Environmental **Impacts** OF WINTER RECREATION

Best Available Science, May 2021

WINTER WILDLANDS ALLIANCE

Table of Contents

Introduction 3

Wildlife 4

UNGULATES 6

Elk and Deer 6

Moose 7

Woodland Caribou 8

Bighorn Sheep 8

Mountain Goats 11

CARNIVORES 13

Bears 13

Grey Wolf 14

Canada Lynx 15

Wolverine 17

Marten 18

Fisher 19

SUBNIVIAN MAMMALS 20

BIRDS 20

Soundscapes 23

Snowpack, Soils, and Vegetation 24

Snow Compaction 24

Soils 24

Vegetation 24

Air and Water Quality 26

Conclusion 28

Works Cited 29

Cover Photo: Sergey_Siberia88

Winter Recreation Impacts: A Comprehensive Survey

By Hilary Eisen, Darça Morgan, Kylie Paul, and Kristina Boyd

Studying the effects of winter recreation on the natural environment is a burgeoning field of scientific research. Studies show that winter recreation of all kinds can impact wildlife, which are particularly vulnerable to disturbance from unpredictable human activities such as off-trail snowmobiling or backcountry skiing. In addition, many papers have quantified ways in which over-snow vehicle (OSV) use can damage vegetation, compress soils, affect air and water quality, and disrupt natural soundscapes.

The vast majority of dispersed winter recreation in the United States occurs on lands managed by the U.S. Forest Service. There are a number of administrative processes that provide opportunities to determine management of winter recreation activities on Forest Service lands. For example, as of 2015, the Forest Service is required to craft a winter travel management plan for each National Forest that receives sufficient snow to support winter recreation, designating specific routes and areas for over-snow vehicle use and prohibiting OSV use beyond the designated system. In designating OSV routes and areas, the Forest Service must comply with the minimization criteria as spelled out in Executive Orders 11644 and 11989.[1] These executive orders require the Forest Service to locate areas or routes that are designated for motorized use in a manner that:

1. **minimizes damage to soil, watershed, vegetation, and other resources of the public lands;**
2. **minimizes harassment of wildlife or significant disruption of wildlife habitats; and**
3. **minimizes conflicts between off-road vehicle use and other existing or proposed recreational uses of the same or neighboring public lands.**[2]

As climate change threatens – and shrinks – winter landscapes, and as population decline continues among certain threatened species, it is particularly important to understand how winter recreation activities impact wildlife and the environment, as we cannot minimize impacts if we do not understand them. The following report summarizes findings from the best-available science related to undeveloped (non-resort) winter recreation.

1 36 C.F.R. §§ 212.1, 212.81(d), 212.55(b).

2 Exec. Order No. 11644, § 3(a), 37 Fed. Reg. 2877 (Feb. 8, 1972), as amended by Exec. Order No. 11,989, 42 Fed. Reg. 26,959 (May 24, 1977).

Photo: KT Miller

Wildlife

For most species, winter is a difficult season. Food availability is scarce, quality is low, and animals are under considerable stress from cold and snow.[3] Animals have varying strategies for surviving the winter, but with the exception of the few species that are specifically adapted to life in the deep snow, most survival strategies boil down to one thing – exert as little energy as possible. For some, like bears and bats, this means hibernating. Other species, like elk and bighorn sheep, migrate to areas with low snow and limit their movement once they've reached these winter ranges.

Regardless of our intentions, many species perceive humans as a threat and respond accordingly. In general, animals respond to threats by first increasing vigilance (time spent looking around versus foraging), and running away if the threat is perceived to be imminent. Ciuti et al (2012) describes the 'landscape of fear' that animals live in, with increased recreation activity resulting in stress levels that exceed those caused by natural predators.[4] In general, wildlife tend to have stronger responses to less predictable forms of recreation (such as off-trail/off-road travel). Habitat generalists are less vulnerable to disturbance than habitat specialists, and pregnant females and young tend to be the most vulnerable.[5] In a literature review considering 274 peer-reviewed studies conducted world-wide, Larson et al (2016) found that 59% of documented recreation impacts on animals were negative[6]. Furthermore, Larson et al.'s review found that snow-based recreation had 1.3 times more evidence of negative effects than all other types of terrestrial recreation, with non-motorized recreation having 1.2 times more evidence of negative effects than motorized recreation. However, as motorized activities often cover larger spatial extents than non-motorized activities, and most studies did not compare effects across multiple spatial scales, Larson et al. qualify this comparison by stating that it is possible the impact of motorized winter recreation has been underestimated.[7]

One way that researchers quantify disturbance and stress in wildlife is to measure glucocorticoid (GC) concentrations. These hormones can affect behavior, immune function, foraging efficiency, glucose metabolism, and locomotion, all of which help an individual to cope in an unpredictable situation.[8] It is important to note that while measuring GC levels has long been the standard for evaluating stress in animals, these hormones respond to many short and long term changes within an animal's body, not all of which are relevant to recreation or whatever other potential stressors are being measured in a particular study.[9] Nonetheless, GC concentrations are the scientific standard for measuring stress in wildlife.

Researchers have found that daily GC levels in elk in Yellowstone National Park fluctuated in parallel with the variation in the number of snowmobiles after controlling for the effects of weather and age, and that both elk and wolves in Yellowstone exhibited a strong correlation between GC concentrations with snowmobile usage on both daily and annual time scales.[10] In this same study, researchers compared GC levels of wolves in Isle Royale National Park, where there are no snowmobiles, to those of wolves in Voyageurs National Park, where snowmobiling is pervasive. The Voyageurs wolves consistently exhibited higher levels of stress hormones, and when snowmobile use declined in Voyageurs between two winter seasons, there was a corresponding drop in fecal GC concentrations within the park's wolf population.[11] Researchers have also documented increased GC levels in correlation with winter recreation in caribou[12] and moose.[13]

3 Goodrich, J.M.; Berger, J. 1994.

4 Ciuti, S., Northrup, J. M., Muhly, T. B., Simi, S., Musiani, M., Pitt, J. A., & Boyce, M. S. 2012.

5 Miller, A.B. King, D., Rowland, M., Chapman, J., Tomosy, M., Liang, C., Abelson, E.S. and Truex, R. 2020.

6 Larson, C.L., Reed, S.E., Merenlender, A.M., and Crooks, K.R. 2016.

7 *Id.*

8 Tomeo, M.A. 2000.

9 Bateman, P.W. and Fleming, P.A. 2017.

10 Creel, S., J. E. Fox, A. Hardy, J. Sands, B. Garrott, and R. O. Peterson. 2002.

11 *Id.*

12 Freeman, N. L. 2008.

13 Tomeo, M.A. 2000.

"Regardless of our intentions, many species perceive humans as a threat and respond accordingly."

Photo: Jami

While snowmobile (or general recreation)-caused stress has not yet been documented to be a chronic issue in wildlife, chronically elevated stress hormone levels can result in health and fitness costs.[14]

In addition to the direct physiological effects of disturbance, evidence suggests that popular winter trails can fragment habitat. Busy trails through core areas create an "edge effect" (the negative influence of the periphery of a habitat on the interior conditions of a habitat) and thereby marginalize the vitality of some species.[15] In Yellowstone National Park, heavy snowmobile traffic has been shown to inhibit free movement of animals across roads to preferred grazing areas and temporarily displaces wildlife from areas immediately adjacent to the roads[16]. Other studies have noted the displacement of elk along roads during periods of fairly continuous travel by snowmobiles[17] and displacement of moose from an area following the development of a Nordic ski trail system.[18]

UNGULATES

Ungulates migrate to areas with low or no snow in winter – this may entail a migration of several hundred miles, or one that is much shorter. Mountain goats, for example, remain in alpine terrain through the winter, seeking out windswept ridges to avoid deep snows. Regardless of the species, however, ungulate winter survival strategy hinges on gaining weight in the fall and expending as little energy as possible while they slowly starve their way through winter. Avoiding excess movement is particularly important, as deep snow can increase the metabolic cost of winter movement up to five times normal levels[19] at a time when ungulates are particularly stressed by forage scarcity and high metabolic demands.

Bighorn sheep and mountain goats may be particularly susceptible to winter recreation due to their specific habitat needs. These mountain ungulates typically live in harsher environments that are colder and receive more snow compared to places where deer, elk, and other ungulates reside. Additionally, sheep and goat habitat needs include rugged areas that are close to escape terrain, which subsequently limits the places they can inhabit and reduces forage availability.[20] Thus, winter range for mountain ungulates is an extremely limited resource.

Elk and Deer

Winter recreation can disturb elk and deer, causing them to change their behavior or flee. In one study elk responded to over-snow vehicles in Yellowstone National Park by increasing vigilance and running away from approaching machines.[21] A study conducted in Minnesota found that white-tailed deer responded to even low intensities of snowmobile activity, and that deer were more likely to change their behavior or flee as the amount of time that snowmobiles were in an area increased.[22] This disturbance resulted in displacement of deer from areas near snowmobile trails and increased home range sizes. However, another study of white-tail deer did not find any change in home-range size or habitat use by white-tailed deer where snowmobile activity was experimentally introduced, although snowmobile activity did cause some deer to leave the immediate vicinity of snowmobile trails.[23] Even if it does not bring significant changes in habitat use or home range, such flight poses an energetic risk for deer and other wildlife. And, as discussed earlier in this report, snowmobile use has been correlated with elevated GC levels in elk, demonstrating a potential impact even in cases when animals do not flee.

Elk are sensitive to disturbance from non-motorized winter recreation as well. Another study in Yellowstone recorded elk behavioral responses to people on foot and found that elk fled from small groups of hikers and cross-country skiers, with adult female elk exhibiting a stronger sensitivity to disturbance.[24]

Summer-season research has shown that off-road recreation, including hiking and ATV riding, has a significant effect on elk, increasing movement

14 *Id.*
15 Baker, E. and Bithmann, E. 2005.
16 Aune, K. E. 1981.
17 Knight, R.L., and D. N. Cole. 1991.
18 Ferguson, M. A., and Keith, L. B. 1982.
19 Parker, K.L., Robbins, C.T. and Hanley, T. A. 1984.
20 Hamel, S. and S.D. Côté. 2007
21 Borkowski, J. J., P. J. White, R. a Garrott, T. Davis, A. R. Hardy, and D. J. Reinhart. 2006.
22 Dorrance, M. J., P. J. Savage, and D. E. Huff. 1975.
23 Eckstein, R.G., T.F. O'Brien, O.J. Rongstad, and J.G. Bollinger. 1979.
24 Cassirer, E., Freddy, D., and Ables, E. 1992.

