kucera, editors. A detection manual for wolverine, fisher, lynx and marten in the western United States. U.S. Department of Agriculture General Technical Report PSW-GTR-157, Pacific Southwest Experiment Station, Albany, California, USA.
Lindström, S., P. Rucks, and P. Wigand. 2000. A contextual overview of human land use and environmental conditions. Pages 23–127 *in* D. D. Murphy and C. M. Knopp, editors. Lake Tahoe watershed assessment. Volume I. U.S. Department of Agriculture Forest Service General Technical Report PSW-GTR-175, Albany, California, USA.
MacKenzie, D. I., J. D. Nichols, J. A. Royle, K. H. Pollock, L. L. Bailey, and J. E. Hines. 2006. Occupancy estimation and modeling: inferring patterns and dynamics of species occurrence. Academic Press, London, United Kingdom.
Mayer, K. E., and W. F. Laudenslayer. 1988. A guide to wildlife habitats of California. California Department of Forestry and Fire, Sacramento, USA. <http://www.dfg.ca.gov/whdab/html/cwhr.html>. Accessed 22 Jun 2008.
McKelvey, K. S., and J. D. Johnston. 1992. Historical perspectives on forests of the Sierra Nevada and the transverse ranges of southern California: forest conditions at the turn of the century. Pages 225–246 *in* J. Verner, K. S. McKelvey, B. R. Noon, R. J. Gutiérrez, G. I. Gould, Jr., and T. W. Beck, editors. The California spotted owl: a technical assessment of its current status. U.S. Department of Agriculture Forest Service Technical Report PSW-GR-133, Pacific Southwest Research Station, Albany, California, USA.
Moen, A. N., S. Whittemore, and B. Buxton. 1982. Effects of disturbance by snowmobiles on heart rate of captive white-tailed deer. New York Fish and Game Journal 29:474–488.
Nevin, O. T., and B. K. Gilbert. 2005. Measuring the cost of risk avoidance in brown bears: further evidence of positive impacts of ecotourism. Biological Conservation 123:453–460.
Richens, V. B., and G. R. Lavigne. 1978. Response of white-tailed deer to snowmobiles and snowmobile trails in Maine. Canadian Field-Naturalist 92:334–344.
Riley, S., R. M. Sauvajot, T. Fuller, E. York, D. Kamradt, C. Bromley, and R. Wayne. 2003. Effects of urbanization and habitat fragmentation on bobcats and coyotes in southern California. Conservation Biology 17: 566–576.
Routledge, R. G. 2000. Use of track plates to detect changes in American marten (*Martes americana*) abundance. Thesis, Laurentian University, Sudbury, Ontario, Canada.
Simon, T. 1980. An ecological study of the marten in the Tahoe National Forest. Thesis, California State University, Sacramento, USA.
Slauson, K., R. Truex, and W. Zielinski. In press. Determining the sexes of American marten and fisher at track plate stations. Northwest Science.
Spencer, W. D. 1981. Pine marten habitat preferences at Sagehen Creek, California. Thesis, University of California, Berkeley, USA.
Spencer, W. D. 1987. Seasonal rest-site preferences of pine martens in the northern Sierra Nevada. Journal of Wildlife Management 51:616–621.
Spencer, W. D., R. H. Barrett, and W. J. Zielinski. 1983. Marten habitat preferences in the northern Sierra Nevada. Journal of Wildlife Management 47:1181–1186.
Taylor, A. R., and R. L. Knight. 2003. Wildlife responses to recreation and associated visitor perceptions. Ecological Applications 13:951–963.
U.S. Department of Agriculture [USDA] Forest Service, Recreation, Heritage and Wilderness Program. 2005. <www.fs.fed.us/recreation/programs/nvum/national_report_final_draft.pdf>. Accessed 27 Jul 2007.
Van Dyke, F. G., R. H. Brocke, H. G. Shaw, B. B. Ackerman, T. P. Hemker, and F. G. Lindzey. 1986. Reactions of mountain lions to logging and human activity. Journal of Wildlife Management 50:95–102.
White, D., Jr., K. C. Kendall, and H. D. Picton. 1999. Potential energetic effects of mountain climbers on foraging grizzly bears. Wildlife Society Bulletin 27:146–151.
Wisdom, M. J., A. A. Ager, H. K. Preisler, N. J. Cimon, and B. K. Johnson. 2004. Effects of off-road recreation on mule deer and elk. Transactions of the North American Wildlife and Natural Resource Conference 69:531–550.
Ydenberg, R. C., and L. M. Dill. 1986. The economics of fleeing from predators. Advances in the Study of Behaviour 16:229–249.
Zielinski, W. J. 1995. Baited track-plate stations. Pages 67–89 *in* W. J. Zielinski and T. E. Kucera, editors. A detection manual for wolverine, fisher, lynx and marten in the western United States. U.S. Department of Agriculture General Technical Report PSW-GTR-157, Pacific Southwest Experiment Station, Albany, California, USA.
Zielinski, W. J., and R. L. Truex. 1995. Distinguishing tracks of marten and fisher at track-plate stations. Journal of Wildlife Management 59: 571–579.
Zielinski, W. J., R. L. Truex, F. V. Schlexer, L. A. Campbell, and C. Carroll. 2005. Historical and contemporary distributions of carnivores in forest of the Sierra Nevada, California, U.S.A. Journal of Biogeography 32:1385–1407.

