Research Studies Related to Snowmobiling Impacts

WILDLIFE – Carnivores, Goats, Sheep, Rabbits and Subnivean

Mammals / Mid-Sized Carnivores (Wolverine, Fisher, Marten, Lynx, Bobcat, Red Fox, and Weasel)

1. **Effects of Winter Recreation on Mid-Sized Carnivores (Wolverine, Fisher, Marten, Lynx, Bobcat, Red Fox, and Weasel).** (1999) Effects of Winter Recreation on Wildlife of the Greater Yellowstone Area: A Literature Review and Assessment. Olliff, T., Legg, K. & Kaeding, B. Greater Yellowstone Coordinating Committee, Yellowstone National Park. pp. 65-71. http://www.nps.gov/yell/parkmgmt/upload/wildlifewint.pdf

Potential Effects: Mortality resulting from an accidental collision with a snowmobile is possible, but the probability is low. Intentional killing of carnivores by a snowmobiler is possible, but most likely it would occur in rare, isolated incidents.

Management Guidelines: A literature search produced little information on how winter recreational activities impact carnivores; research on carnivores is extremely expensive and is mostly non-existent on mid-sized carnivores.

Mammals / Wolves, Gray

1. **Effects of Winter Recreation on Gray Wolves.** (1999) Effects of Winter Recreation on Wildlife of the Greater Yellowstone Area: A Literature Review and Assessment. Olliff, T., Legg, K. & Kaeding, B. Greater Yellowstone Coordinating Committee, Yellowstone National Park. pp. 31-35. http://www.nps.gov/yell/parkmgmt/upload/wildlifewint.pdf

Potential Effects: Conflicts could occur when routes groomed for snowmobiles bisect habitats used by wolves in the winter, affecting wolf movements and foraging patterns. Moreover, grooming of roads and trails may affect ungulate movements (Meagher 1993), and this may influence wolf movements as well. Areas of particular concern are ungulate concentration sites where winter-killed carcasses are available. These include both geothermally influenced and low-elevation sites. Wolf activity could be affected in ungroomed areas used by snowmobiles. Although areas of ungroomed snowmobile use typically occur at high elevations where wolves do not occupy winter habitats, there is potential for conflicts between wolves and recreationists if winter snowmobiling occurs on low-elevation or geothermally influenced ungulate winter range. Impacts would also occur if wolves were deliberately chased by recreationists on snowmobiles.

Management Guidelines: New groomed motorized routes should be located in areas that are not classified as ungulate winter range or important wolf habitat. Grooming and use of snowmobile roads and trails should end between March 15 and April 1, allowing wolves to use spring denning sites without harassment. Dispersed motorized use should not occur on or near ungulate winter range or on spring range after wolf denning begins, usually between March 15 and April 1.

Mammals / Mountain Goats

1. **Effects of Winter Recreation on Mountain Goats.** (1999) Effects of Winter Recreation on Wildlife of the Greater Yellowstone Area: A Literature Review and Assessment. Olliff, T., Legg, K. & Kaeding, B. Greater Yellowstone Coordinating Committee, Yellowstone National Park. pp. 87-96. http://www.nps.gov/yell/parkmgmt/upload/wildlifewint.pdf

Potential Effects: Because of the remote and rugged nature of goat wintering habits, recreational use of such areas is unlikely. Because mountain goats are sensitive to loud noises, snowmobiles and helicopters could affect their behavior depending upon the proximity and duration of the disturbance. In most cases, it appears that wilderness designation and area use limitations have adequately protected mountain goat habitats from motorized-related disturbances in the Greater Yellowstone Area. Because mountain goat winter range is inaccessible and precipitous, goats and recreationists are not often coming into conflict. For recreation, humans tend not to seek the combination of rocky, rugged terrain, and low-snow conditions required for by mountain goats. Rather, snowmobilers and skiers prefer deep snow conditions, which are typically avoided by goats.

Management Guidelines: No immediate management recommendations are offered.

Mammals / Mountain (Bighorn) Sheep

1. **Effects of Winter Recreation on Bighorn Sheep.** (1999) Effects of Winter Recreation on Wildlife of the Greater Yellowstone Area: A Literature Review and Assessment. Olliff, T., Legg, K. & Kaeding, B. Greater Yellowstone Coordinating Committee, Yellowstone National Park. pp. 5-9. http://www.nps.gov/yell/parkmgmt/upload/wildlifewint.pdf

Potential Effects: Bighorns may abandon high quality winter range that is heavily used by humans, or they may limit their use to a small area near escape terrain.