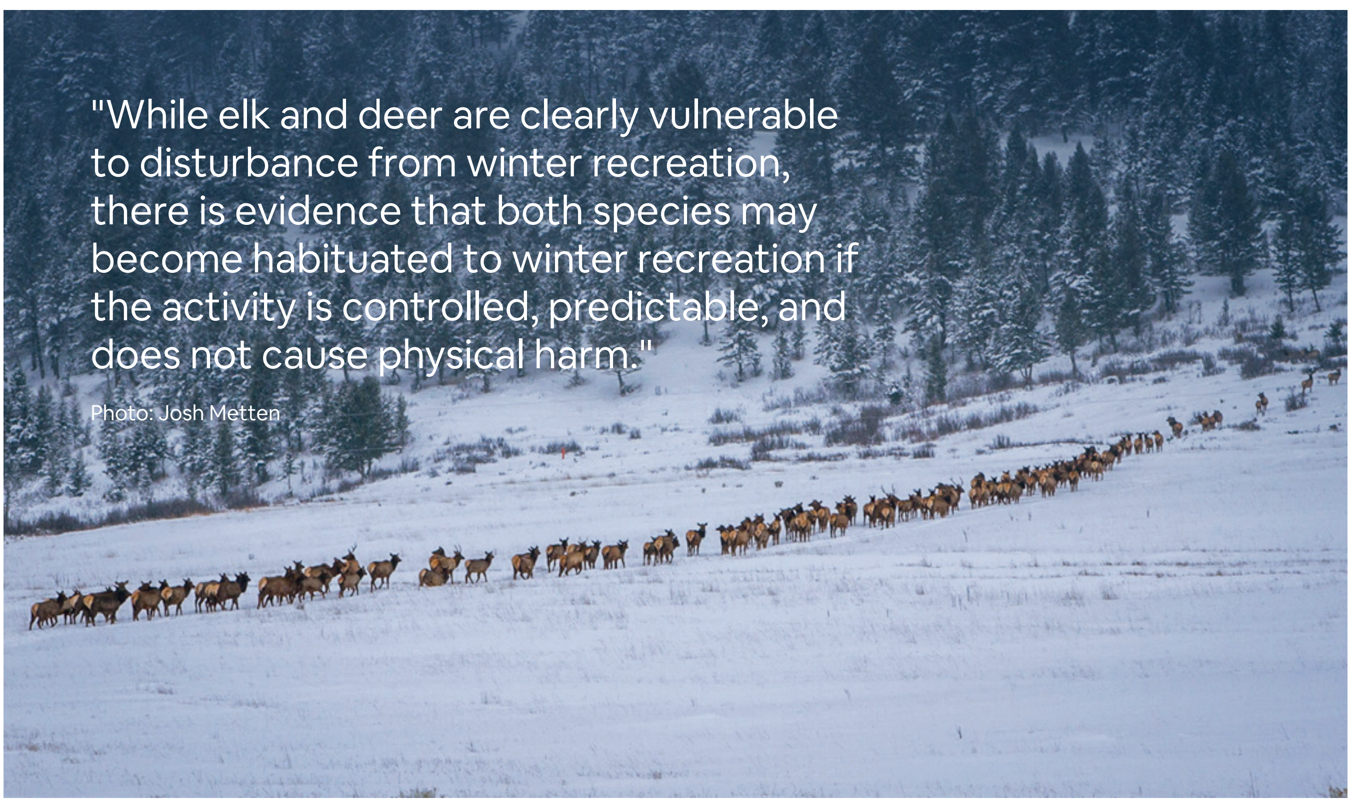
rates and probability of a flight response.[25 26] In contrast, Wisdom et al. (2004) found little change in movement for mule deer in response to off-road recreation, but postulated that mule deer may respond to recreation activities by seeking dense hiding cover rather than fleeing.[27]

While elk and deer are clearly vulnerable to disturbance from winter recreation, there is evidence that both species may become habituated to winter recreation if the activity is controlled, predictable, and does not cause physical harm.[28]

Moose

Studies examining how moose respond to snowmobile recreation have found that moose avoid motorized recreation but appear to be less impacted by predictable disturbances. One study found that moose avoid areas with snowmobiles and roads, even if this means they spend more time in areas with lower quality forage.[29] A study in Wyoming quantified the distance at which moose appear to be disturbed, finding that the zone of disturbance extends about 300 meters from bedding and feeding animals, and that moose gradually moved away from trails as use increased over the course of a day.[30] Another study noted that snowmobile disturbance to moose was greater when the disturbance was unpredictable and longer in extent and duration.[31] A study in Alaska found that moose fecal GC concentrations were higher in areas with snowmobile use versus those areas without snowmobile use, indicating higher stress for animals living in areas with snowmobile activity.[32] Together, these studies indicate that moose may not be significantly stressed by a snowmobile passing by on a route that is regularly traveled by snowmobiles, especially if the trail is a more than 300 meters away from the animal, and they will be much more stressed if surprised by an encounter with snowmobiles in a meadow far from any roads or trails. Likewise, a busy trail brings more impact (and likely displacement), and consistent snowmobile use throughout the winter may result in chronic stress for moose.

25 Wisdom, M. J., Ager, A. A., Preisler, H. K., Cimon, N. J., and Johnson, B. K.2004.
26 Naylor, L. M., Wisdom, M. J., and Anthony, R. G. 2009.
27 Wisdom, M. J., Ager, A. A., Preisler, H. K., Cimon, N. J., and Johnson, B. K. 2004.
28 Borkowski et al. 2006, Dorrance et al. 1975, Cassirer et al. 1992
29 Mullet, T.C. 2014.
30 Colescott, J.H. and M.P. Gillingham 1998.
31 Harris, G., Nielson, R.M., and Rinaldi, T. 2014.
32 Tomeo, M.A. 2000.



Moose also avoid areas with intense non-motorized recreation and are stressed by unpredictable encounters with skiers. One study compared elk and moose distribution for 3 years before and 3 years after Nordic ski trail development in Alberta, Canada in the late 1970's.[33] It found that moose seasonal movement changed to avoid areas with heavily used Nordic ski trails, and that moose were displaced from some areas that they had used prior to trail development. In another study, researchers documented the disturbance effect of backcountry skiers on moose and found a distinct, but short-term, response in which adult female moose moved faster and used considerably more energy after being disturbed by backcountry skiers.[34] This study found no evidence of habituation to disturbance in moose and warned that repetitive disturbance by skiers could have significant impacts on an animal's energy budget, particularly for calves. However, the researchers note that this lack of habituation was likely based on heavy human hunting pressure in the study area (where hunting occurs on foot). They did not examine the effect of snowmobiles. Therefore, it is unknown whether skiing disturbs moose more or less than snowmobile use.

Woodland Caribou

Woodland caribou are listed as an endangered species, and are considered one of the most endangered large mammals in North America. Snowmobiling represents the greatest threat to woodland caribou within the Southern Selkirk Mountains population (which historically moved between British Columbia, northern Idaho, and northeastern Washington) relative to other winter recreation activities due to the overlap between caribou winter habitat and preferred snowmobile destinations.[35] Intensive snowmobile activity on woodland caribou winter range results in displacement of caribou from high quality habitat.[36] The primary concern related to habitat displacement from preferred late winter foraging areas by snowmobiles is that it can lead to declines in physical body condition due to reduced forage intake and increased energy expenditure.[37] Snowmobile and heli-ski activity has also been documented to increase stress hormones in caribou, including when the motorized activity is a substantial distance away from the animals.[38] This indicates that motorized backcountry recreation may result in chronic stress. Wolves have also been documented using snowmobile trails to hunt caribou.[39]

Although snowmobiling is the more common threat to woodland caribou, particularly in western North America, caribou are sensitive to disturbance from all forms of winter recreation. In eastern Canada, scientists have found that woodland caribou are disturbed and displaced by backcountry skiers as well.[40] Caribou adjusted their response relative to the intensity of the disturbance, but with sufficient disturbance, they were displaced into lower elevations.[41] In the absence of winter recreation, caribou in the study area avoid lower elevation terrain, as it is where their primary predator (coyote) resides. This population of caribou (in Gaspesie National Park, Quebec), may be somewhat habituated to backcountry skiers, but still demonstrated sensitivity to backcountry skier disturbance, indicating that other caribou populations may be even more disturbed by this activity.

Relative to other winter recreation activities (heli-skiing, snow-cat skiing, and backcountry skiing), snowmobiling poses the greatest perceived threat to woodland caribou because preferred snowmobile terrain overlaps significant with caribou habitat (open forest with deep snow and gentle terrain), and snowmobiles can easily access and potentially affect extensive areas of subalpine winter range.[42]

Bighorn Sheep

Winter range and over-winter survival is the main limiting factor in bighorn sheep population dynamics. During the time when sheep are on their winter ranges, generally December through April,[43] they face the highest risk of mortality. While most bighorn

33 Ferguson, M. A., and Keith, L. B. 1982.
34 Neumann, W., G. Ericsson, and H. Dettki. 2009.
35 U.S. Fish and Wildlife Service. 2019.
36 Seip, D.R.; Johnson, C.J. and G.S. Watts. 2007.

37 Simpson, K., and Terry, E. 2000.
38 Freeman, N. L. 2008.
39 *Id.*
40 Lesmerises, F., Déry, F., Johnson, C. J., and St-Laurent, M. H. 2018.
41 *Id.*
42 Simpson, K., and Terry, E. 2000.
43 Portier, C., M. Festa-Bianchet, J.M. Gaillard, J.T. Jorgenson and N.G. Yoccoz. 1998.

"Relative to other winter recreation activities (heli-skiing, snow-cat skiing, and backcountry skiing), snowmobiling poses the greatest perceived threat to woodland caribou because preferred snowmobile terrain overlaps significantly with caribou habitat and snowmobiles can easily access and potentially affect extensive areas of subalpine winter range."

Photo: mariemilyphotos

sheep herds winter in low elevation snow free areas that provide grass and reprieve from deep snow, in Grand Teton National Park, bighorn have been observed wintering on high-elevation wind-swept ridges.[44] Although bighorn use of high elevation sites such as this are not well documented, such use likely occurs outside of Grand Teton National Park.

There has been very little research on winter recreation impacts to bighorn sheep, with no data on potential snowmobile disturbance to sheep. Many mountain ungulate biologists suspect motorized access will adversely affect these species. However, no peer-reviewed studies are available to back up this intuition. The literature suggests that bighorn sheep are disturbed by motorized human recreation, with emphasis on automobiles. In Rocky Mountain National Park (RMNP), the time it took sheep to cross roads was positively correlated to the number of vehicles.[45] Vehicular traffic elicited a 14.3% rise in mean heart rate in another population of sheep.[46] Additionally, in RMNP sheep decreased access to a mineral lick, a vital resource, due to car traffic. In Canyonlands National Park, sheep fled from vehicles in 17% of encounters.[47] Additionally, Canyonlands sheep were found 490 meters farther from roads than expected, suggesting avoidance and a 15% loss of available habitat.