Associate Editor: Bowman.

Appendix. Seasonal L_{Aeq} summary statistics for each study area by season and use or non-use areas at the Lake Tahoe and High Sierra study sites, Sierra Nevada, California, USA, 2003–2004. L_{Aeq} is a measure of the average sound exposure over time.

Study area and season	Total L_{Aeq}				Vehicle L_{Aeq}			
	Weekday		Weekend		Weekday		Weekend	
	Day	Night	Day	Night	Day	Night	Day	Night
Lake Tahoe								
Winter								
Use $\bar{x}$	38.70	29.73	39.74	36.62	42.81	21.95	41.59	21.62
Use SE	4.38	3.79	3.92	3.96	6.64	5.22	5.41	4.46
Non-use $\bar{x}$	31.47	33.39	32.35	33.84	37.56	11.46	27.48	14.49
Non-use SE	3.31	1.07	3.37	1.11	7.68	5.91	6.69	6.24
Spring								
Use $\bar{x}$	42.48	39.56	41.20	37.72	55.12	44.86	56.21	39.41
Use SE	1.86	1.43	1.07	0.94	1.95	5.42	1.86	5.23
Non-use $\bar{x}$	40.78	37.81	34.45	32.38	49.28	19.53	39.74	14.40
Non-use SE	3.45	2.93	4.22	3.88	7.23	7.99	6.95	7.41
Summer								
Use $\bar{x}$	40.70	36.71	33.56	30.83	54.04	37.59	38.97	27.71
Use SE	1.94	1.58	3.32	2.92	2.51	6.69	5.57	5.89
Non-use $\bar{x}$	38.93	33.13	37.50	33.25	50.83	22.05	49.33	16.91
Non-use SE	4.09	1.37	1.33	1.15	4.59	8.40	1.05	8.25
High Sierra								
Fall								
Use $\bar{x}$	36.27	34.78	37.08	34.90	41.02	18.00	40.65	27.91
Use SE	1.07	1.13	1.07	0.94	4.47	6.03	5.64	6.26
Non-use $\bar{x}$	35.64	34.40	31.87	28.65	31.37	10.65	13.25	5.93
Non-use SE	0.99	1.05	5.03	4.17	9.39	7.03	8.78	5.93
Winter								
Use $\bar{x}$	38.08	37.67	36.41	34.54	51.39	45.47	39.61	22.10
Use SE	1.29	1.39	1.71	1.10	2.01	4.19	5.25	5.56
Non-use $\bar{x}$	36.11	35.24	36.78	35.18	19.41	12.24	13.83	0
Non-use SE	0.80	0.76	0.96	0.93	9.25	7.94	8.98	0
Spring								
Use $\bar{x}$	40.33	34.77	37.81	35.34	51.39	45.47	39.61	22.10
Use SE	2.08	0.76	1.26	1.04	2.01	4.19	5.25	5.56
Non-use $\bar{x}$	34.98	33.80	34.85	34.45	6.61	0	0	0
Non-use SE	1.52	1.39	1.84	2.06	0.51	0	0	0
Summer								
Use $\bar{x}$	38.88	36.86	39.71	35.76	41.69	34.89	46.74	31.46
Use SE	1.16	1.61	1.27	0.42	5.27	6.04	4.14	5.72
Non-use $\bar{x}$	36.74	34.81	41.24	33.76	35.01	14.71	14.63	0
Non-use SE	1.09	0.79	1.69	0.63	9.42	9.56	9.45	0