Winter Recreation Effects on the Subnivean Environment of Five Sierra Nevada Meadows

Winter Recreation Effects on the Subnivean Environment of Five Sierra Nevada Meadows

Placer, Plumas, and El Dorado County, California;
Washoe County, Nevada

Funded by a Grant to the
Lake Tahoe Basin Management Unit
by the California Department of Parks and Recreation's Green Sticker Program
Project # OR-2-LTB-49

DRAFT REPORT

Prepared for:

Lake Tahoe Basin Management Unit
United States Forest Service
35 College Drive
South Lake Tahoe, CA 96150

Prepared by:
Wildlife Resource Consultants
P.O. Box 8493
Truckee, CA 96162

Contact:
Sue Fox
530.550.0206

In association with:
River Run Consulting
P.O. Box 8538
Truckee, CA 96162

Contact:
Matt Kiesse
530.550.7629

Table of Contents

INTRODUCTION

Adaptations to snowpack are an important component of the ecology of small mammals in temperate climates. Some small mammals, such as chipmunks (*Tamias spp*), hibernate and have limited interaction with the snowpack environment. However, shrews (*Sorex spp*) and voles (*Microtus spp*) stay active throughout the winter, and much of their activity occurs in the subnivean space under the snowpack. Other species undergo bouts of torpor between activity (Family: Muridae; deer mouse *Peromyscus maniculatus*). The habitat of species active in the winter includes mesic and dry meadows throughout the Sierra Nevada.

These subnivean mammals are dependent on the subnivean space between the basal layer of snow and the ground for shelter, foraging, and travel. Past research suggests that subnivean space may be formed in one of two ways: mechanically or thermally (Dr. William Pruitt, personal communication). The relative importance of each of these mechanisms in forming biologically useful subnivean space varies by region and type of snow. Subnivean space forms mechanically when the weight of the snowpack is supported by vegetation, woody debris, or complex rocky environments.

Extensive subnivean space may be formed thermally in environments with a temperature gradient between the bottom and top of the snowpack. The snowpack undergoes changes in vertical structure through a process called constructive or temperature gradient metamorphism (Marchand 1991). As water vapor migrates up from warmer to colder regions of the snow, depth hoar forms just above the ground at the base of the snowpack. Open space develops due to loss of water and snowpack during coalescence into larger crystals and transfer of water vapor up through the snowpack. Depth hoar is brittle, loosely arranged crystals that create space in the subnivean environment and facilitate travel by small mammals who readily move through the fragile crystals. In some areas, the basal layer of depth hoar may be 10 to 20 cm thick with individual crystals as large as 10 mm across (Pruitt 1984).

Depth hoar commonly forms and is most well-developed in cold, continental type regions where temperature throughout the snowpack varies significantly. It is documented in three of six snow classes: tundra, taiga, and alpine. These classes were delineated by Sturm et al. (1995) who developed a seasonal snow cover classification based on three climatic variables (temperature, wind speed, and snowfall). Depth hoar is rare to nonexistent in snow classified as maritime, which also tends to be more isothermal.

Study Need

Concern about the effects of winter recreation on wildlife, particularly snowmobiling and grooming of snowmobile and cross country ski trails, has grown as these sports have become more popular (USDA 1980; USDA 1996; Greater Yellowstone Winter Working Group 1999; Joslin and Youmans 1999; Snowmobile Effects on Wildlife – Monitoring Protocols Workshop). Impacts from snowmobile use have received the most attention (Newman and Merriam 1972) and include the following: (1) disturbance resulting in animal weight loss and increased susceptibility to disease; (2) displacement of animals from critical habitats, travel corridors, and den sites to less optimal habitats; (3) abandonment of preferred foraging areas; (4) damage to vegetation; (5) harassment or chasing of wildlife that leads to death; (6) increases stress and energy use in response to snowmobiles possibly limiting population size; and (7) compaction of snow destroys the subnivean environment, which reduces temperatures leading to increased metabolic rates, restricts movement, suffocates animals, and increases winter mortality (Bury 1978; Jarvinen and Schmid 1971; Picton 1999; Rongstad 1980; Ryerson et al. 1977; US DOI 1978; Wanek and Schumacher 1975).

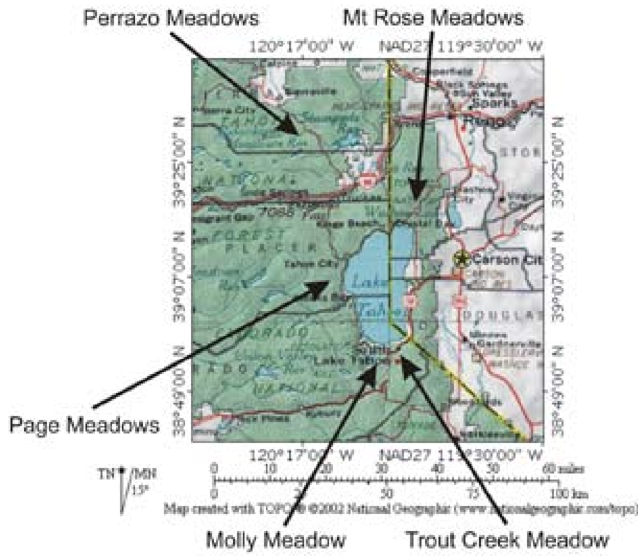


Figure 1. Location of study sites.

Most of these potential impacts are not an issue in the Tahoe National Forest because the large mammal species for which such effects have been documented do not inhabit this area (e.g., elk (*Cervus elaphus*), bison (*Bos bison*), white-tailed deer (*Odocoileus virginianus*), lynx (*Lynx lynx*)), and wildlife use naturally decreases because many animals hibernate (e.g., black bears (*Ursus americanus*)) or migrate (e.g., mule deer (*Odocoileus hemionus*)) to lower elevations where snowmobile use does not occur. However, snowmobiles could potentially impact subnivean animals through compaction of the subnivean space. Any adverse effects to subnivean animals could indirectly affect the prey base for many Forest Service sensitive species, including the northern goshawk (*Accipiter gentilis*) and pine marten (*Martes americana*). A reduction in the number of prey could cause a decline in the diversity or numbers of wildlife occurring in an affected area, and could preclude the establishment of a sensitive species later in time as additional acreage of suitable habitat develops in response to Forest Service management direction.

Studies cited as the basis for impacts to the subnivean environment and subnivean animals were generally conducted in locations with continental snowpacks (e.g., alpine) where depth hoar develops. When these studies are cited in environmental documents for agency management decisions (USDA 1999a, 1999b) and in public comments and lawsuits (Biodiversity Legal Foundation. 1995; Bluewater Network. 1999), no caveats are applied regarding the utility of the results to different snowpack classes. No studies are known to have investigated the distribution of subnivean space or the effects of winter recreation on subnivean space in maritime snowpack conditions, such as those found in the Sierra Nevada Mountains. This study was designed to examine the distribution of subnivean space in Sierra meadows, how it is formed, and the impacts of winter recreation on snowpack characteristics and subnivean space.

STUDY AREA

Five meadows were selected for inclusion in this study (Figure 1), all of which were known to contain populations of shrews and voles based on summer observations and/or sampling (Manley and Schlesinger 2001; Unpublished data Trout Creek Restoration Monitoring). Perrazo Meadows, on the Little Truckee River, was selected because it is a destination site for dispersed snowmobile play. It is accessed via a groomed trail system. Page Meadows, in the Ward Creek watershed of the Lake Tahoe Basin, was sampled because cross country skiing use is extensive and snowmobiles are prohibited. A meadow along Trout Creek, a tributary to the Upper Truckee River in South Lake Tahoe, was selected because vegetation characteristics were well-known from prior studies, and the role of different types of vegetation in producing subnivean space could be evaluated. Recreational use of the Trout Creek meadow is primarily non-motorized such as cross country skiing, although snowmobiles are not prohibited.

Molly Meadow, located in a drainage of the Upper Truckee River in South Lake Tahoe, was selected to increase representation of meadow sites at low elevations. Compared to the other project areas, this site receives less cross country skiing and snowmobile use. Mount Rose meadow was sampled because the site is divided by the Mount Rose Highway (Route 431) into two USFS management units. The northern site is managed for snowmobiles and the southern site is restricted to cross country skiing and other non-motorized recreational use. The former four sites are situated in the Tahoe National Forest while Mount Rose meadow is located in Toiyabe National Forest.

Table 1. Summary of the number of pits dug at each survey site and UTM coordinates (NAD 27) of the snow pits' location.

Location	Number of Pits	Average Elevation of Snow Pits (m)	UTM Location of Snow Pits
Page Meadows	8	2,127	10S0743791/4336944 10S0744298/4336899 10S0743740/4336364
Perazzo Meadows	16	1,986	10S0731611/ 4374444 10S0727715/ 4374434 10S0727272/ 4374974
Trout Creek	16	1,917	11S0242534/ 4310725
Molly Meadow	10	1,933	11S0241144/ 4309650
Mount Rose Meadow	15	2,619	11S0248527/ 4354191 11S0248264/ 4354153 11S0248555/ 4354150 11S0248487/ 4354117S

Photo 1. Snow pit, Mt. Rose Meadows.