Compared to vehicles, bighorn sheep respond more strongly to non-motorized recreation.[48] [49] In the one study that examined winter recreation impacts to bighorn sheep, sheep were significantly impacted by backcountry skiing and snowboarding. This study, in Grand Teton National Park, found that bighorn sheep avoided high quality habitat that received backcountry winter recreation (skiing and snowboarding), regardless of whether recreation use was low or high.[50] This resulted in a 30% reduction in available high quality habitat for sheep. Furthermore, individuals exposed to recreation had increased daily movements and home range sizes compared to those that did not encounter recreationists.[51] Sheep in Grand Teton are fairly unique in their use of high elevation winter ranges, which increases this herd's interactions with winter recreationists. Furthermore, because the high elevation ridges that comprise these winter ranges are very limited in spatial extent, home ranges and movement are extremely constricted for the Teton bighorn sheep herd during the winter.

Studies of bighorn sheep responses to hiking further demonstrate a sensitivity to people on foot. In

44 Courtemanch, A.B. And M.J. Kauffman. 2014.
45 Keller, B.J. And L.C. Bender. 2007.
46 Macarthur, R.A., R.H. Johnston and V. Geist. 1979.
47 Papouchis, C.M., F.J. Singer and W.B. Sloan. 2001.
48 *Id.*
49 Stankowich, T. 2008.
50 Courtemanch, A.B. And M.J. Kauffman. 2014.
51 *Id.*

Canyonlands, bighorn fled from 61% of encounters with hikers.[52] Hikers caused a 20% increase in sheep heart rate in another population.[53] In another national park, bighorn sheep moved further away from trails during weekends when visitation increased.[54] Then, in yet another national park, increased hiking associated with a new trail caused bighorn sheep abandonment of a lambing area and subsequent declines in recruitment and female abundance.[55] Higher disturbance from hikers compared to vehicles is attributed to: 1) unpredictability of disturbances, and 2) people on foot directly approaching sheep.[56 57]

Mountain Goats

To date, there is no published research specifically examining the effects of snowmobiles and snowbikes on mountain goats. Several literature reviews from the 1980's and 1990's addressed the effects of snowmobile recreation on mountain goats.[58 59 60] However, contemporaneous literature lacked any direct research on the subject. The authors instead cited information from personal communications or research of other disturbance effects on goats. Their professional consensus was that snowmobile recreation in goat habitat during the energetically taxing seasons of winter and spring would elicit vigilance and flight behavior, add to goats' energetic burden, and ultimately lead to declines in herd health and productivity.[61]

There are several published studies on the effects of helicopters on mountain goats. Seminal studies on this topic indicate that goats are highly disturbed by helicopters hovering within 500 horizontal feet of their location, leading to group disintegration, flight behavior, physical injury, and potential reductions in herd productivity.[62 63 64 65] More recent studies also support this conclusion, with the caveat that mountain goat responses can vary depending on helicopter approach technique and goat proximity to escape terrain: directness of helicopter approach and distance of goats from escape terrain are positively correlated with intensity of goat disturbance.[66 67 68] One team of researchers tested whether a mountain goat population they had studied 10-15 years earlier had habituated to consistent helicopter traffic over the intervening years. They found similar results between study periods, with goats exhibiting strong physical indications of fear and overt flight behavior.[69] All research on the effects of helicopters on mountain goats supports a management standard of prohibiting helicopter fight (including heli-skiing) within 1.5 km of goat habitat.

There is limited research on the impacts of non-motorized winter recreation to mountain goats. Based on goat habitat use, a 1999 literature review concluded that skiers target areas of high snowload during winter while goats target areas of low snowload, therefore mitigating any potential conflict.[70] More recent research has illuminated potential effects of skiing on mountain goats. A 2014 study found that the likelihood of goat observations decreased with increased ski track or route presence in areas where winter goat habitat and cross-country ski use overlap.[71] And, in 2016 researchers found that mountain goats strictly avoided high quality winter habitat within a commercial alpine ski basin and moved away from downhill skiers when they came within 1 km of the goat's location.[72] This research indicates that goats are displaced from high quality winter habitat by spatially overlapping and recurring cross-country and downhill skiing, although it is important to note that a ski resort is a much more intensely used landscape than even the most popular backcountry areas.

52 Papouchis, C.M., F.J. Singer and W.B. Sloan. 2001.

53 Macarthur, R.A., R.H. Johnston and V. Geist. 1979.

54 Longshore, K. And D.B. Thompson. 2013.

55 Wiedmann, B.P. And V.C. Bleich. 2014.

56 Papouchis, C.M., F.J. Singer and W.B. Sloan. 2001.

57 Wiedmann, B.P. And V.C. Bleich. 2014.

58 Joslin, G. 1980.

59 Joslin, G., and H. Youmans. 1999.

60 Olliff, T., K. Legg, and B. Kaeding. 1999.

61 See Joslin, G. (1980); Joslin, G., and H. Youmans (1999); and Olliff, T., K. Legg, and B. Kaeding (1999).

62 Foster, B. R., and E. Y. Rahs. 1982.

63 Joslin, G. 1986.

64 Penner, D. F. 1988.

65 Côté, S.D. 1996.

66 Andrus, K. J. 2005.

67 Goldstein, M. I., A. J. Poe, E. Cooper, D. Youkey, B. A. Brown, and T. L. McDonald. 2005.

68 Cadsand, B. A. 2012.

69 Côté, S. D., S. Hamel, A. St-Louis, and J. Mainguy. 2013.

70 Olliff, T., K. Legg, and B. Kaeding. 1999.

71 Nepal, N. 2014.

72 Richard, J. H., and S. D. Coté. 2016.

"Human disturbance within one kilometer of a den site has a been shown to bring significant risk of abandonment, especially early in the denning season."

Photo: byrdyak

CARNIVORES

Winter recreation impacts carnivore habitat use, movement rates, and behavior. Many North American carnivores are active year-round and adapted for life in the snow. Each species has unique adaptations, but across this class, one important trait that influences winter behavior and habitat use is the species' footload (body mass/foot surface area). Animals with a higher footload, such as coyotes and wolves, sink deeper into the snow and tend to selectively travel on compacted snow surfaces.[73]

Regardless of whether snow compaction and condition is natural or influenced by human activities, it strongly influences carnivore habitat use. One study, which examined whether prey abundance, snow depth, compaction, and/or habitat characteristics influenced mesocarnivore occurrence, found that snow condition was the strongest predictor of occurrence across species.[74] This study concluded that changes in snow conditions due to climate change has the potential to directly affect the distributions of mesocarnivores across their range. Winter recreation, particularly over-snow vehicle use, can also result in widespread and significant changes in snow condition and compaction, which in turn influences mesocarnivore habitat use and interspecific dynamics. For example, snow grooming and cross-country OSV travel disrupts seasonal habitat partitioning among mesocarnivores by facilitating generalists, such as coyote, into deep snow habitat where they would otherwise not be able to intrude.[75] This, in turn, can have population level consequences for other mesocarnivores or prey species.

An additional concern related to OSV use for many carnivores is that motorized access leads to increased trapping pressure (direct or indirect capture) for forest carnivores such as marten, fisher, lynx, and wolverine that prefer the more mesic (wetter) habitat conditions generally found at higher elevations or in riparian habitats. Furbearer trapping season is limited to the winter months, and most trappers prefer the relatively easy access to suitable habitat provided by over-snow vehicles. Small populations in isolated mountain ranges can be very susceptible to trapping pressure.

73 Whiteman, J.P. and Buskirk, S.W. 2013.

74 Pozzanghera, C. B., Sivy, K. J., Lindberg, M. S., and Prugh, L. R. 2016.

75 Wengert, G.M., M.W. Gabriel, S.M. Matthews, J.M. Higley, R.A. Sweitzer, C.M. Thompson, K.L. Purcell, R.H. Barrett, L.W. Woods, R.E. Green, S.M. Keller, P.M. Gaffney, M. Jones, and B.N. Sacks. 2014.

Bears

Both brown and black bears are sensitive to human disturbance during hibernation, which can be disrupted by winter recreation.[76] [77] [78] [79] Interruption of hibernation is extremely costly for bears and can lead to den abandonment, weight loss and decreased cub survival.[80] [81] Den abandonment results in short-term energetic costs and poses potentially long-term consequences if bears avoid favorable den habitat in the future because of disturbance from winter recreation activities.[82] After documenting brown (grizzly) bear den abandonment in response to heli-skiing, Crupi et al (2020) postulated that use of suboptimal denning sites could affect bear distribution patterns and lead to population level declines in reproduction and survival.[83] Because brown bears exist at low population densities, the loss of a few individuals bears may have strong negative effects on overall population viability.[84]

Brown bear denning habitat falls within the lower elevational extent of available alpine terrain, on moderately steep slopes, and in less rugged terrain with better drained soils with more stable snow conditions.[85] [86] [87] This same habitat is frequently used by winter recreationists. Human disturbance within one kilometer of a den site has a been shown to bring significant risk of abandonment, especially early in the denning season,[88] therefore, winter recreation could have a considerable

76 Crupi A.P., D.P. Gregovich, and K.S. White. 2020.

77 Goldstein, M. I., A. J. Poe, L. H. Suring, R. M. Nielson, and T. L. McDonald. 2010.

78 Linnell, J.D.C., J.E. Swenson, R. Andersen, B. Brain. 2000.

79 Miller, A.B. King, D., Rowland, M., Chapman, J., Tomosy, M., Liang, C., Abelson, E.S. and Truex, R. 2020.

80 Crupi A.P., D.P. Gregovich, and K.S. White. 2020.

81 Goldstein, M. I., A. J. Poe, L. H. Suring, R. M. Nielson, and T. L. McDonald. 2010.

82 Crupi A.P., D.P. Gregovich, and K.S. White. 2020.

83 *Id.*

84 Hilderbrand, G. V., Lewis, L. L., Larrivee, J., and Farley, S. D. 2000.

85 Goldstein, M. I., A. J. Poe, L. H. Suring, R. M. Nielson, and T. L. McDonald. 2010.

86 Linnell, J.D.C., J.E. Swenson, R. Andersen, B. Brain. 2000.

87 Podruzny, S., S. Cherry, C. Schwartz, and L. Landenburger. 2002.

88 *Id.*

Photo: Josh Metten

impact on grizzly bears. Snowmobile use is a particular concern, as snowmobiles travel farther into backcountry, resulting in a larger extent of recreation/denning habitat overlap compared to non-motorized recreation.[89] Heli-skiing also poses a considerable threat to denning bears. Crupi et al. (2020) found that that brown bears in Alaska avoided previously favored den habitat and used suboptimal denning sites following heli-ski disturbance.[90]