Management Guidelines: Skiing, snowmobiling, mountaineering, and snowshoeing will most likely only affect bighorn sheep wintering at higher elevations. The encounters between these recreationists and the bighorns may be infrequent enough that there would be little or no impact to the animals. However, if use increases at these higher elevation winter ranges, managers need to monitor the situation in order to prevent the loss of bighorn sheep on isolated winter ranges; human activities should be limited to roads or trails to minimize disturbance to bighorn sheep.

2. **How off-highway vehicles affect mountain sheep.** Laing, M. E. (1992) National Off-Highway Vehicle Conservation Council**:** 1-2 http://nohvcclibrary.forestry.uga.edu/SCANNED%20FILES/W-0014-how%20OHV%20affect%20mt.%20sheep.pdf

Abstract: A NOHVCC Fact Sheet summarizing one study in Alberta of sheep response. Humans on foot, humans with dogs, and humans approaching from above (over a ridge) proved to be more disturbing than motor vehicle traffic.

3. **Cardiac and behavioral responses of mountain sheep to human disturbance**. Macarthur, R. A., Geist, V., & Johnston, R. H. (1982). Journal of Wildlife Management., 46(2), 351-358. http://nohvcclibrary.forestry.uga.edu/SCANNED%20FILES/W-0039pdf.pdf

Abstract: Telemetered heart rates and behavioral responses of mountain sheep were recorded in response to human disturbance in the Sheep River Wildlife Sanctuary in S.W. Alberta. Cardiac and behavioral responses of sheep to an approaching human were greatest when the person was accompanied by a dog or approached sheep from over a ridge. Because the road is the focal point of human activity in the sanctuary, few responses were observed in reaction to traffic or approach by humans walking directly from a parked vehicle. Similarly, there were no responses to helicopters or fixed winged aircraft at distances >400m from the sheep. This shows that wildlife respond to the predictability of humans.

4. **Observations on the decline of the Rock Creek, Montana, population of bighorn sheep.** Berwick, S. H. (1968). University of Montana, Missoula: 245pp.

Abstract: Among factors that may be responsible for an observed decline in a Montana bighorn sheep population are human disturbance and harassment of sheep. Snowmobile use of an important segment of sheep winter range is increasing. It is suggested that harassment may be debilitating to winter-stressed animals.

Mammals / Rabbits

1. **Effect of snowmobile noise and deer and rabbits in their natural habitat**. Bollinger, J. (1974)

Abstract: The behavioral patterns of deer and rabbits before, during, and after extensive snowmobile activities were studied. The data gathered was used to assess the noise wildlife levels associated with various behavior patterns, and to assess the noise levels generated by different snowmobile uses on various types of terrain. Additional objectives were to determine the effects snowmobile noise and activity had on the home range of the deer and rabbits and their seasonal movements; to determine the reactions these animals had to men in the area not using snowmobiles but equipped with skis and snowshoes; and to determine if there was a difference in predator behavior in areas where snowmobiles were used versus those where no vehicles were operated. The research team was unable to detect a severe or negative animal reaction to noise generated by vehicles. Conclusions of the study indicate that the deer and rabbits were not forced to move out of their normal home ranges, nor did they seek shelter or remain stationary with fright while snowmobiles were being operated. The only negative effect determined was that the animals did increase their movement during extensive vehicle use periods. Researchers were unable to determine whether it was the noise, physical presence or both that caused the disturbance.

Mammals / Subnivean (under-the-snow)

1. **Winter Recreation Effects on the Subnivean Environment of Five Sierra Nevada Meadows.** Wildlife Resource Consultants, (2004) U.S. Forest Service, Lake Tahoe Basin Management Unit.

Study 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 that 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. Impacts from snowmobile use have received the most attention and include concern that the compaction of snow destroys the subnivean environment, which reduces temperatures leading to increased metabolic rates, restricts movement, suffocates animals, and increases winter mortality.

Most of typically listed 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, bison, white-tailed deer, lynx), and wildlife use naturally decreases because many animals hibernate (e.g., black bears) or migrate (e.g., mule deer) 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, and pine marten. 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.

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 of the study.

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. One pit (Number 14; Page Meadows; January 25) intentionally excavated over a large down log (estimate > 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).

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. 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.