METHODS

A total of 65 relatively rectangular or square pits were dug from January 16 to April 9, 2004 (Table 1). Depending on snow conditions, the pits varied in perimeter from a minimum of 306 cm to a maximum of 685 cm. The mean pit size was 385 cm. The pits were dug in the snow down to the ground surface. On a single day, all pits were dug in the same meadow; the number of pits dug in a day varied from 2 to 10.

With two exceptions, at least one of the pits was dug in an area that had not been affected by recreational use. At Page Meadows, weather conditions prevented a control pit from being dug on March 12. Mount Rose meadow receives extensive recreational use from the Reno metropolitan area as well as by visitors from the Lake Tahoe Basin. No control sites could be found because the recreational use was consistently widely dispersed.

Photo 2. A vole burrow.

All other pits were centered on snowmobile or cross country ski tracks. These pit types were subdivided into either concentrated or dispersed use. Concentrated use pits were dug over regularly used track systems. Dispersed use pits were dug over tracks that were not part of a trail system. Trail classification was determined by consultation with the USFS recreation officer and/or by long-term observations (e.g., cross country ski trails known to be maintained by daily skier use).

Characteristics of the vegetation at the bottom of the pit were noted. Pits were unevenly distributed among four vegetation types: wet meadow, dry meadow, silver sage (*Artemesia tridentata*), and riparian shrub. Wet meadow habitat consisted of more than 75% ground cover (ocular estimate) of grasses, sedges and forbs. Dry meadow consisted of grasses and bare ground, with less than 75% ground cover. Silver sage vegetation type was one or more sagebrush shrubs on a bare ground. The riparian shrub vegetation type consisted of willows (*Salix spp*) and/or down wood with an understory of herbaceous vegetation.

Subnivean space was defined as any space 1 cm or greater that extended under the basal layer of snow for at least 5 cm. The height was chosen on the basis of the size of openings that captive voles were observed to squeeze through and on their skull heights. The 5 cm figure was arbitrarily chosen to represent the minimum biologically useful space. The presence or absence of subnivean space along the entire perimeter of the snow pit was measured with a tape measure. The vertical height of openings was recorded at 10 cm intervals.

Photo 3. Vole scat collected from a runway under the basal layer of snow.

For all subnivean space, the presumed genesis was noted (mechanical, thermal, biological). Any evidence of small mammal use of the space (trail systems with scat, burrows) was recorded and photographed. For the purposes of data analysis, subnivean sign was classified into one of three categories: 0: No Use; 1: Low to moderate activity indicated by the presence of a single sign of activity such as a burrow or runway; 2: Heavy use indicted by the presence of multiple signs such as burrows, runways, and nests. In addition to physical features of activity, the presence of vole scat was noted when observed. Photographs were also taken of most pits in relationship to the recreational use, of the pit floor, and at the intersection of the snowpack with the ground.

The height of the four snow pit walls was measured and an average height was recorded. For each pit, the average snow pit wall height was classified into one of four categories: Type 1: 0-64cm; Type 2: 65-100 cm; Type 3: 100-150 cm; and Type 4: > 150 cm. The classifications were made on the basis of natural breaks in snow depths recorded at the different project locations.

Snowpack density was directly measured by taking samples of snow with a 1-liter pie cutter in the wall of the pit at 10 cm intervals from the base of the pit to the snow surface. Samples were weighed in the field on a 5,000 gram compact scale (Ohaus Corporation Model CS 5000). In some cases, the presence of an ice layer precluded collecting a sample at a given height. For pits centered on areas of recreational use, two columns of density samples were taken from two different walls directly affected by the recreational use. The study's original design included taking a second line of density samples from a wall that was unaffected by recreational use. However, this proved impossible due to difficulties in aligning and digging the snow pits over both recreational and no-use areas. Temperatures of each of the density sampling columns were also taken at 10 cm intervals with a metal-encased thermometer.

Relative snowpack density was also measured with a ram penetrometer. This instrument is used to estimate relative density of the snowpack without snow pit construction, and it was hypothesized that this instrument may be able to detect subnivean space. The penetrometer consists of a metal tubular shaft, which is pounded into the snowpack by dropping known weights (the hammer) onto the shaft. A relative measure of snowpack hardness, ram hardness, is calculated based on the weight of the hammer, the number of blows with the hammer, the fall height of the hammer, and the depth of penetration:

$$RN = T + H + (nfH/p)$$

Where:
RN = Ram hardness
n = number of blows of hammer
f = fall height of the hammer
p = increment of penetration for n blows (cm)
T = weight of tubes including guide rod (N) = 10 x mass (kg)
H = weight of hammer (N) = 10 x mass (kg)

Penetrometer density estimates were made near density profiles taken inside each snow pit, about 60 cm back from the edge of the pit.

Perimeter maps of the space at the base of each pit were drawn and the percent open space was calculated. Mean vertical height of the subnivean space was calculated for each pit from the systematic 10 cm samples. Snowpack density and temperature from direct measurements were plotted by depth for the two sampling locations within each pit. Ram hardness was also plotted by depth for all locations. Ram hardness profiles were compared to density profiles obtained directly in snow pit walls. Also, ram hardness profiles were analyzed for their ability to detect potential subnivean space near the soil-snowpack interface.

RESULTS

Sixty-five snow pits were examined for subnivean space, density characteristics, temperature, vegetation type, and the presence of small mammal sign. A summary of the major characteristics of these pits is given in Table 2 in Appendix A.

Photo 4. Subnivean space in dense vegetation.

Photo 5. Basal layer of snow directly on the ground.

Subnivean Space

A total of 25,037 cm of snow pit perimeter was examined for subnivean space. Among all 65 pits, a total of 15.6% (3,991 cm) was classified as subnivean space. The percent of subnivean space per snow pit varied from 0 to 70% (Table 2, Appendix A). The subnivean space did not contain depth hoar. The basal layer of snow above the subnivean space was characterized by either wet snow consisting of rounded crystals or a layer of ice. The ground below the ice layer was typically moist, but was never frozen. Some snow pits dug later in the season (i.e., March and April) intersected pooled water. In some cases, the water was extensive enough that the perimeter of the pit could not be sampled and a new pit had to be dug. Where subnivean space was absent, the basal layer of snow rested directly on the ground.

Pooled data for all sites were analyzed by recreational use category (Table 3, page 7). One pit (Number 14; Page Meadows; January 25) intentionally excavated over a large down log (estimate $\geq$ 18" dbh) was excluded from this analysis because similar woody debris sites were not replicated in all recreational use categories. The pit's total perimeter was 360 cm of which 237 cm (65.8%) were subnivean space. The subnivean space had a smooth, glazed roof with an average vertical height of 6.4 cm.

The "No Use" category had substantially more subnivean space than all other use categories, with an average of 31.4% of the total pit perimeter averaged over 18 pits. This was nearly three times the percent of the pit perimeter occupied by subnivean space for any of the other use categories. Pits classified under one of the two skiing uses or the dispersed over-snow vehicle use were very similar, with an average of about 10.5% of the perimeter occupied by subnivean space. Pits classified as concentrated over-snow vehicle use had the least subnivean space, an average of 6.0% (n=7).

Photo 6. A vole runway with scat.

The vertical height of the subnivean space ranged from 1 cm, the minimum height chosen to represent subnivean space in this study, to 6.9 cm (Table 2, Appendix A). The greatest vertical height was associated with four factors: (1) riparian shrubs, such as willows (e.g., pit 16); (2) large diameter downed wood (e.g., pit 14); (3) vole runways depressed in the ground (often several centimeters) that traversed under the perimeter of the snow wall (e.g., pit 23); and (4) a dense mat of grasses, sedges, and forbs (e.g., pits 19-34). Snow pits dug at Trout Creek Meadow had a relatively large vertical height due to both rodent burrows and the dense mat of herbaceous vegetation.

Table 3. Pooled percent of subnivean space for all survey locations for each type of use.

Use	Number of Pits	Total Perimeter (cm)	Total Subnivean Space (cm)	Percent Subnivean Space
Concentrated cross country ski	7	2,362	259	10.9%
Dispersed cross country ski	15	5,885	619	10.5%
Concentrated snow mobile	7	2,428	140	6.0%
Dispersed snowmobile	17	6,984	745	10.6%
None	18	7,373	2,439	31.4%
Total	64	25,037	3,991	15.2%

The presence of subnivean space was highly variable by site. The total percent of subnivean space for all samples from a given study site varied by location (Table 4, page 8). Snow pits dug at Trout Creek had the greatest percentage of subnivean space in the perimeter while those dug at Mount Rose Meadow had the least. Alternatively, snow pits at higher elevations had the least amount of subnivean space, while those at the lowest elevation had the greatest amount.

Table 4. Percentage subnivean space for all uses for each survey site.