Linnell et al. (2000) recommends that "winter activities should be minimized in suitable or traditional denning areas; if winter activity is unavoidable, it should begin around the time bears naturally enter dens, so that they can choose to avoid disturbed areas; and winter activity should be confined to regular routes as much as possible."[91] To this end, in both Montana and Alaska, land managers have utilized modeling to better understand and manage potential winter recreation conflicts with denning bears.[92]

89 Miller, A.B. King, D., Rowland, M., Chapman, J., Tomosy, M., Liang, C., Abelson, E.S. and Truex, R. 2020.

90 Crupi A.P., D.P. Gregovich, and K.S. White. 2020.

91 *Id.*

92 Switalski, A. 2016(b).

Gray Wolf

Wolves are well adapted to winter environments, utilizing deep snow to their advantage when hunting ungulates.[93 94] They also exhibit high behavioral plasticity, allowing them to adapt to exploit conditions to improve hunting success. For example, in natural conditions, wolves gain access to areas with deep snow by traveling under the forest canopy, but they will readily follow compacted trails created by winter recreationists. In particular, snowmobiles can significantly transform the landscape to wolves' advantage, because extensive snow compaction decreases energy costs and allows for faster travel across long distances.[95] As wolves are cursorial predators who rely on long-distance movements to find prey[96], snowmobile use may benefit wolves to the detriment of their ungulate prey.[97 98]

93 Nelson, M.E., and Mech, L.D. 1986.

94 Fuller, T.K. 1991.

95 Droghini, A. and S. Boutin. 2017.

96 Mech, D.L. 1970.

97 Paquet, P. C., Alexander, S., Donelon, S., and Callaghan, C. 2010.

98 Simpson, K. and Terry, E. 2000.

Canada Lynx

Canada lynx are listed as threatened under the Endangered Species Act, and population number and trends in the contiguous United States is unknown. The range of lynx in the West has diminished over the last century, suggesting that lynx may be negatively impacted by human activities.[99]

Maintaining connectivity for lynx between the United States and Canada is critical to lynx conservation, but this may become increasingly difficult as lynx populations become more isolated with climate change. Climate modeling suggests that lynx habitat and populations are anticipated to decline[100] and may disappear completely from parts of the range by the end of this century.[101] Remaining lynx populations would likely be smaller than at present and, because of small population size and increased isolation, populations would likely be more vulnerable to stochastic (unpredictable) environmental and demographic events.[102]

Mechanisms through which recreational activities could impact lynx may include loss of habitat, reductions in habitat availability due to disturbance, or changes in competition for snowshoe hare prey.[103] Lynx habitat can generally be described as moist boreal forests that have cold, deep snowy winters and a high-density snowshoe hare prey base.[104] As snow levels diminish with climate change, winter recreation use will become more concentrated in those snowy areas still remaining – where lynx are trying to persist as well. Winter recreation will thus continually become a more serious threat to the persistence of lynx over time.

A study examining dispersed winter recreation in Colorado found that lynx appear to change their activity levels temporally in relation to human activity.[105] Lynx decreased movement rates and were more active at night in areas dominated by high levels of snowmobile use and backcountry skiing. They also appeared to avoid high intensity developed ski resorts, especially when recreation was most intense. However, lynx in this study appeared to tolerate low and moderate intensity backcountry skiing and packed-trail skiing, as they did not avoid areas in close proximity to trails for these forms of recreation. It is possible that these patterns reflect shared habitat preference of lynx and skiers (high elevation, dense canopy cover and steep slopes) while areas with greater snowmobile use, which lynx avoided, were also lower quality habitat for lynx (mostly lower elevation open areas). However, this study found that lynx habitat use appeared to be strongly influenced by both canopy cover and high intensity dispersed recreation, rather than canopy cover alone, indicating that recreation use does impact lynx habitat use.[106]

To further understand lynx habitat selection as related to winter recreation, researchers developed a Resource Selection Model (RSF) for lynx habitat choices vis à vis recreation use patterns.[107] These models showed that lynx avoided areas selected by motorized winter recreationists. This again may be in part because motorized use was restricted to the open areas lynx tend to avoid. There was no negative association between lynx and either hybrid or backcountry skiing, and mid-levels of backcountry skiing were positively associated with lynx occurrence. This positive relationship was likely because both lynx and skiers select for steep, forested, high-elevation slopes. While there was heli-skiing in the study areas as well, this use occurred in habitat with lower canopy cover than what lynx selected, thus heli-skiing and lynx were spatially segregated.

Snow-packed trails created by snowmobiles have long been considered as possibly serving as travel routes for potential competitors and predators of lynx, especially coyotes.[108 109 110 111 112] Due to morphological differences in foot size and weight load, coyotes and lynx are typically spatially segregated, as lynx are better able to move across

99 Koehler, G. M. and K. B. Aubry. 1994.

100 Carroll, C. 2007.

101 Johnston, K. M., K. A. Freund, and O. J. Schmitz. 2012.

102 Carroll, C. 2007.

103 Interagency Lynx Biology Team. 2013.

104 *Id.*

105 Olson, L.E.; Squires, J.R.; Roberts, E.K.; Ivan, J.S., and M. Hebblewhite. 2018.

106 *Id.*

107 Squires, J. R., L. E. Olson, E. K. Roberts, J. S. Ivan, and M. Hebblewhite. 2019.

108 Ozoga, J. J. and E. M. Harger. 1966.

109 Murray, D. L. and S. Boutin. 1991.

110 Koehler, G. M. and K. B. Aubry. 1994.

111 Murray, D. L., S. Boutin, M. O'Donoghue, and V. O. Nams. 1995.

112 Buskirk, S. W., L. F. Ruggiero, and C. J. Krebs. 2000.

"Lynx decreased movement rates and were more active at night in areas dominated by high levels of snowmobile use and backcountry skiing. They also appeared to avoid high intensity developed ski resorts, especially when recreation was most intense. However, lynx in this study appeared to tolerate low and moderate intensity backcountry skiing and packed-trail skiing, as they did not avoid areas in close proximity to trails for these forms of recreation."

Photo: Adam Jones/Danita Delimont

deep soft snow.[113 114] This segregation in winter may break down, however, where human modifications such as snow-packed tracks from snowmobiles allow coyotes to access deep snow areas.[115] Bunnell et al. (2006) observed more coyote activity along trails compacted by snowmobiles than those that were not.[116] Burghardt-Dowd (2010) found that coyotes in her study area traveled closer to compacted snowmobile trails than would be expected.[117] As both coyotes and lynx prey on snowshoe hares, this increased access of coyotes may lead to competition for prey and thus negatively impact lynx. Meanwhile, Kolbe et al. (2007) snow-tracked coyotes and found that although they did use snowmobile trails, they did not travel closer to these trails than randomly expected.[118] The overall relationship is not entirely clear, as snow penetrability in the region seems to determine whether or not snowmobile trails influence coyote movement patterns in lynx habitats.[119 120 121]

An additional concern related to over-snow vehicle use is that open roads and motorized winter access increases lynx vulnerability.[122 123 124 125] Human access can increase the potential for mortality or injury of lynx captured incidentally in traps aimed at other species or through illegal shooting. Such vulnerability is reduced if there is less motorized winter recreation access.

Wolverine

Wolverines are a snow-dependent species and many areas in the Northern Rockies with backcountry winter recreation use are also occupied by wolverines or contain suitable wolverine habitat.[126] Researchers and natural resource managers have long expressed concerns about effects of winter recreation on wolverine populations, as dispersed recreational activities have the potential to negatively impact this species, particularly by disrupting natal denning areas.[127 128 129 130] Wolverines have one of the lowest successful reproductive rates known in mammals, and this is hypothesized as linked to winter energy constraints. Female wolverines select and enter dens and give birth in February to mid-March[131] and the overlap of winter recreation with this energetically taxing period is highly concerning. Any disturbance during this important winter period can negatively affect productivity and other vital rates.[132 133]

Researchers have reported that female wolverines may be sensitive to human disturbance in the vicinity of natal and maternal dens, and disturbance from ski and snowmobile traffic has been purported to cause maternal females to abandon or move dens.[134 135] Researchers have also found that females tended to avoid areas with heli-skiing or backcountry skiing.[136] High-cirque snowmobile use, especially cross-country use and "high marking," may also present a substantial threat to wolverines.

Recent research specifically examining how wolverines respond to winter recreation use found that wolverines avoided areas where winter recreation occurred, regardless of whether the recreation activity was motorized or non-motorized.[137] The study found that female wolverines demonstrated the highest avoidance of areas with off-road (dispersed) motorized winter recreation. This research also found that wolverines changed their activity level at time periods and days of higher recreational use, shifting their activity to avoid the most heavily used areas within their home ranges and changing the timing of their activity. Denning female wolverines in areas with high levels of recreation were less active during the day and more active at night compared to females in areas

113 Murray, D. L. and S. Boutin. 1991.
114 Litvaitis, J. A. 1992.
115 Buskirk, S. W., L. F. Ruggiero, and C. J. Krebs. 2000.
116 Bunnell, K. D., J. T. Flinders, and M .L. Wolfe. 2006.
117 Burghardt-Dowd, J. L. 2010.
118 Kolbe, J. A., J. R. Squires, D. H. Pletscher, and L. F. Ruggiero. 2007.
119 Bunnell, K. D., J. T. Flinders, and M .L. Wolfe. 2006.
120 Kolbe, J. A., J. R. Squires, D. H. Pletscher, and L. F. Ruggiero. 2007.
121 Burghardt-Dowd, J. L. 2010.
122 Koehler, G. M. and J. D. Brittell. 1990.
123 McKay, R. 1991.
124 Koehler, G. M. and K. B. Aubry. 1994.
125 Aubry, K. B., G. M. Koehler, and J. R. Squires. 2000.
126 Heinemeyer K., J. Squires, M. Hebblewhite, J.J. O'Keefe, J.D. Holbrook, and J. Copeland. 2019.
127 Hornocker, M.G., and H.S. Hash. 1981.
128 Carroll, C., Noss, R. F., & Paquet, P. C. 2001.
129 Rowland, M.M., M.J. Wisdom, D.H. Johnson, B.C. Wales, J.P. Copeland, and F.B. Edelmann. 2003.
130 Ruggiero, L. F., K. S. McKelvey, K. B. Aubry, J. P. Copeland, D. H. Pletscher, and M. G. Hornocker. 2007.
131 Magoun, A. J., and J. P. Copeland. 1998.
132 May, R., A. Landa, J. van Dijk, J.D.C. Linnell, and R. Andersen. 2006.
133 Krebs, J., E.C. Lofroth, and I. Parfitt. 2007.
134 Magoun, A. J., and J. P. Copeland. 1998.
135 Inman, R.M., K.H. Inman, M.L. Packila, and A.J. McCue. 2007.
136 Krebs, J., E.C. Lofroth, and I. Parfitt. 2007.
137 Heinemeyer K., J. Squires, M. Hebblewhite, J.J. O'Keefe, J.D. Holbrook, and J. Copeland. 2019.

with little recreation.[138] The wolverines in this study also had higher movement rates due to fewer resting periods in recreated areas.