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. 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 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 Snowmobile	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%

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. Pits dug in riparian shrub communities had the highest percent of the pit perimeter occupied by subnivean space, and the highest 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.

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

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. 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.

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. 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.

Excluding pits dug in the shrub vegetation community types, average percent perimeter occupied by subnivean space was calculated for all sites by recreational use, 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 significant conclusions within this study.

Snow Density – A scatter-plot of all density samples in all pits was constructed. 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. 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 oversnow 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.

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. There is no detectable relationship in the scatter-plot between recreational use and temperature.

Profiles of temperature by depth were also plotted for each pit. 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. Ram profiles generally agreed with directly measured profiles, and contain more detail. However, there was no evidence that the ram penetrometers can accurately detect the presence of subnivean space.

STUDY SUMMARY 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.

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?

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 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.

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).

<u>Recommendations for Future Studies:</u> 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 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.

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 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.

2. **Effects of Winter Recreation on Subnivean Fauna.** (1999) Effects of Winter Recreation on Wildlife of the Greater Yellowstone Area: A Literature Review and Assessment. Olliff, T., Legg, K. & Kaeding, B. Greater Yellowstone Coordinating Committee, Yellowstone National Park. pp. 97-99. http://www.nps.gov/yell/parkmgmt/upload/wildlifewint.pdf

Potential Effects: Most research relating to the impacts of winter recreation on subnivean fauna has concerned the effects of snow compaction due to snowmobiles on the animals. One of the potential impacts of snow compaction is alteration of the snow microclimate, especially the physical and thermal aspects (Corbet 1970). Some possible changes in snow conditions resulting from snow compaction include a decrease in subnivean air space, a change in temperature, and accumulation of toxix air under the snow (Jarvinen and Schmid 1971, Schmid 1971a and b).

According to Halfpenny and Ozanne (1989), skiers may do more damage to the snowpack than snowmobilers because narrow skis cut deeper into the snowpack and because skis have a greater footload (amount of weight per surface area) in comparison to a snowmobile track. For both ski tracks and snowmobile tracks, multiple passes over the same track will have more impact than a single pass.

Management Guidelines: The lack of information about impacts to subnivean mammals from winter use makes it difficult to draw conclusions…the only management guideline is to encourage more research on the subject.

3. **Ecological impacts of off-road recreation vehicles: Outdoor recreation research applying the results:** Brander, R. B. (1974)

Abstract: This paper focuses on the environmental impacts of snowmobiles. It is not a scientific study; instead the author infers some effects from existing literature on the structure and mechanics of snow and the significance of snow to small mammals and their predators. The insulation that snow provides is very important to small mammals which spend most of the winter at the ground and snow interface. Mechanical compaction reduces snow depth and increases thermal conductivity and snow densities by destroying air spaces. This can result in loss of habitat and in some cases mortality in some small mammal populations. The decrease in small populations of small mammals can in turn negatively affect their predators, and on up the food chain. More scientific information is needed. Because snowmobiles accelerate the rate of environmental degradation compared to hikers, existing information should be used in making management decisions. One suggestion is to restrict traffic to a few trails and roads rather than allowing free access to fields, etc.

4. **Snowmobile activity, subnivean microclimate and winter mortality of small animals**. Schmid, W. D. (1972) Bulletin of Ecological Society of America, 53(2), 37.

Abstract: Mechanical compaction of snowfields by snowmobiles alters the mild subnivean microclimate and promotes densification of snow. The stress of winter temperatures may increase for organisms that live within or beneath these compacted snowfields and the densified snow may be a greater barrier to animal movement in the subnivean space. Experimental manipulation of a snowfield has shown that the winter mortalities of small mammals are markedly increased under snowmobile compaction. We recovered none of the twenty-one marked animals from the experimental plot, whereas eight of eighteen marked specimens were captured at least once on an adjacent control plot.

5. **Snowmobile use and winter mortality of small mammals.** Jarvinen, J. A. & Schmid, W.D. (1971) Paper presented at the M. Chubb, ed. Proceedings of the 1971 Snowmobile and Off the Road Vehicle Research Symposium, East Lansing, MI. Michigan State University.

Abstract: Trapping results in Minnesota showed increased winter mortality of small mammals beneath snowmobile compacted snowfields. It is suggested that compaction inhibits mammal movements beneath snow and subjects subnivean organisms to greater temperature stress. Report states that more information is necessary.