Percent Subnivean Space N = number of snow pits Range of subnivean space (cm)					
Use	Page Meadows Elevation (m) 2,127	Perazzo Meadows Elevation (m) 1,986	Trout Creek Meadow Elevation (m) 1,917	Molly Meadow Elevation (m) 1,933	Mount Rose Meadows Elevation (m) 2,619
Concentrated cross country ski	2.7% N = 3 Range: 0-30	-	15.9% N = 4 Range:46-95	-	-
Dispersed cross country ski	0% N = 1 Range:0-0	-	36% N = 4 Range:27-270	-	0.35% N = 11 Range: 0-15
Concentrated snow mobile	-	12% N = 2 Range: 0-94	-	4.8% N = 3 Range: 0-37	0% N = 2 Range: 0-0
Dispersed snowmobile	-	15.6% N = 10 Range:0-246	-	7.8% N = 4 Range: 8-49	0.3% N = 3 Range: 0-5
None	1.3% N=4 Range:0-22	45% N = 3 Range:33-241	46.5% N = 8 Range:45-374	0.8% N = 3 Range: 0-9	-
Total Percent of Subnivean Space	3.3%	20.8%	31.8%	4.8%	0.3%
Total Number of Pits	8	15	16	10	16

Because pits were generally constructed in areas representing a range of recreational uses at each site, other factors than recreational use influence the presence of subniveal space. For example, the amount of subniveal space in Page Meadows pits was substantially lower across all recreational use categories than at any other site. Compared to other sites, Page Meadows had deep snow and less dense vegetation. Thus, while this analysis suggests that recreational uses had a negative effect on the presence of subnivean space, examination of the entire data set showed that other factors are also influential. The type of vegetation and snow depth appear to play a major role in either the development or maintenance of subnivean space.

Influence of Vegetation

The average percent of subnivean space in the pit perimeter was calculated for all pits pooled by vegetation community type, as well as the average height of subnivean space (Figure 2, page 10). Pits dug in riparian shrub communities had the highest percent of the pit perimeter occupied by subnivean space, and the highest

Photo 7. Subnivean space mechanically created in riparian shrub habitat.

Photo 8. A layer of ice above the ground. Slender branches did not create subnivean space.

average height of subnivean space. Silver sage and wet meadow communities had similar subnivean characteristics, and while both were lower in subnivean space occurrence and height than the riparian shrub community both were also substantially higher than the dry meadow vegetation community.

Vegetation structure appears to be an important factor in creating subnivean space. Subnivean space was high in the vegetation communities with woody shrubs, likely due to the influence of stems that are less compressible than in herbaceous vegetation communities. However, subnivean mammal use was not noted in pits dug in the riparian shrub or silver sage community types. Absence of mammal sign may have been an artifact of pit construction, as the pits with woody shrubs were extremely difficult to construct and sign may have been obliterated during construction. Because no mammal use was noted in the shrub communities, and because the sample size in these communities was small and was not proportionately distributed among recreational use categories, the shrub communities were excluded from the following analysis of recreational effects.

Wet meadows, with their additional herbaceous density and height, may provide more subnivean space compared to dry meadows. For example, the vegetation in the snow pits at Trout Creek consisted of a dense mat of sedges, grasses, and forbs that formed the subnivean space between the basal layer of snow and the ground. The mats were loosely packed between the snow and the ground, which presumably allowed for easy movement by subnivean mammals and multiple signs of activity were common at this site. Trout Creek and Perazzo Meadows contained the greatest proportion of wet meadow and had the first and second largest amounts of subnivean space, respectively (Table 2, Appendix A).

Dry meadows typically consisted of patches of low herbaceous vegetation (<10 cm height) interspersed among larger areas of bare ground. The bare ground was sometimes characterized by the sparse, flattened remains of decomposed vegetation. The decomposition appeared to have already occurred as a cover of grasses was observed at the snow pit locations (e.g., Page Meadows, Mount Rose Meadow) prior to the snow study.

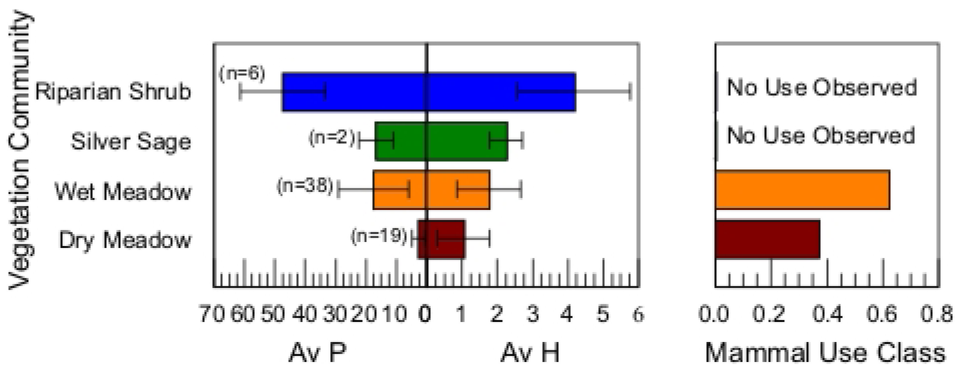


Figure 2. Subnivean space characteristics among vegetation community types. Av P is the average percent perimeter of the snow pit occupied by subnivean space. Av H is the average height of subnivean space. Error bars represent the standard deviation.

Influence of Snow Depth

The average percent of subnivean space in the pit perimeter was calculated for all pits pooled by snow depth class, as well as the average height of subnivean space (Figure 3). Pits dug in shallower snow had substantially more subnivean space than pits dug in deeper snow, and the height of the space was greater in the shallower pits. This suggests that the depth of snow, which is affected by elevation, strongly influences the development and maintenance of subnivean space. However, there was also a correlation between snow depth and vegetation communities, as most of the pits constructed in low snow depths were also constructed in wet meadows.

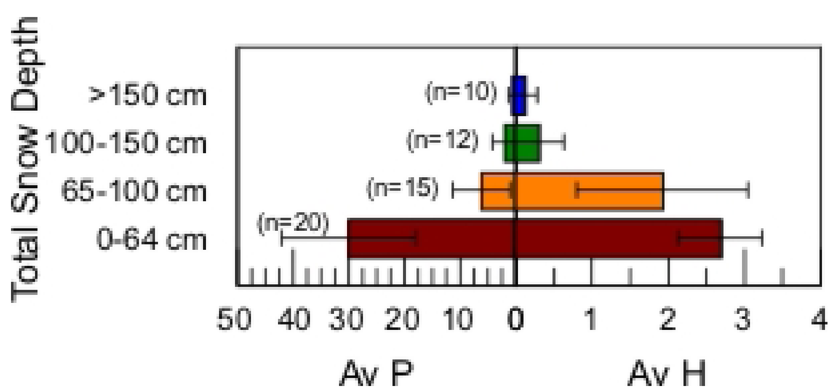


Figure 3. Subnivean space characteristics among snow depth classes. Av P is the average percent perimeter of the snow pit occupied by subnivean space. Av H is the average height of subnivean space. Error bars represent the standard deviation.

Influence of Recreational Use

Except for concentrated cross country skiing, all classes of recreational use, including no use, were fairly well distributed among dry meadow sites (Table 5-the shrub vegetation communities have been removed from further analysis). Pits dug in wet meadow vegetation communities were also well distributed among recreational uses, but there were more pits dug in areas categorized as no use. Also, more pits dug in shallow snow were in the no use recreational category than in other recreational use categories. Given that low snow depth and wet meadow vegetation are correlated with high subnivean space, some of the difference in the amount of subnivean space development between recreational use categories in the following analyses is likely due to these factors.

Table 5. The number and distribution of snow pits in the two meadow vegetation communities and the number and distribution of snow pits by snow depth class.

	Recreational Use*					
Vegetation Community	None	C/ccs	Ccs	C/osv	Osv	Total
Wet Meadow	12	6	8	4	8	38
Dry Meadow	4	1	5	4	5	19
Total	16	7	13	8	13	57
Snow Class: Depth Range						
1: 0-64 cm	9	5	2	4	0	20
2: 65-100 cm	4	0	1	2	8	15
3:101-150 cm	3	1	6	0	2	12
4: > 150 cm	0	1	4	2	3	10
Total	16	7	13	8	13	57

*C/ccs-concentrated cross country ski
Ccs-dispersed cross country ski
C/osv-concentrated snowmobile
Osv-dispersed snowmobile

Excluding pits dug in the shrub vegetation community types, average percent perimeter occupied by subnivean space was calculated for all sites by recreational use (Figure 4, page 12), along with the average height of subnivean space. The percent of subnivean space in the pit perimeter was highest in the no use category, followed by concentrated cross country skiing. Both had more subnivean space than the other three uses. Standard deviations of all averages by category overlap due to high variability between pits within categories. None of the differences between use categories would be statistically significant.

Somewhat similar trends were seen in average height of the subnivean space. Concentrated cross country skiing had the highest average height, closely followed by no use. Both over-snow categories were only slightly lower, while cross country skiing was substantially lower.