These behavioral changes result in functional habitat loss for wolverines and can negatively affect individuals' physiological stress levels and reproductive capacity in several ways. It may reduce the amount of time and thus ability of female wolverines to hunt or to utilize food caches. This would result in significant additive energetic effects, reducing foraging success for adult females already stressed by the demands of bearing and raising a litter.[139] Additionally, this could reduce kit survival rates by increasing the potential for predation and exposure to cold temperatures.

As snowmobiling and backcountry skiing continue to grow in popularity and as snowpack continues to decline due to climate change, there is increasing concern that wolverine denning habitat may become limiting. Recent warming has already led to substantial reductions in spring snow cover in the mountains of western North America.[140] Numerous recent and sophisticated studies support the conclusion that climate changes caused by global climate change are likely to negatively affect wolverine habitat.[141] Protection of denning habitat, including from recreation impacts, may be critical for the persistence of the species in the Rockies. Although the US Fish and Wildlife Service decided against listing the wolverine as either Threatened or Endangered, there is ongoing litigation over this matter.

Marten

Like wolverine, marten are solitary and territorial, and generally avoid human encounters. Human activity discourages marten from otherwise suitable habitat.[142] Because of their small body size and low reproductive rate, marten are particularly vulnerable to predation[143] [144] [145] and stochastic extinction.[146] Marten appear to seek deep snow during winter time, despite their lack of adaptations to cold temperatures, in order to isolate themselves from humans and to escape predators such as bobcat, fisher, and even coyote that are unable to cross deep

138 *Id.*

139 Heinemeyer, K. and J. Squires. 2013.

140 Pederson, G.T., L.J. Graumlich, D.B. Fagre, T. Kipfer and C.C. Muhlfeld. 2010.

141 See for example, Johnston, K. M., K. A. Freund, and O. J. Schmitz. 2012 and Peacock, Synte. 2011.

142 Slauson, K. M., Zielinski, W. J., and Schwartz, M. K. 2017.

143 *Id.*

144 Slauson, K.M. and K.M. Moriarty. 2010.

145 Witmer, G. W., S. K. Martin, and R. D. Sayler. 1998.

146 Buskirk, S. and L. Ruggiero. 1994.

Photo: Claudine Lamothe

Marten
Photo: Patrick Cross

Fisher
Photo: geoffkuchera

snow.[147] [148] Indeed, several studies have found greater winter predation rates on marten in the absence of deep snow.[149] [150] Coyote, a known predator of marten and a habitat generalist, have only two limiting factors: deep, soft snow and wolves.[151] Predictably, recent studies have demonstrated that snowmobiles allow coyotes access to areas where deep snow-adapted carnivores go to take refuge from predators.[152]

Fisher

The West Coast distinct population segment of fishers was listed as Threatened in 2019. However, in 2020 the US Fish and Wildlife Service reversed this listing, lifting protections for most of the West Coast population while granting an Endangered status to the Southern Sierra Nevada population of fishers.

There is little scientific literature that addresses the impacts of motorized recreation to fishers. Fishers are often characterized as a species that avoids humans,[153] tending to be more common in areas where the density of humans is low and human disturbance is reduced.[154] This species is susceptible to habitat fragmentation and population isolation and certain recreational activities may contribute to these impacts.[155]

As fishers prefer mature, moist coniferous forests and are thought to avoid high elevation and deep snowfall,[156] [157] potential impacts to fisher from winter recreation are most likely to occur in areas where roads, trails, or recreation areas are within riparian corridors, or at low elevations.

Over-snow vehicle use access leads to increased trapping pressure for fishers. Greater densities of forest roads and motorized winter recreation provides greater access to forests where fishers may occur, and the threats to fishers from poaching, off-highway and over-snow recreational vehicles, and other types of human activities may thus be greater.[158] [159] [160] [161] While fishers are not legally trapped in most of their range, they are frequently caught incidentally. Trapping season is limited to the winter months, and most trappers prefer the relatively easy access to suitable habitat provided by over-snow vehicles. Trapping pressure is dramatically reduced if there is less motorized winter access.

147 Krohn, W., W. J. Zielinski, and R. B. Boone. 1997.
148 Buskirk, S. and L. Ruggiero. 1994.
149 Bull E.L. and T. W. Heater. 2001.
150 Moriarty, K.M. 2014.
151 Buskirk, S. W. and W. J. Zielinski. 2003.
152 Bunnell, K.D., J.T. Flinders, and M.L. Wolfe. 2006.
153 Douglas, C.W., and M.A. Strickland. 1987.
154 Powell, R.A., and W. J. Zielinski. 1994.
155 Claar, J.J, N. Anderson, and D. Boyd. 1999.
156 Krohn, W.B., S.M. Arthur, and T.F. Paragi. 1994.
157 Krohn, W.B. 2012.
158 Weaver, J. 1993.
159 Hodgman, T.P., D.J. Harrison, D.D. Katnik, and K.D. Elowe. 1994.
160 Naney, R. H., L. L Finley, E. C. Lofroth, P. J. Happe, A. L. Krause, C. M. Raley, R. L. Truex, L. J. Hale, J. M. Higley, A. D. Kosic, J. C. Lewis, S. A. Livingston, D. C. Macfarlane, A. M. Myers, and J. S. Yaeger. 2012.
161 Switalksi, T.A. and A. Jones. 2012.

SUBNIVIAN MAMMALS

Small mammals that remain active during the winter depend on the insulated space between the snowpack and the ground – the subnivian zone – for winter survival. While compacted snow can benefit wildlife who travel on top of the snow, such as coyotes or elk, snow compaction fundamentally alters habitat quality in the subnivian zone.[162 163] When snow compaction from snowmobiles occurs, subnivian temperatures decrease, which can lead to increased metabolic rates in these small mammal species, such as voles, shrews, and mice. For example, if the subnivian air space is cooled by as little as 3 degrees Celsius, the metabolic demands of small mammals living in the space would increase by about 25 calories per hour.[164]

Through controlled experiments, researchers have demonstrated that compaction due to snowmobile use reduced rodent and shrew use of subnivian habitats to near zero – a decline attributed to direct mortality, not outmigration.[165] Elsewhere, scientists have documented a decline in small mammals following snowmobile activity that compressed the subnivian zone.[166] Because small mammals make up the majority of prey for many species, from raptors to mesocarnivores, habitat changes that affect subnivian populations could cascade through the food chain.[167]

BIRDS

Anthropogenic noise, particularly that from motor vehicles, has been shown to alter bird behavior.[168 169 170] Snowmachine use has been demonstrated to alter the behavior of many birds that commonly inhabit snowy landscapes – such as the raven, black-capped chickadee, and gray jay – as the frequency and range of sounds emitted from snowmachines overlaps with their vocalizations. In a 2018 study on the Stanislaus National Forest, scientists documented that the listening area for white-breasted nuthatches was reduced by more than 90 percent within the snowmobile noise footprint zone, preventing intraspecific communication across a large area.[171]

Birds demonstrate behavioral and habitat use changes in response to winter recreation in addition to being affected by OSV noise. Several studies have examined winter recreation impacts to black grouse, finding that birds that experience repeated disturbance by humans in winter exhibit higher concentrations of stress hormones, and that black grouse avoid winter recreation areas.[172 173] Furthermore, scientists found that black grouse increase foraging time following a disturbance, demonstrating an energetic cost to being flushed from their snow burrows.[174] Black grouse is a European species, but the findings from these studies can be applied to North American grouse species and provide insight into possible effects to other bird species as well.

One study, in northern Finland, examined golden eagle territory occupancy and breeding success within 40 kilometers of winter tourist destinations over a 10-year period.[175] It found that large-sized (over 30,000 registered overnight guests in April winter recreation destinations) were associated with low golden eagle occupancy of potential territory. In addition, this study found a reduction in golden eagle territory occupancy in areas with a greater density of snowmobile and ski trails, although there did not appear to be a relationship between route density and eagle breeding success. Although habitat attributes beyond winter tourism, such as prey abundance, local climate conditions, or changes in landscape – which were not quantified in this study – could explain some of the variation in territory occupancy or breeding success, this study may indicate that the area around large winter resorts contributes to a reduction in breeding habitat quality for golden eagles.

162 Keddy, P. A., A. J. Spavold, and C. J. Keddy. 1979.
163 Sanecki, G. M., K. Green, H. Wood, and D. Lindenmayer. 2006.
164 Neumann, P.W. and H.G. Merriam. 1972.
165 Jarvinen, J.A. and W.D. Schmid. 1971.
166 Sanecki, G. M., K. Green, H. Wood, and D. Lindenmayer. 2006.
167 Brander, R.B. 1974.
168 Goodwin, S.E., and W.G. Shriver. 2010.
169 Ortega, C.P. 2012.
170 McClure, C.J.W., H.E. Ware, J. Carlisle, G. Kaltenecker, and J.R. Barber. 2013.
171 Keyel, A.C., S.E. Reed, K. Nuessly, E. Cinto-Mejia, J.R. Barber and G. Wittemyer. 2018.
172 Arlettaz, R.; Patthey, P.; Baltic, M.; Leu, T.; Schaub, M.; Palme, R.; Jenni-Eiermann, S. 2007.
173 Braunisch, V.; Patthey, P.; Arlettaz, R.L. 2011.
174 Arlettaz, R., Nusslé, S., Baltic, M., Vogel, P., Palme, R., Jenni-Eiermann, S., Patthey, P., and Genoud, M. 2015.
175 Kaisanlahti-Jokimaki, M., Jokimaki, J., Huhta, E., Ukkola, M., Helle, P., and Ollila, T. 2008.

Photo: Josh Metten

"Motorized winter recreation can severely impact the natural soundscape, with the extent of impact being dependent upon the distance from the source (OSV), number of OSVs in a group, and other variables such as atmospheric conditions, wind speed and direction, topography, snow cover, and vegetative cover."

Photos (above and below): Josh Metten

Soundscapes

Natural soundscapes are intrinsic elements of the environment and are necessary for natural ecological functioning.[176] They also play an important role in the "opportunities for solitude" enshrined and protected by the Wilderness Act.[177] Motorized winter recreation can severely impact the natural soundscape, with the extent of impact being dependent upon the distance from the source (OSV), number of OSVs in a group, and other variables such as atmospheric conditions, wind speed and direction, topography, snow cover, and vegetative cover.[178] A noise study from Yellowstone involving four-stroke snowmachines found that under a "best case scenario" (upwind, no temperature inversion, soft snow) snowmobiles were audible at distances of up to a half mile.[179] When there was a temperature inversion or firm snow, or when downwind of a snowmobile, the machines could be heard more than two miles away.[180] At Yellowstone's Shoshone Geyser Basin, four-stroke snowmobiles can be audible from eight miles away.[181] Other studies have found that snowmobile noise can travel up to ten miles.[182] One study of noise impacts to Wilderness areas in the Kenai National Wildlife Refuge indicated that snowmobiling was profoundly impacting natural soundscapes that would otherwise be quiet, with the acoustic footprint of snowmobiles affecting over a third of the Wilderness in the study area.[183] Although newer snowmobiles are quieter than older-model machines, research has shown that a medium-sized group (8) of newest-model snowmobiles has the same noise footprint as an equally sized group of older snowmobiles.[184]

Natural soundscapes assist "in providing a deep connection to nature that is restorative and even spiritual for some visitors."[185] Because many non-motorized winter recreationists seek this experience, OSV noise is one of the biggest sources of use conflict in winter.[186] OSV noise reduces the quality of the backcountry experience for many non-motorized users, creating an annoyance and may even lead to displacement.[187] [188] In a strictly controlled study in Norway, researchers documented that noise was the single most significant variable to negatively affect a cross country skier's recreational experience.[189]

Anthropogenic noise is pervasive and has a profound impact on wildlife, causing changes in behavior, density and community structure, and reduced reproduction.[190] Motorized winter recreation is a concerning source of anthropogenic noise because it often extends far into backcountry environments, and because OSVs emit a low frequency noise that can travel long distances, affecting wildlife in areas that would otherwise provide secure, undisturbed, habitat.[191] As discussed previously, OSV noise can mask or otherwise disrupt animal communications, alter behavior, increase stress, and may reduce survival fitness.

176 Burson, S. 2008.
177 16 U.S.C. Ch. 23 § 1131 et seq.
178 Burson, S. 2017.
179 Menge CW and Ross JC. 2000.
180 *Id.*
181 Burson, S. 2008.
182 Hastings, A.L., G.G. Fleming, and C.S.Y. Lee. 2006.
183 Mullet, T.C., J.M. Morton, S.A. Gage and F. Huettmann. 2017.
184 Keyel, A.C., S.E. Reed, K. Nuessly, E. Cinto-Mejia, J.R. Barber and G. Wittemyer. 2018.
185 Freimund, W., M. Patterson, K. Bosak, and S. Walker Saxen. 2009.
186 Switalski, A. 2016(a).
187 *Id.*
188 Adams, J.C., and S.F. McCool. 2010.
189 Vittersø, J., R. Chipeniuk, M. Skår, and O. I. Vistad. 2004.
190 Barber, J. R., K.R. Crooks, and K.M Fristrup. 2010.
191 Mullet, T.C., J.M. Morton, S.A. Gage and F. Huettmann. 2017.

Snowpack, Soils, and Vegetation

Snow Compaction

Winter recreation compacts snow. This can be a cause for concern in areas with off-trail activity, where compaction is somewhat random and not confined to hardened surfaces such as roads and trails. Snow compaction has the potential to affect soils and vegetation, as well as wildlife (as described previously).

Snowmobile use has been shown to increase snowpack density, hardness, and ram resistance.[192] In experimental treatments, snowmobile use in areas with shallow snowpack (less than 30 centimeters, or 12 inches) resulted in snowpack hardness that was 500-2,000 times greater than in areas of equal snow depth where no snowmobile use occurred. However, the authors found that snowmobile use on snow deeper than 120 centimeters (47 inches) has a limited effect on snowpack density, temperature, hardness and ram resistance.

Soils

Snow compaction can lower soil temperatures and reduce the survival of plants and soil microbes.[193] A natural, un-compacted snowpack greater than 45 cm (18 inches) deep will prevent frost from penetrating the soil.[194] However, the thermal conductivity of compacted snow is greatly increased, resulting in both greater temperature fluctuations and overall lower soil temperatures.[195]

In areas of low or no snow, OSV use can cause direct soil compaction, increasing soil density, which reduces permeability of water and air.[196] In turn, these physical changes to soil increase erosion. This erosion can lead to increased soil runoff, causing sedimentation and turbidity in surface waters.[197]

192 Fassnacht, S. R., J.T. Heath, N.B.H. Venable and K. J. Elder. 2018.

193 Wanek, W. J. 1974.

194 Baker, E. and Bithmann, E., 2005.

195 *Id.*

196 Switalski, A. 2016(a).

197 Olliff, T., K. Legg, and B. Kaeding. 1999.

Vegetation

Snow compaction and resultant changes to soil temperatures inhibits the soil bacteria that play a critical role in the plant food cycle.[198] In turn, this can slow or reduce the growth and reproductive success of early spring flowers.[199] [200]

Winter recreation, particularly from OSV use, can also cause direct physical damage to vegetation, slowing growth or causing direct mortality. Abrasion and breakage of seedlings, shrubs, and other exposed vegetation is common in areas where OSV use occurs.[201] In a study of snowmobile impacts on old field and marsh vegetation, researchers concluded that compaction may affect the soil surface microstructure, early spring germination and growth, seed dispersal from capsules still attached to dead stalks, and may modify seed predation patterns by subnivian rodents.[202]

In one study examining damage to vegetation at and above snow surface from OSVs, more than 78% of the saplings on a trail were damaged after a single pass by a snowmobile, and nearly 27% of saplings were damaged seriously enough to cause a high probability of mortality.[203] Young conifers were found to be extremely susceptible to damage from snowmobiles.[204] A more recent study on snowmobile effects to vegetation found that snowmobile activity significantly reduced plant growth (measured as stem height and stem abundance) in riparian plants, with greater impacts in shallow snow (less than 150 centimeters deep).[205] This study postulated that this reduction in plant growth was due to snowmobile compaction of the subnivian environment lowering subnivian temperatures, which caused frost damage to vegetation.[206]

198 *Id.*

199 Wanek, W. J. 1974.

200 Rongstad, O.J., 1980.

201 Olliff, T., K. Legg, and B. Kaeding. 1999.

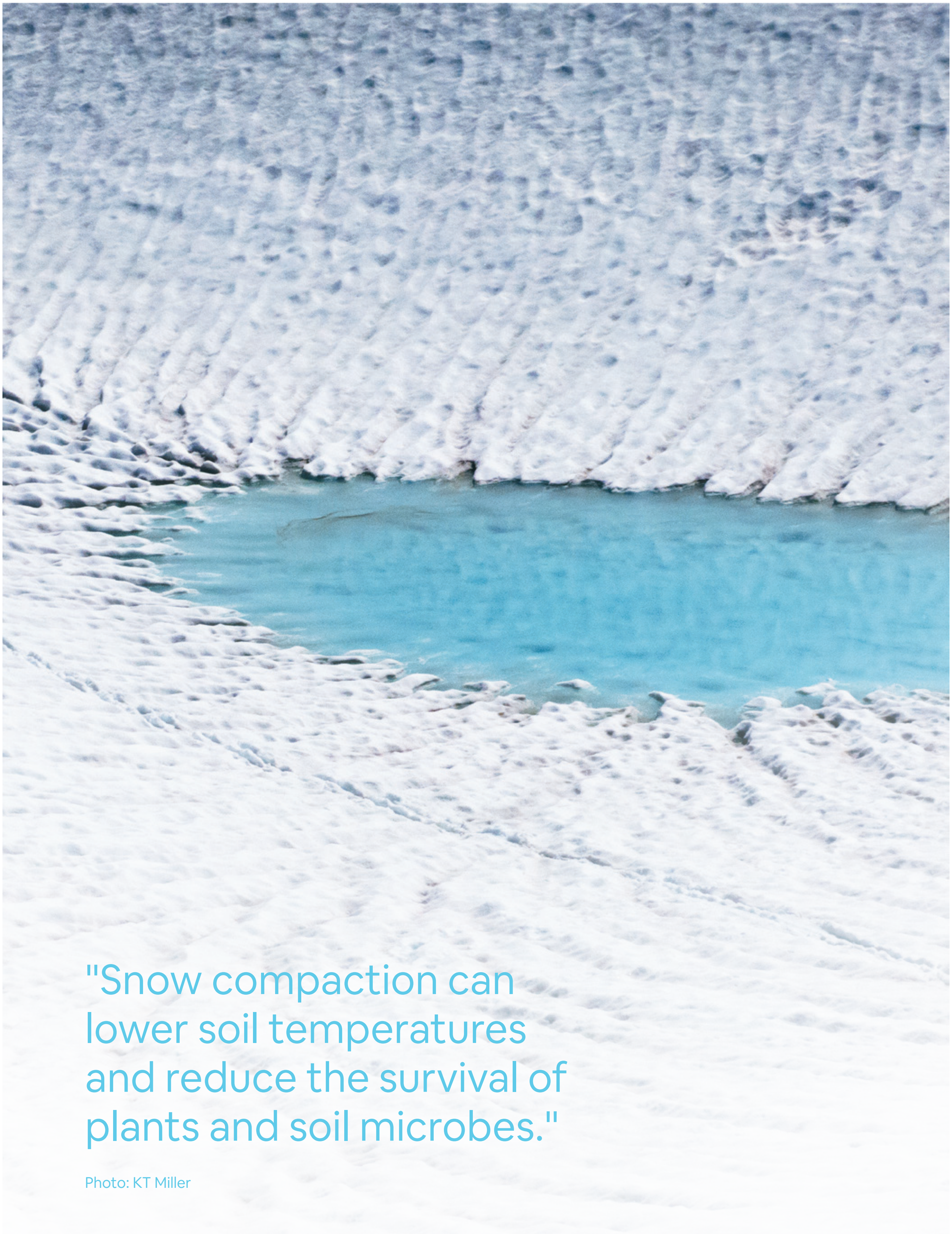
202 Keddy, P.A., Spavold, A.J., and Keddy, C.J., 1979.

203 Neumann, P.W., Merriam, H.G. 1972.

204 *Id.*

205 Mullet, T.C and J. M. Morton. 2021.

206 *Id.*



"Snow compaction can lower soil temperatures and reduce the survival of plants and soil microbes."