These data suggest that recreational use has a negative effect on the development and maintenance of subnivean space. It is important to note, however, that high variability between pits and the presence of other factors

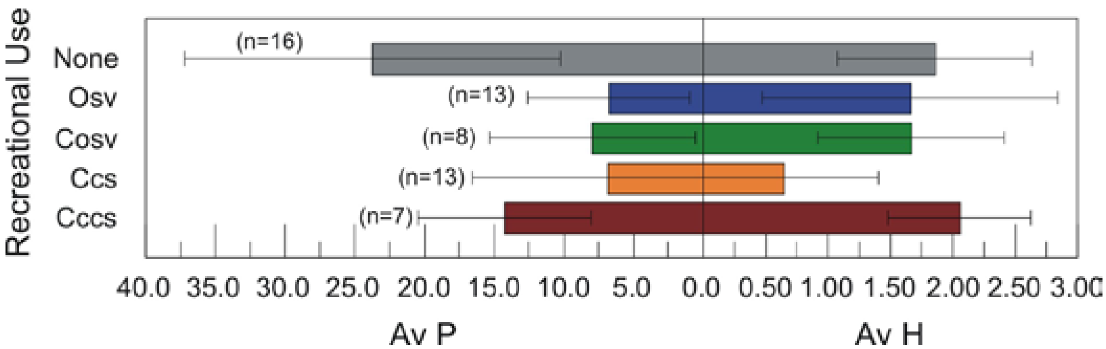


Figure 4. Subnivean space characteristics among recreational use types. Av P is the average percent perimeter of the snow pit occupied by subnivean space. Av H is the average height of subnivean space. Error bars represent the standard deviation.

that influence subnivean space did not allow for statistically significant conclusions within this study.

Snow Density

A scatterplot of all density samples in all pits was constructed (Figure 5). Samples taken in pits constructed in no use areas tend to cluster toward lower density, suggesting that recreational use tends to increase snow compaction.

Profiles of snow density by depth were also plotted for each pit (Appendix B). To eliminate the effects of snow depth or season, single plots contain profiles only for one meadow on one day. These plots generally show consistent increases in density with depth among all uses. On plots comparing over-snow vehicle density to no use, over-snow vehicle profiles tend to show higher density (e.g., Perazzo Meadows 17 and 25-Jan-04, Molly Meadow 8-Mar-04). There was no detectable difference between no use profiles and profiles for either cross country skiing category.

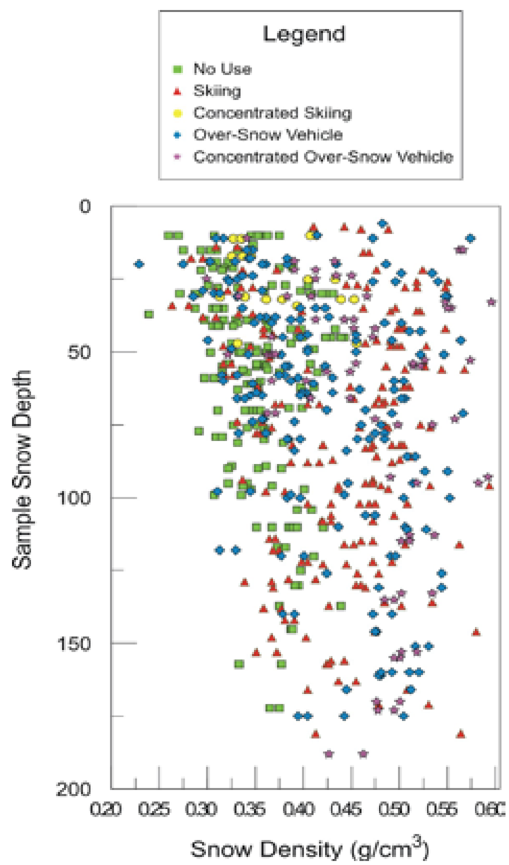


Figure 5. Scatterplot of snow density by snow depth.

Snow Temperature

Most of the pits constructed were relatively isothermal. While temperatures in the pit walls varied between -7 and 5 degrees C over the course of the study, more than 90% of the temperature measurements were between -3 and 2 degrees C regardless of depth (Figure 6, page 13). There is no detectable relationship in the scatterplot between recreational use and temperature.

Profiles of temperature by depth were also plotted for each pit (Appendix C). To eliminate the effects of snow depth or season, single plots contain profiles only for one meadow on one day. These plots generally reinforce the conclusions that the pits tended to be isothermal, but there is no consistent relationship between recreational use and temperature.

Ram Hardness Profiles

Ram hardness depth profiles were compared to directly measured density at two pit locations (see example, Figure 7). Ram profiles generally agreed with directly measured profiles, and contain more detail. However, there was no evidence that the ram penetrometer can accurately detect the presence of subnivean space.

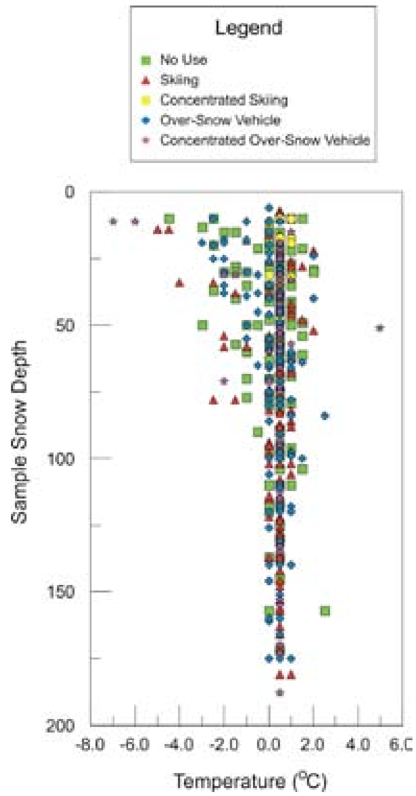


Figure 6. Scatterplot of snow temperature by snow depth.

DISCUSSION

Implications for Subnivean Animals

This study's results suggest that snowmobiles and cross country skiing may affect the amount of subnivean space, but both snow depth and vegetation are also strong influences. While recreational use did appear to affect snowpack density, it could not cause the same adverse effects reported in other study locations such as destruction of depth hoar, since this snow type did not occur in the study areas. The effects of winter recreation on subnivean space have been best documented in continental climates; it appears that different effects are likely to occur in the maritime climate of the Sierra Nevada where the conditions that lead to the formation of depth hoar do not exist. (This phenomenon was already known to snow scientists (Sturm et al. 1995)). Instead, the distribution of subnivean space correlates with snow depth, vegetation type, and woody debris.

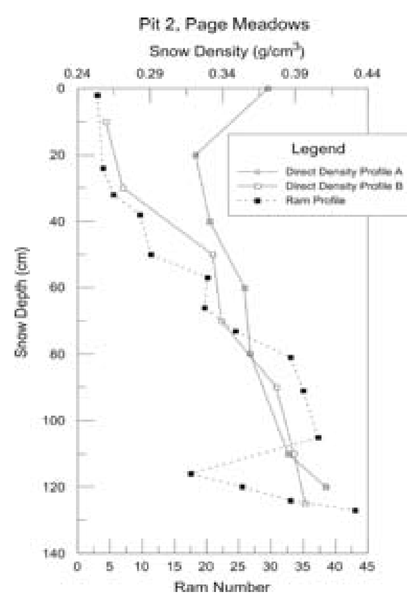


Figure 7. Comparison of density profiles from measurements made directly and by the Ram penetrometer.

In environments with fluctuating temperatures, the moisture gradient may move down from the snow surface as well as moving up from the bottom (Dr. Pruit, William, personal communication). In such cases, the snowpack rests directly on the ground as it does in the study area's portion of the Sierra Nevada Mountain Range. Pruit observed (1984) that only one species of vole was found on the Strait of Belle Isle in Newfoundland. He postulated that the lack of depth hoar in the maritime climate was an important factor governing the depauperate small mammal fauna. However, in the Sierra Nevada study sites, at least four species of subnivean mammals are known to occur in the study's meadows (Manley and Schlesinger 2001; Unpublished data Trout Creek Restoration Monitoring).

The lack of depth hoar in the subnivean space presents an interesting dilemma for understanding the winter ecology of subnivean animals in Sierra Nevada meadows. The question arises, how do the subnivean animals that occupy the meadows in the summer adapt to a maritime snow pack that rests primarily on the ground with very little subnivean space?

Photo 9. Material from inside a gopher's niveal tunnel.

Photo 10. Some niveal gopher burrows were extensive.

In the Ural Mountains of Russia, subnivean mammals were found to migrate before winter from meadows to talus slopes (Bolshakov 1984). The Ural Mountains have a dense maritime snowpack, which probably produces little thermally created subnivean space in meadow areas. Talus slopes, however, provide subnivean space due to support of the snowpack by larger rocks and boulders.

Perhaps subnivean animals that occupy dry meadows in the Sierra Nevada move to and concentrate in mechanically formed subnivean space located in dense herbaceous vegetation, woody shrubs, or around large down logs. If so, then winter recreationists would be unlikely to affect the early season formation of subnivean space over woody shrubs or large woody debris. Until there is a deep snow cover, recreationists tend to avoid woody shrubs as they are difficult to move through and logs can be difficult to cross because of breaking into the subniveal space. Later in the season as snow depth increases, recreational use of these sites probably has a minimal effect due to the snow depth (as seen in pits 14-18).

Not all subnivean animals are restricted to the subnivean environment. In the tundra of Alaska, temporarily enlarged winter claws enable *Dicrostonyx* lemmings to dig tunnels up through harder layers of snow (Pruitt 1984). However, no burrows constructed by voles or shrews were observed in the basal or upper layers of snow within the pits. Burrows dug by voles descended into the soil.

Niveal (in the snow) burrows constructed by gophers (*Thomomys spp*) were observed at Perazzo Meadows, Page Meadows, and Mount Rose Meadows. The tunnels were observed at a variety of heights above the ground (5-12 cm) in the wall of the study pits. Gophers have long claws, which facilitate their digging in hard snow. When

Photo 11. A gopher's niveal tunnel dug beneath a groomed snowmobile trail in Perazzo Meadow.

excavated, many of the tunnels were extensive.

The material inside the tunnels consisted of a loose or solid mix of dirt, dead vegetation, and occasionally gopher scat. A careful search of the material from multiple tunnels did not reveal any vole scat. Shrew scat would most likely be too indistinct to detect in such material. Subniveal space was observed beneath the dirt core of some niveal burrows, especially as they descended down toward the soil surface. It is unknown whether voles or shrews used this space or used the gophers' fossorial burrows that connected to the niveal tunnels.

Recreation use did not appear to affect niveal burrows as they were noted in areas with concentrated snowmobile use in Mount Rose. Subsequent to this study, on April 27, 2004, a niveal gopher burrow was observed at Perazzo Meadow traversing under a groomed snowmobile trail located on a hard surface road.

The actions of the subniveal animals themselves appear to create subnivean space. Vole runways depressed into the ground sometimes contributed several centimeters to the measured height of the subnivean space. It was unclear whether repeated use contributed to the runways' depression or whether they were excavated into the ground.

Photo 12. Some pits were constructed over water.

The configuration of the measured subnivean space was disjunct and highly variable. Whether subnivean animals use the available spaces and how they move from one area of open space to another is unknown. Grass vole nests observed on the surface of Mount Rose meadow following snowmelt suggests that voles do occupy the space between the basal snow layer and ground. Although a network of depressed runways could facilitate travel under the snow, it seems unlikely that voles could forage effectively where the snowpack rests directly on the soil surface. These findings suggest the importance of food hoarding for winter survival of active subnivean mammals such as shrews and voles (Vander Wall 1990).

Recommendations for Future Studies

This study was specifically designed to examine the effects of established winter recreation use as it actually occurs over time. However, relying on "natural" use patterns created several problems, including the lack of control pits at Mount Rose meadow. Because it was unknown exactly where the recreational use would occur for each site, pit locations could not be delineated prior to snowfall. Therefore, vegetation community type could not be predicted and could only be determined once

Photo 13. Riparian shrub habitat in which snow pits were dug.

a pit was dug. Even in study areas well known to the primary investigator, problems were still encountered. For example, several late season (March) pits dug at Page Meadows were placed over pools of water even though efforts were made to avoid them

Digging pits was labor and time intensive. The number of pits that could be dug each day depended on snow depth and on weather. Fewer pits were dug in deep snow and in harsh weather conditions. Ideally, the ram penetrometer could be used to characterize the snowpack density, thus precluding the need to dig snow pits. However, the ram was ineffective at detecting subnivean space in the maritime snow conditions. The ram could not be used to detect mechanically formed space at the base of the snowpack in riparian shrub habitat as its downward progress was blocked by a network of unseen limbs.

If additional work is conducted, consideration should be given to excavating linear trenches, which might allow sampling in the same pit for both use and non-use. Conducting the snow pit survey from January through April might have confounded the investigation by increasing the number of variables. Future research should consider increasing the number of pits dug to produce statistical significance and limiting seasonal variability by concentrating pit digging in one month.

It was not possible to perform a multifactorial analysis in this study because the importance of snow depth and vegetation type on the formation of subnivean space was not understood. Therefore, any future study must identify vegetation type prior to snowfall. The best method to locate pits in known vegetation types would require a detailed vegetation map with significant areas of each vegetation type so that pits could be accurately sited. However, staking sites before snow cover is impractical because of the labor required to maintain the stakes as snow depth increases and because people could move the stakes.

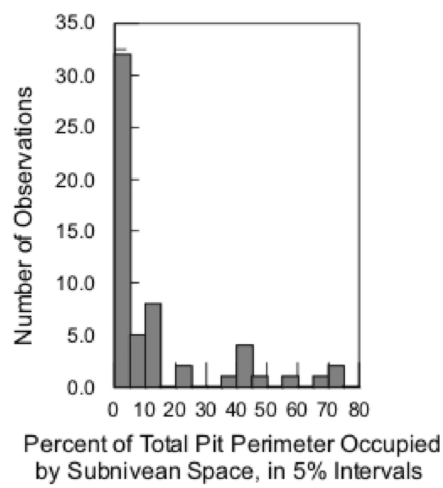


Figure 8. Histogram of the distribution of percent of pit perimeter occupied by subnivean space.

Percent of the pit perimeter occupied by subnivean space appears to be a useful metric in evaluating the effects of recreational use. However, data from this study show that the variable is highly skewed (Figure 8), and non-parametric tests may be required. It should be possible to design a multifactorial study that would evaluate the statistical significance of snow depth, vegetation type, and recreational use. A controlled study with recreational use simulated in known environments is likely to provide the best results. Natural recreation use patterns do not allow for sufficient comparison of recreation type, vegetation type, and snow depths. However, the time and expense required would be greater than this study, and excluding regular recreationists from a site to maintain a control location could be problematical.

Potential future research should investigate the winter use of dry meadow habitat by subnivean animals. If subnivean animals migrate out of these sites, then winter recreation use is likely to have a reduced or no effect on these animals.

Recommendations for Management

Vegetation community types should be considered in managing winter recreation use in the Sierra Nevada. This study strongly suggests that wet meadows at low elevations with low snow depth probably have the most subnivean space. This study's findings were not as conclusive regarding the effects of recreational use on subnivean space. But there is some suggestion that winter recreation may impact subnivean space at low elevations. Winter recreation probably has the greatest effect at low snow depths. Further research is needed to produce data that can be tested for statistical significance, with controlled variables, and even distribution of snow pits among the recreational use categories, snow depth, and vegetation types.

Literature Cited and Personal Communication

Biodiversity Legal Foundation. 1995. Comments on the Draft Revised Forest Plan (DRFP) and Draft Environmental Impact Statement (DEIS) for the Rio Grande National Forest. Boulder, CO.

Bluewater Network. 1999. Petition to prohibit snowmobiling and road grooming in national Parks. January 21, 1999.

Bolshakov, V.N. 1984. Winter ecology of small mammals in the Ural Mountains. In *Winter Ecology of Small Mammals*, Special Publication No. 10, J.F. Merritt (Ed.). Carnegie Museum of Natural History, Pittsburgh, pp.1-8.

Greater Yellowstone Winter Working Wildlife Group. 1999.

Jarvinen, J.A. and W.D. Schmid. 1971. Snowmobile use and winter mortality of small mammals. Pp. 133-140 in proceedings 1971 Snowmobile and off-road vehicle research symposium. Michigan State Univ. Dept. Park and Recr. Resource. Tech Rep. 8.

Joslin, G. and H. Youmans, coordinators. 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.

Manley, P.N. and M.D. Schlesinger. 2001. Riparian Biological Diversity in the Lake Tahoe Basin. Final report for the California Tahoe Conservancy and the U.S. Forest Service Riparian Grant # CTA-3024.

Marchand, P. 1991. *Life in the Cold An Introduction to Winter Ecology*, second edition. University Press of New England, Hanover and London.

Newman, P.W. and H.G. Merriam. 1972. Ecological effects of snowmobiles. Trans. N. Amer. Wildl. and Nat. Resource. Conf. 32:429-433.

Rongstad, O.J. 1980. Research needs on environmental impacts of snowmobiles. In Andrew, N.L. Richard, and P. Nowak. Off-road vehicle use: A management challenge. U.S. Department of Agriculture, Office of Environmental Quality, Wash. D.C.

Picton, H.D. 1999. Energetic cost of displacement to wildlife by winter recreation. In S.T. Olliff and K.L. Legg (Eds). The Effects of winter recreation on wildlife: a literature review and assessment. National Park Service, Yellowstone National Park.

Pruitt, W.O. Jr. 1984. Snow and small mammals. In *Winter Ecology of Small Mammals*, Special Publication No. 10, J.F. Merritt (Ed.). Carnegie Museum of Natural History, Pittsburgh, pp.1-8.

Pruitt, William. Personal communication. January 20, 2004. Department of Zoology, The University of Manitoba, Winnipeg, Manitoba, Canada.

Schmid, W.D. 1971. Modifications of subnivian microclimate by snowmobiles. Pages 251-257 in Proceedings of Snow and Ice Symposium. Coop. Wildl. Res. Unit, Iowa State Univ., Ames.

Snowmobile Effects on Wildlife – Monitoring Protocols Workshop. April 10-12, 2001. Missoula, Montana.

Stateline Snowmobile Environmental Assessment 1996. Lolo National Forest, Missoula, Montana.

Sturm, M. Holmgren, J. Konig, and Liston, G.E. 1995. A seasonal snow cover classification system for local to global applications. J. Climate, 8, 1261-1283.

United States Department of Agriculture (USDA). 1980. Department of the Interior/Grand Teton National Park. Alternatives for the management of oversnow vehicle use.