Photo: KT Miller

Air and Water Quality

Over-snow vehicles can cause significant localized impacts to air quality. Two-stroke engines, which represent the vast majority of OSV use on National Forest lands, are particularly concerning. An older two-stroke snowmobile can emit as many hydrocarbons and nitrogen oxides as 100 cars and create up to 1,000 times more carbon monoxide.[207] Snowmobiles made since 2006 and sold in the United States have to meet emissions standards set by the Environmental Protection Agency to reduce particulate matter and hydrocarbons in exhaust, but these standards only lessen, not reduce pollutants. All snowmobiles with combustion engines emit polycyclic aromatic hydrocarbons (PAH) and other pollutants.[208] PAHs are highly persistent in the environment and can accumulate in plant and animal tissues, do not easily dissolve in water, and readily settle on the bottom of lakes and streams adhering to sediment particles.[209]

A study on the Medicine-Bow National Forest documented a decline in air quality with increased snowmobile activity, attributable to snowmobile exhaust.[210] This study measured ambient concentrations of CO2, NOx, NO, and NO2 at a snowmobile staging site and found significantly higher concentrations of these pollutants on days with significantly more snowmobile activity.

Not only do OSVs create localized air pollution, this pollution settles into the snowpack and affects snow chemistry, potentially affecting water quality once the snow melts. Two stroke engines discharge a significant percent of their fuel mixture unburned directly onto the snow.[211] Several studies conducted across the United States have found that snow from roadways used by snowmachines contains detectable concentrations of several volatile organic compounds (VOCs), including benzene, methyl tert-butyl ether, m- and p-xylene, o-xylene, and toluene.[212] Musselman and Kormacher (2007) found several changes to snow chemistry on snowmobile trails when compared to untracked snow, including elevated numbers of cations and some anions and a significant drop in pH.[213] A study in Yellowstone – where regulations only allow for "best available technology" snowmobiles – detected concentrations of VOCs in snowmelt in areas that receive high levels of OSV use.[214] Additionally, this study found that snowmelt transported these VOCs to rivers and streams as the snow melted, but at diluted concentrations that are unlikely to pose a danger to aquatic systems. This same study documented large amounts of petroleum-based products in snowmelt, and raised concerns about PAHs in snowmelt and surface water.[215] In the Lake Tahoe Basin, researchers documented significantly greater concentrations of PAH in snow in areas with concentrated snowmobile tracks, and detected PAH in snowmelt and surface water samples in areas with heavy snowmobile activity as well.[216] This study found that PAH concentrations in snowmelt from areas with heavily snowmobile use was as much as six times higher as in areas without snowmobile traffic.

207 Environmental Protection Agency (EPA), 2002.
208 McDaniel, M. and B. Zielinska. 2015.
209 Agency for Toxic Substances and Disease Registry (ATSDR). 1995.
210 Musselman, Robert & Korfmacher, John. 2007.
211 California Air Resources Board. 1999.
212 Arnold, J.L. and T.M. Koel, 2007.
213 Musselman, Robert & Korfmacher, John. 2007.
214 Arnold, J.L. and T.M. Koel, 2007.
215 *Id.*
216 McDaniel, M. and B. Zielinska. 2015.

Photo: Kevin Kobe

Conclusion

The existing body of evidence indicates that winter recreation can have a substantial impact on wildlife and natural resources if not properly managed. Given our growing understanding of the catastrophic declines in biodiversity, along with fast-increasing pressures of habitat fragmentation from climate change, increased and expanding recreation use and development, we must incorporate this science into sound recreation management that errs on the side of conservation and protection of species and natural resources.

Photo: 6 AXIS AERIAL

Works Cited

Adams, J.C., and S.F. McCool. 2010. Finite Recreation Opportunities: The Forest Service, the Bureau of Land Management, and Off-Road Vehicle Management. Natural Resources Journal 49:45-116.

Agency for Toxic Substances and Disease Registry (ATSDR). 1995. Toxicological profile for polycyclic aromatic hydrocarbons (PAH's). U.S. Department of Health and Human Services, Public Health Service, Atlanta, Ga.

Andrus, K. J. 2005. A heli-skiing and mountain goat (Oreamnus americanus) habitat management model: a case study of the Skeena region interim wildlife management objectives. Thesis, Royal Roads University, Victoria, British Columbia, Canada.

Arlettaz, R., Nusslé, S., Baltic, M., Vogel, P., Palme, R., Jenni-Eiermann, S., Patthey, P., and Genoud, M. 2015. Disturbance of wildlife by outdoor winter recreation: allostatic stress response and altered activity–energy budgets. Ecological Applications 25(5):1197-1212.

Arlettaz, R.; Patthey, P.; Baltic, M.; Leu, T.; Schaub, M.; Palme, R.; Jenni- Eiermann, S. 2007. Spreading free-riding snow sports represent a novel serious threat for wildlife. Proceedings of the Royal Society of London, Series B: Biological Sciences. 274: 1219–1224.

Arnold, J.L. and T.M. Koel, 2007. Effects of snowmobile emissions on the chemistry of snowmelt runoff in Yellowstone National Park. Yellowstone National Park, Center for Resources, Fisheries and Aquatic Sciences Section.

Aubry, K. B., G. M. Koehler, and J. R. Squires. 2000. Ecology of Canada lynx in southern boreal forests. Pages 373–396 in L. F. Ruggiero, K. B. Aubry, S. W. Buskirk, G. M. Koehler, C. J. Krebs, K. S. McKelvey, and J. R. Squires, editors. Ecology and conservation of lynx in the United States. University Press of Colorado. Boulder, Colorado, USA.

Aune, K. E. 1981. Impacts of winter recreationists on wildlife in a portion of Yellowstone National Park, Wyoming. Thesis, Montana State University, Bozeman, Montana, USA

Baker, E. and Bithmann, E., 2005. Snowmobiling in the Adirondack Park: Environmental and Social Impacts. St. Lawrence University, Department of Biology.

Barber, J. R., K.R. Crooks, and K.M Fristrup. 2010. The Costs of Chronic Noise Exposure for Terrestrial Organisms. Trends Ecology and Evolution 25:180-189.

Bateman, P.W. and Fleming, P.A. 2017. Are negative effects of tourist activities on wildlife over-reported? A review of assessment methods and empirical results. Biological Conservation 211: 10–19.

Borkowski et al. 2006, Dorrance et al. 1975, Cassirer et al. 1992

Borkowski, J. J., P. J. White, R. a Garrott, T. Davis, A. R. Hardy, and D. J. Reinhart. 2006. Behavioral responses of bison and elk in Yellowstone to snowmobiles and snow coaches. Ecological Applications 16:1911–1925.

Brander, R.B. 1974. Outdoor recreation research: applying the results: ecological impacts of off-road recreation vehicles. North Central Forest Experiment Station, USDA Forest Service St. Paul, MN. General Technical Report NC-9.

Braunisch, V.; Patthey, P.; Arlettaz, R.L. 2011. Spatially explicit modeling of conflict zones between wildlife and snow sports: prioritizing areas for winter refuges. Ecological Applications 21(3):955–967.

Bull E.L. and T. W. Heater. 2001. Survival, Causes of Mortality, and Reproduction in the American Marten in Northeastern Oregon Northwestern Naturalist Vol. 82, No. 1(1-6).

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

Burghardt-Dowd, J. L. 2010. Coyote diet and movements in relation to winter recreation in northwestern Wyoming: Implications for lynx conservation. Thesis, Utah State University, Logan, UT, USA.

Burson, S. 2008. Natural soundscape monitoring in Yellowstone National Park December 2007– March 2008. National Park Service, Yellowstone Center for Resources, Mammoth, WY.

Burson, S. 2017. Winter Acoustic Monitoring in Yellowstone National Park December 2017-March 2018. National Park Service, Yellowstone Center for Resources, Mammoth, WY.

Buskirk, S. and L. Ruggiero. 1994. American Marten. In: L.F. Ruggiero, et al., technical editors. 1994. The scientific basis for conserving forest carnivores: American marten, fisher, lynx and wolverine in the Western United States. General Technical Report RM--254. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. Ft. Collins, CO. 184 pages.

Buskirk, S. W. and W. J. Zielinski. 2003. Small and mid-sized carnivores. Pages 207-249 In: C. Zabel and B. Anthony, editors. Mammal Community Dynamics: Management and Conservation in the Coniferous Forests of Western North America, Cambridge University Press, Cambridge, UK.

Buskirk, S. W., L. F. Ruggiero, and C. J. Krebs. 2000. Habitat fragmentation and interspecific competition: implications for lynx conservation. Pages 83–100 in L. F. Ruggiero, K. B. Aubry, S. W. Buskirk, G. M. Koehler, C. J. Krebs, K. S. McKelvey, and J. R. Squires, editors. Ecology and conservation of lynx in the United States. University Press of Colorado. Boulder, Colorado, USA.

Cadsand, B. A. 2012. Responses of mountain goats to heli-skiing activity: movements and resource selection. Thesis, University of Northern British Columbia, Prince George, British Columbia, Canada.

California Air Resources Board Fact Sheet, 2/99. 1999. "New Regulations for Gasoline Engines" found at Fact Sheet: 1999-02-00 New Regulations for Gasoline Marine Engines.

Carroll, C. 2007. Interacting effects of climate change, landscape conversion, and harvest on carnivore populations at the range margin: marten and lynx in the Northern Appalachians. Conservation Biology 21: 1092-1104.

Carroll, C., Noss, R. F., & Paquet, P. C. 2001. Carnivores as focal species for conservation planning in the Rocky Mountain region. Ecological Applications, 11(4): 961-980.

Cassirer, E., Freddy, D., and Ables, E. 1992. Elk responses to disturbance by cross-country skiers in Yellowstone National Park. Wildlife Society Bulletin 20(4):375-381.

Ciuti, S., Northrup, J. M., Muhly, T. B., Simi, S., Musiani, M., Pitt, J. A., & Boyce, M. S. 2012. Effects of humans on behavior of wildlife exceed those of natural predators in a landscape of fear. PloSONE 7(11): e50611.

Claar, J.J, N. Anderson, and D. Boyd [et al.]. 1999. Carnivores. In: Joslin, G., H. Youmans, cords. Effects of recreation on Rocky Mountain wildlife: a review for Montana. Helena, MT: Committee on Effects of Recreation on Wildlife, Montana Chapter of The Wildlife Society: 7.1-7.63.

Colescott, J.H. and M.P. Gillingham 1998. Reaction of moose (Alces alces) to snowmobile traffic in the Greys River Valley, Wyoming. Alces 34(2):329-338.