-----1996. Voyageurs National Park. Restricted Winter Use Report. National Park Service/Voyageurs National Park.

-----1999a. Biological evaluation for birds and mammals Little Truckee Summit parking lot expansion project. Sierraville Ranger District, Tahoe National Forest. June 1, 1999.

-----1999b. Biological evaluation birds, mammals, amphibians, reptiles, fish, invertebrates, Donner Summit snow-park expansion project. Truckee District, Tahoe National Forest. June 30, 1999.

Vander Wall, S. 1990. Food hoarding in animals. The University of Chicago Press. Chicago, IL. 445 p.

Wanek, W.J. and L.H. Schumacher. 1975. A continuing study of the ecological impact of snowmobiling in northern Minnesota. Final Research Report for 1974-1975. Bemidji State College, Bemidji, MN.

Acknowledgements

Wildlife Resource Consultants would like to thank the following people for help with this project:
Kelly Elder, Research Hydrologist, Rocky Mountain Research Station, USDA Forest Service, Fort Collins, CO; Randal Osterhausser, Central Sierra Snow Laboratory, University of California Berkeley, Soda Springs, CA; Jeff Wiley, Recreation Specialist, Tahoe National Forest, Sierraville, CA; Rick Maddalena, Recreation Officer, Tahoe National Forest, Truckee, CA; Molly Hurt, Wildlife Biologist, Victor Lyon, Wildlife Biologist, Mary Morgan, Engineering, USFS Lake Tahoe Basin Management Unit, South Lake Tahoe, CA; and Brandon Grove, Scott Scheibner, technicians. Matt Kiesse of River Run Consulting, Truckee, CA, performed data analysis, report writing and formatting.

Appendix A

Table 2. Snow pit characteristics.

Pit No.	Location	Date	Total Snow Depth (cm)	Snow Depth Class*	Rec. Use	Vegetation Community	Percent of Pit Perimeter With Subnivean Space (>1cm in height)	Mean Height of Subnivean Space (cm)	Subnivean Mammal Use Class**	Notes on Subnivean Mammal Use
1	Page Meadows	16 Jan	134	3	Cccs	Dry meadow	8.2	1.7	0	-
2	Page Meadows	16 Jan	127	3	None	Dry meadow	0	0	0	-
3	Perazzo Meadow	17 Jan	81	2	Cosv	Silver sage	24.7	2.9	0	-
4	Perazzo Meadow	17 Jan	79	2	Osv	Silver sage	8.8	1.6	0	-
5	Perazzo Meadow	17 Jan	85	2	Osv	Dry meadow	0.5	0	0	-
6	Perazzo Meadow	24 Jan	75	2	Osv	Dry meadow	0	-	0	-
7	Perazzo Meadow	24 Jan	70	2	Osv	Dry meadow	0	0	0	-
8	Perazzo Meadow	24 Jan	68	2	None	Wet meadow	8.2	1.4	0	-
9	Perazzo Meadow	24 Jan	71	2	Osv	Wet meadow	5.3	1.0	0	-
10	Perazzo Meadow	24 Jan	78	2	Osv	Wet meadow	40.3	5.0	0	-
11	Perazzo Meadow	24 Jan	75	2	None	Wet meadow	5.0	1.7	0	-
12	Page Meadows	25 Jan	150	3	None	Wet meadow	0	0	0	-
13	Page Meadows	25 Jan	158	4	Cccs	Wet meadow	0	0	0	-
14	Page Meadows	25 Jan	101	3	None	Riparian shrub	65.8	6.4	0	-
15	Page Meadows	25 Jan	115	3	None	Riparian shrub	0	0	0	-
16	Perazzo Meadow	6 Feb	177	4	None	Riparian shrub	63.0	6.9	0	-
17	Perazzo Meadow	6 Feb	138	3	Osv	Riparian shrub	62.4	Data not collected due to weather	0	-
18	Perazzo Meadow	6 Feb	119	3	None	Riparian shrub	66.9	Data not collected due to weather	0	-
19	Trout Creek	11 Feb	59	1	None	Wet meadow	20.4	2.9	1	Vole runway
20	Trout Creek	11 Feb	51	1	Cccs	Wet meadow	5.2	3.7	0	-
21	Trout Creek	11 Feb	52	1	Cccs	Wet meadow	12.3	2.1	0	-
22	Trout Creek	11 Feb	55	1	None	Wet meadow	11.9	4.1	2	Multiple vole runways

Table 2. Snow pit characteristics (cont.)

Pit No.	Location	Date	Total Snow Depth (cm)	Snow Depth Class*	Rec. Use	Vegetation Community	Percent of Pit Perimeter With Subnivean Space (>1cm in height)	Mean Height of Subnivean Space (cm)	Subnivean Mammal Use Class**	Notes on Subnivean Mammal Use
23	Trout Creek	11 Feb	49	1	Ccs	Wet meadow	14.3	4.6	2	Multiple vole runways and burrow
24	Trout Creek	11 Feb	59	1	None	Wet meadow	68.8	2.9	0	-
25	Trout Creek	11 Feb	57	1	Ccs	Wet meadow	70.0	3.1	2	Multiple vole runways, grass nest
26	Trout Creek	11 Feb	61	1	None	Wet meadow	43.5	2.7	0	-
27	Trout Creek	20 Feb	47	1	None	Wet meadow	59.9	4.3	2	Multiple vole runways, grass nest
28	Trout Creek	20 Feb	37	1	Cccs	Wet meadow	13.2	2.8	1	Vole runway
29	Trout Creek	20 Feb	50	1	None	Wet meadow	71.1	3.4	2	Multiple vole runways
30	Trout Creek	20 Feb	39	1	Cccs	Wet meadow	24.2	1.7	0	-
31	Trout Creek	20 Feb	37	1	Cccs	Wet meadow	36.5	2.4	2	Multiple vole runways and burrows
32	Trout Creek	20 Feb	50	1	None	Wet meadow	45.7	2.3	1	Burrow
33	Trout Creek	20 Feb	30	1	Cosv	Wet meadow	43.5	2.0	2	Burrows
34	Trout Creek	20 Feb	50	1	None	Wet meadow	43.1	3.0	2	Burrows
35	Perazzo Meadow	21 Feb	109	3	None	Dry meadow	0	0	0	-
36	Perazzo Meadow	21 Feb	115	3	Osv	Wet meadow	0	0	0	-
37	Perazzo Meadow	21 Feb	104	3	Osv	Dry meadow	14.7	1.8	1	Dirt filled niveal tube
38	Perazzo Meadow	21 Feb	180	4	Osv	Riparian shrub	26.8	3.4	0	-
39	Molly Meadow	8 Mar	65	2	Cosv	Dry meadow	4.0	3	2	Vole runway, grass-filled niveal tube
40	Molly Meadow	8 Mar	66	2	Osv	Wet meadow	13.5	6.7	0	-
41	Molly Meadow	8 Mar	81	2	None	Dry meadow	0	0	0	-
42	Molly Meadow	8 Mar	71	2	Cosv	Dry meadow	2.2	3.8	2	Burrows, dirt niveal tube
43	Molly Meadow	8 Mar	69	2	Osv	Dry meadow	12.6	4.4	0	-
44	Molly Meadow	8 Mar	44	1	Cosv	Wet meadow	10.9	2.5	0	-

Table 2. Snow pit characteristics (cont.)

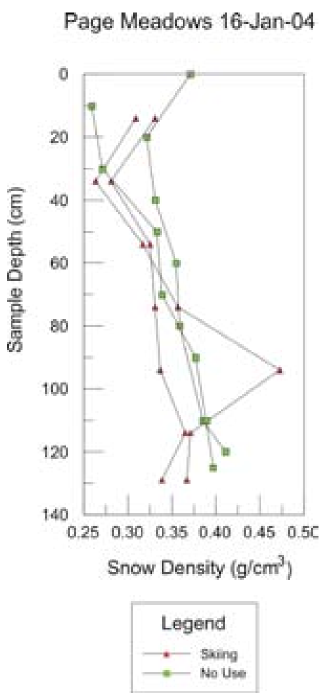
Pit No.	Location	Date	Total Snow Depth (cm)	Snow Depth Class*	Rec. Use	Vegetation Community	Percent of Pit Perimeter With Subnivean Space (>1cm in height)	Mean Height of Subnivean Space (cm)	Subnivean Mammal Use Class**	Notes on Subnivean Mammal Use
45	Molly Meadow	8 Mar	59	1	Cosv	Dry meadow	2.9	2.0	0	-
46	Molly Meadow	8 Mar	62	1	Cosv	Dry meadow	0	0	0	-
47	Molly Meadow	8 Mar	67	2	None	Wet meadow	0	0	0	-
48	Molly Meadow	8 Mar	62	1	None	Dry meadow	2.3	1.0	1	Tunnel impression in snow
49	Page Meadows	12 Mar	162	4	Ccs	Dry meadow	0	0	1	Dirt niveal tube
50	Page Meadows	12 Mar	168	4	Ccs	Dry meadow	0	0	0	-
51	Mount Rose	19 Mar	176	4	Ccs	Dry meadow	4.4	-	0	-
52	Mount Rose	19 Mar	186	4	Ccs	Wet meadow	0	0	0	-
53	Mount Rose	19 Mar	136	3	Ccs	Wet meadow	0	0	0	-
54	Mount Rose	19 Mar	128	3	Ccs	Wet meadow	0	0	1	Vole runway
55	Mount Rose	23 Mar	175	4	Cosv	Wet meadow	0	0	2	Vole runway, dirt-filled niveal tube
56	Mount Rose	23 Mar	193	4	Cosv	Wet meadow	0	0	0	-
57	Mount Rose	23 Mar	180	4	Osv	Wet meadow	1.4	1.0	0	-
58	Mount Rose	23 Mar	171	4	Osv	Wet meadow	0	0	0	-
59	Mount Rose	23 Mar	166	4	Osv	Wet meadow	0	0	0	-
60	Mount Rose	2 Apr	135	3	Ccs	Dry meadow	0	0	0	-
61	Mount Rose	2 Apr	142	3	Ccs	Dry meadow	0	0	0	-
62	Mount Rose	9 Apr	102	3	Ccs	Wet meadow	0	0		Dirt filled niveal tube
63	Mount Rose	9 Apr	107	3	Ccs	Wet meadow	0	0	1	Dirt filled niveal tube
64	Mount Rose	9 Apr	83	2	Osv	Wet meadow	0	0	0	-
65	Mount Rose	9 Apr	88	2	Ccs	Wet meadow	0	0	0	-

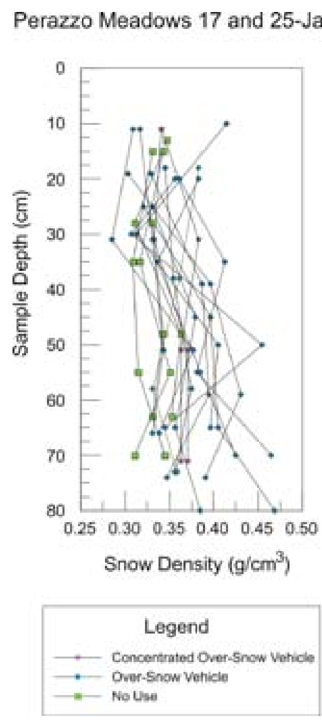
*Snow Depth Class
1:0-64cm
2:65-100cm
3:101-150cm
4:>150cm

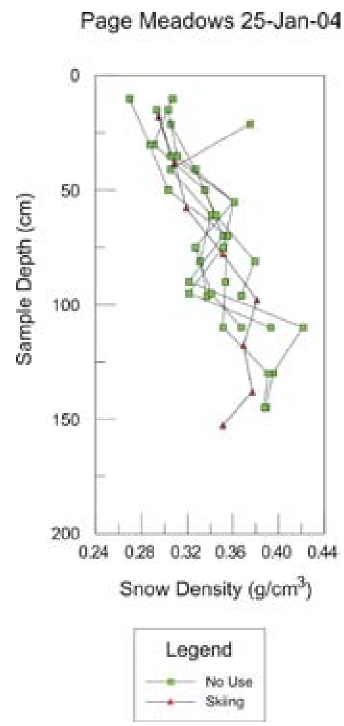
**Small Mammal Use Code
0:No sign
1: Low to Moderate
2: Heavy Use

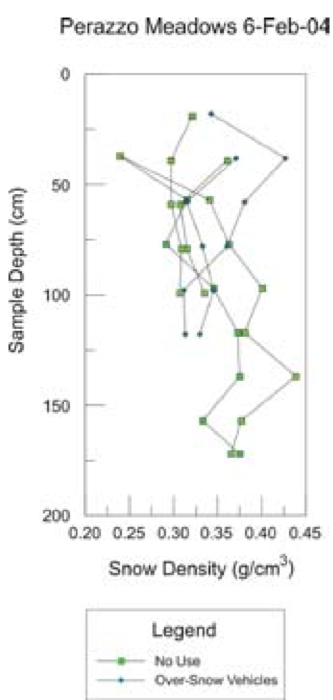
Appendix B

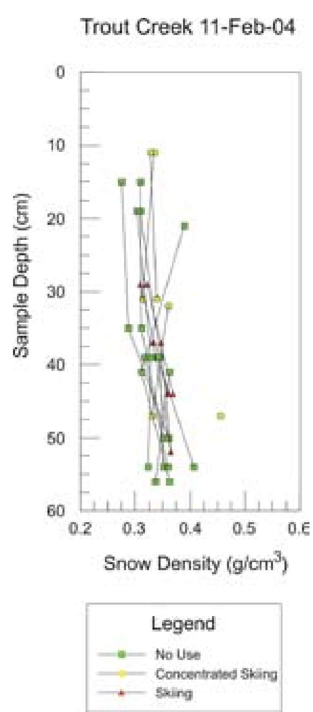
Density-Depth Profiles



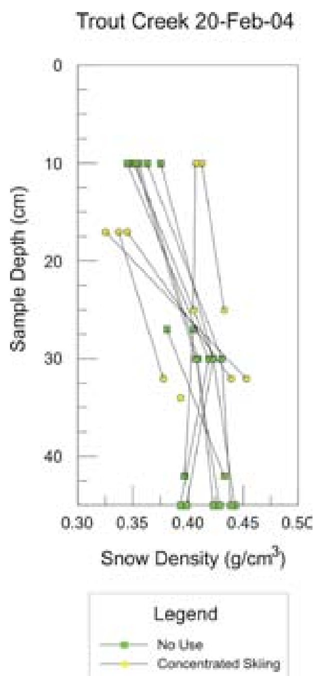


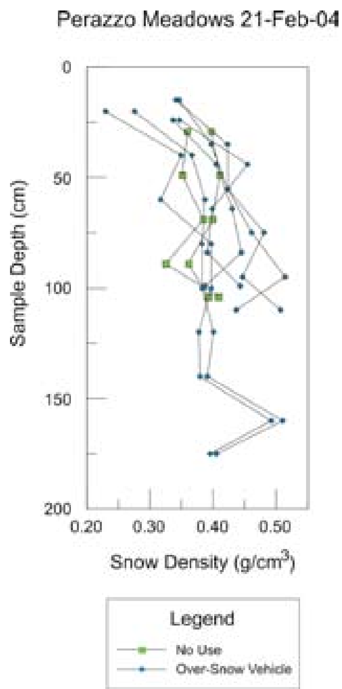


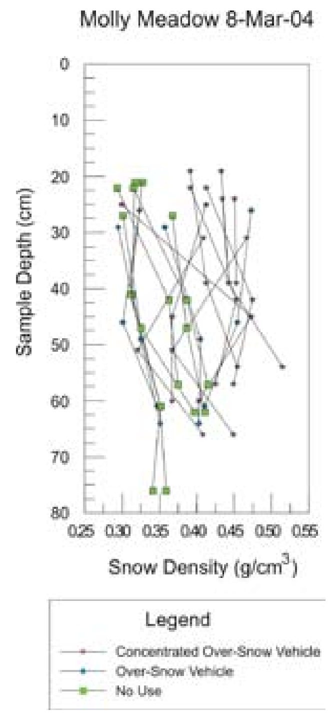


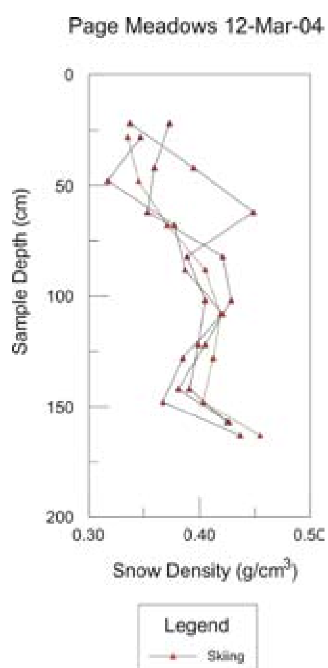


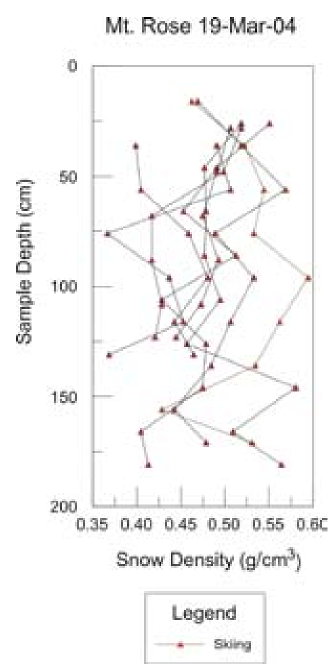
Density-Depth Profiles (cont.)



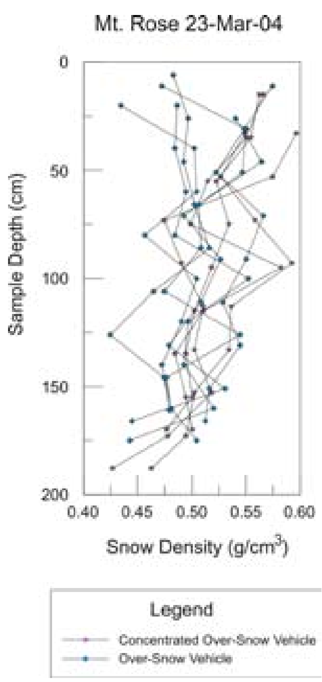


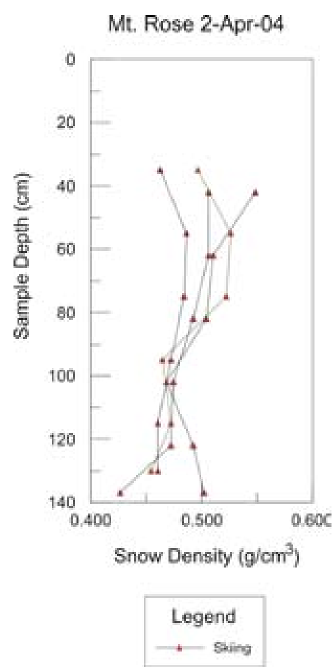


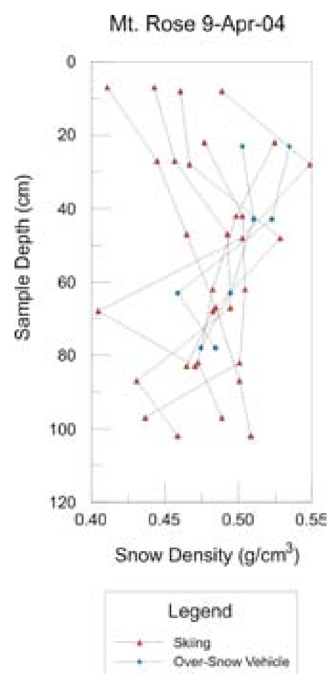




Density-Depth Profiles (cont.)

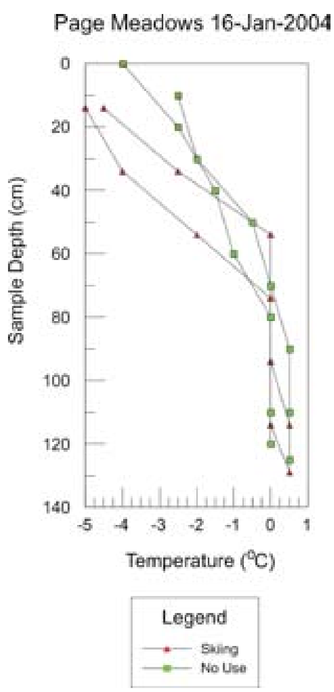


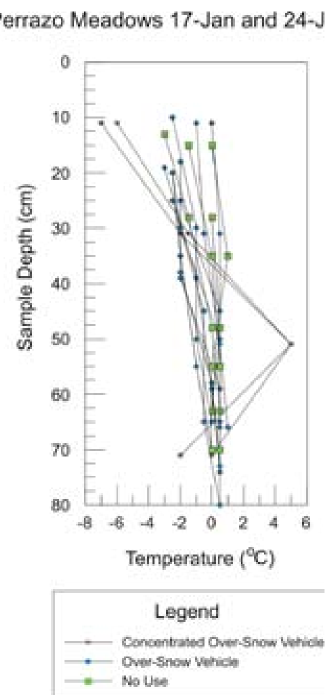


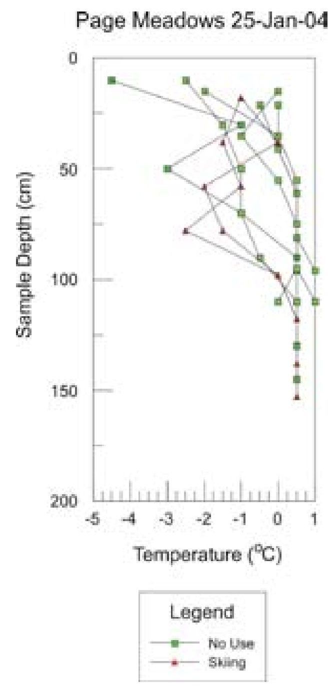


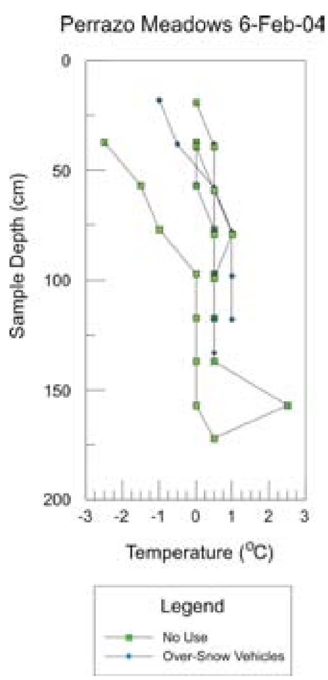
Appendix C

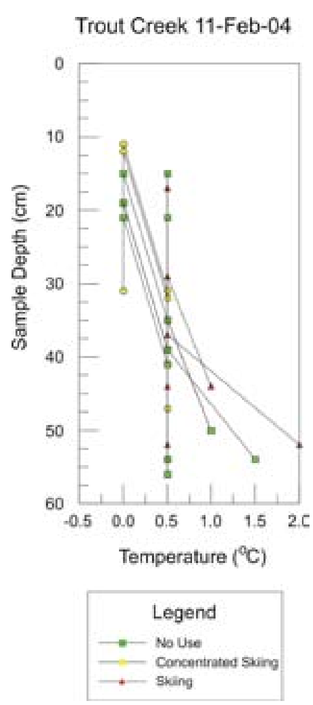
Temperature-Depth Profiles



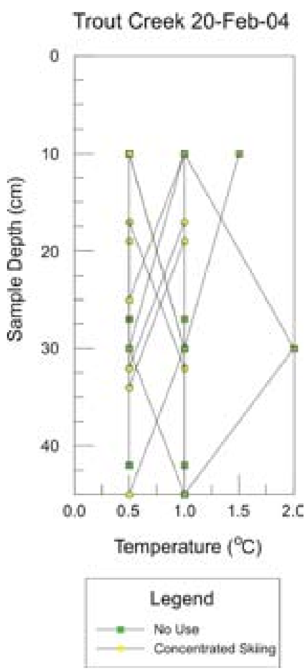


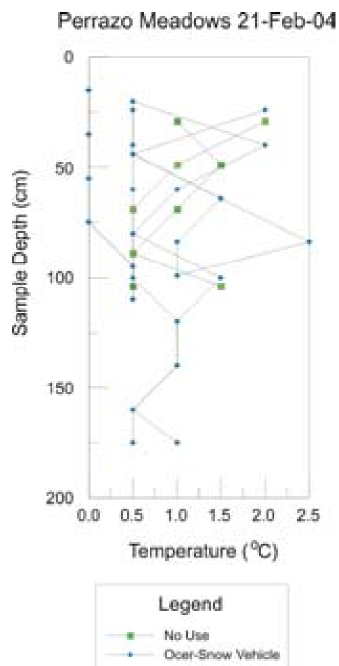


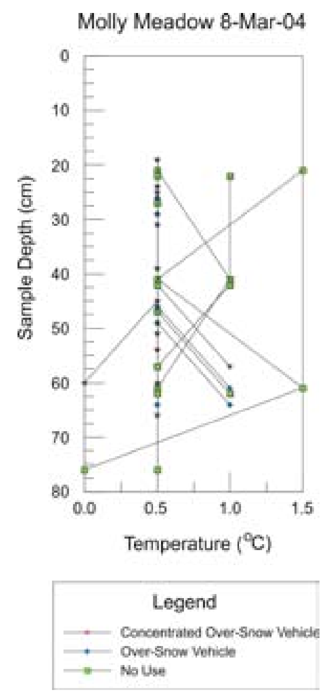


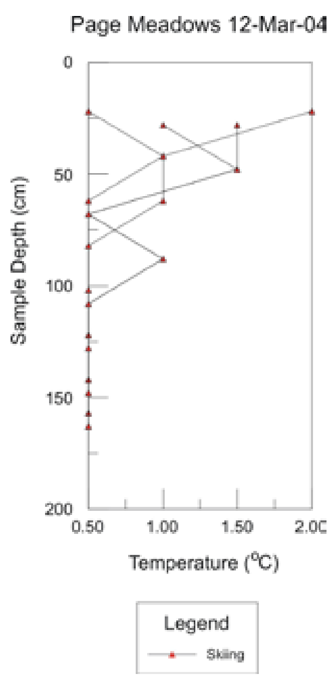


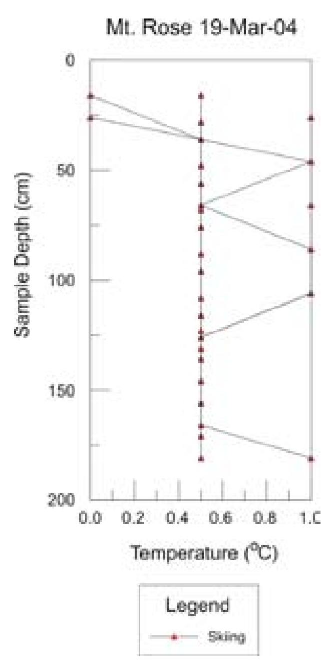
Temperature-Depth Profiles (cont.)











Temperature-Depth Profiles (cont.)