Côté, S. D., S. Hamel, A. St-Louis, and J. Mainguy. 2013. Do mountain goats habituate to helicopter disturbance? Journal of Wildlife Management 77:1244-1248.

Côté, S.D. 1996. Mountain goat responses to helicopter disturbance. Wildlife Society Bulletin 24(4):681-685.

Courtemanch, A.B. And M.J. Kauffman. 2014. Seasonal Habitat Selection and Impacts of Backcountry Recreation on a Formerly Migratory Bighorn Sheep Population in Northwest Wyoming, USA. University of Wyoming.

Creel, S., J. E. Fox, A. Hardy, J. Sands, B. Garrott, and R. O. Peterson. 2002. Snowmobile Activity Responses in Wolves and Glucocorticoid Stress Elk. Conservation Biology 16:809–814.

Crupi A.P., D.P. Gregovich, and K.S. White. 2020. Steep and deep: Terrain and climate factors explain brown bear (Ursus arctos) alpine den site selection to guide heli-skiing management. PLoS ONE 15(9): e0238711

Dorrance, M. J., P. J. Savage, and D. E. Huff. 1975. Effects of Snowmobiles on White-Tailed Deer. Journal of Wildlife Management 39:563–569.

Douglas, C.W., and M.A. Strickland. 1987. Fisher. Pages 511-529 in M. Novak, J.A. Baker, M.E. Obbard, and B. Malloch (eds.): Wild furbearer management and conservation in North America. Ontario Ministry of Natural Resources and Ontario Trappers Association, North Bay, Canada. 1150 pp.

Droghini, A. and S. Boutin. 2017. Snow conditions influence gray wolf (Canis lupus) travel paths: the effect of human-created linear features. Canadian Journal of Zoology 96(1):39-47.

Eckstein, R.G., T.F. O'Brien, O.J. Rongstad, and J.G. Bollinger. 1979. Snowmobile effects on movements of white-tailed deer: a case study. Environmental Conservation 6:45–51.

Environmental Protection Agency (EPA), 2002. Environmental Impacts of Newly Regulated Non-road Engines: Frequently Asked Questions. Environmental Protection Agency, Office of Transportation and Air Quality, Washington, D.C.

Fassnacht, S. R., J.T. Heath, N.B.H. Venable and K. J. Elder. 2018. Snowmobile impacts on snowpack physical and mechanical properties. The Cryosphere 12:1121–1135.

Ferguson, M. A., and Keith, L. B. 1982. Influence of Nordic skiing on distribution of moose and elk in Elk Island National Park, Alberta. Canadian Field Naturalist 96(1):69-78.

Foster, B. R., and E. Y. Rahs. 1982. Implications of maternal separation on overwinter survival of mountain goat kids. Proceedings of the Biennial Symposium of the Northern Wild Sheep and Goat Council 3:351-363.

Freeman, N. L. 2008. Motorized backcountry recreation and stress response in mountain caribou (Rangifer tarandus caribou). Ph.D. dissertation, University of British Columbia.

Freimund, W., M. Patterson, K. Bosak, and S. Walker Saxen. 2009. Winter experiences of Old Faithful visitors in Yellowstone National Park. University of Montana, Missoula, MT.

Fuller, T.K. 1991. Effect of snow depth on wolf activity and prey selection in north central Minnesota. Canadian Journal of Zoology. 69(2): 283–287.

Goldstein, M. I., A. J. Poe, E. Cooper, D. Youkey, B. A. Brown, and T. L. McDonald. 2005. Mountain goat response to helicopter overflights in Alaska. Wildlife Society Bulletin 33:688-699.

Goldstein, M. I., A. J. Poe, L. H. Suring, R. M. Nielson, and T. L. McDonald. 2010. Brown Bear Den Habitat and Winter Recreation in South-Central Alaska. Journal of Wildlife Management 74:35–42.

Goodrich, J.M.; Berger, J. 1994. Winter recreation and hibernating black bears Ursus americanus. Biological Conservation. 67: 105–110.

Goodwin, S.E., and W.G. Shriver. 2010. Effects of traffic noise on occupancy patterns of birds. Conservation Biology 25:406-411.

Hamel, S. and S.D. Côté. 2007. Habitat Use Patterns in Relation to Escape Terrain: Are Alpine Ungulate Females Trading Off Better Foraging Sites for Safety? Canadian Journal of Zoology 85:933–943.

Harris, G., Nielson, R.M., and Rinaldi, T. 2014. Effects of winter recreation on northern ungulates with focus on moose (Alces alces) and snowmobiles. European Journal of Wildlife Research 60:45–58.

Hastings, A.L., G.G. Fleming, and C.S.Y. Lee. 2006. Modeling sound due to over-snow vehicles in Yellowstone and Grand Teton National Parks. Report DOT-VNTSC-NPS-06- 06, Volpe Transportation Center, Cambridge, MA.

Heinemeyer K., J. Squires, M. Hebblewhite, J.J. O'Keefe, J.D. Holbrook, and J. Copeland. 2019. Wolverines in Winter: Indirect Habitat Loss and Functional Responses to Backcountry Recreation. Ecosphere 10 (2): e02611.

Heinemeyer, K. and J. Squires. 2013. Wolverine-winter recreation research project: Investigating the interactions between wolverines and winter recreation use: 2013 progress report. Round River Conservation Studies, Salt Lake City, Utah, USA.

Hilderbrand, G. V., Lewis, L. L., Larrivee, J., and Farley, S. D. 2000. A denning brown bear, Ursus arctos, sow and two cubs killed in an avalanche on the Kenai Peninsula, Alaska. Canadian Field-Naturalist, 114(3):498.

Hodgman, T.P., D.J. Harrison, D.D. Katnik, and K.D. Elowe. 1994. Survival in an intensively trapped marten population in Maine. The Journal of Wildlife Management 58(4):593-600.

Hornocker, M.G., and H.S. Hash. 1981. Ecology of the wolverine in northwestern Montana. Canadian Journal of Zoology 59:1286–1301.

Inman, R.M., K.H. Inman, M.L. Packila, and A.J. McCue. 2007. Wolverine reproductive rates and maternal habitat in Greater Yellowstone. In: Wildlife Conservation Society, Greater Yellowstone Wolverine Program, Cumulative Report, May 2007.

Interagency Lynx Biology Team. 2013. Canada lynx conservation assessment and strategy. 3rd edition USDA Forest Service, USDI Fish and Wildlife Service, USDI Bureau of Land Management, and USDI National Park Service. Forest Service Publication #R1-13-19, Missoula, Montana. 128 pp.

Jarvinen, J.A. and W.D. Schmid. 1971. Snowmobiles use and winter mortality of small mammals. In Chubb, M. (ed.) Proceedings of the Snowmobile and Off the Road Vehicle Research Symposium. College of Agriculture and Natural Resources, Department of Park and Recreation Resources, Recreation Resources and Planning Unit, Tech. Rep. 8, Michigan State University, East Lansing, MI.

Johnston, K. M., K. A. Freund, and O. J. Schmitz. 2012. Projected range shifting by montane mammals under climate change: implications for Cascadia's National Parks. Ecosphere 3(11):97. 17 pp.

Johnston, K. M., K. A. Freund, and O. J. Schmitz. 2012. Projected range shifting by montane mammals under climate change: implications for Cascadia's National Parks. Ecosphere 3(11):97. 17 pp.

Joslin, G. 1980. Mountain goat habitat management plan for the Cabinet Mountains. Montana Fish Wildlife & Parks, Ecological Services Division. Helena, Montana, USA

Joslin, G. 1986. Mountain goat population changes in relation to energy exploration along Montana's Rocky Mountain front. Proceedings of the Biennial Symposium of the Northern Wild Sheep and Goat Council 5:253-269.

Joslin, G., and H. Youmans, editors. 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, Helena, Montana, USA.

Kaisanlahti-Jokimaki, M., Jokimaki, J., Huhta, E., Ukkola, M., Helle, P., and Ollila, T. 2008. Territory occupancy and breeding success of the Golden Eagle (Aquila chrysaetos) around tourist destinations in northern Finland. Ornis Fennica 85(1): 2-12

Keddy, P.A., Spavold, A.J., and Keddy, C.J., 1979. Snowmobile Impact on Old Field and March Vegetation in Nova Scotia, Canada: An Experimental Study. Environmental Management. 3(5):409-415.

Keller, B.J. And L.C. Bender. 2007. Bighorn sheep response to road-related disturbances in Rocky Mountain National Park, Colorado. Journal of Wildlife Management 71:2329–2337.

Keyel, A.C., S.E. Reed, K. Nuessly, E. Cinto-Mejia, J.R. Barber and G. Wittemyer. 2018. Modeling anthropogenic noise impacts on animals in natural areas. Landscape and Urban Planning 180: 76–84.

Knight, R.L., and D. N. Cole. 1991. Effects of recreational activity on wildlife in wildlands. Transactions of the North American Wildlife and Natural Resource Conference 56:238-247

Koehler, G. M. and J. D. Brittell. 1990. Managing spruce-fir habitat for lynx and snowshoe hares. Journal of Forestry 88:10–14.

Koehler, G. M. and K. B. Aubry. 1994. Lynx. Pages 74-98 In L. F. Ruggiero, K. B. Aubry, S. W. Buskirk, and W. J. Zielinski, editors. The scientific basis for conserving forest carnivores: American marten, fisher, lynx, and wolverine. USDA Forest Service, Rocky Mountain Forest and Range Experimental Station, Fort Collins, Colorado, USA.

Kolbe, J. A., J. R. Squires, D. H. Pletscher, and L. F. Ruggiero. 2007. The effect of snowmobile trails on coyote movements within lynx home ranges. Journal of Wildlife Management 71:1409–1418.

Krebs, J., E.C. Lofroth, and I. Parfitt. 2007. Multiscale habitat use by wolverines in British Columbia, Canada. Journal of Wildlife Management 71:2180–2192.

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

Krohn, W.B. 2012. Distribution changes of American Martens and Fishers in Eastern North America, 1699–2001. Pp. 58-73, in K.B. Aubry, W.J. Zielinski, M.G. Raphael, G. Proulx, and S.W. Buskirk (eds.). Biology and Conservation of Martens, Sables, and Fishers: a New Synthesis. Cornell University Press, Ithaca, NY. Kyle, C.J., and C. Strobeck. 2001. Genetic structure of North American wolverine (Gulo gulo) populations. Molecular Ecology 10:337-347.

Krohn, W.B., S.M. Arthur, and T.F. Paragi. 1994. Mortality and vulnerability of a heavily trapped fisher population. Pages 137-145 in S.W. Buskirk, A.S. Harestad, M.G. Raphael, and R.A. Powell (eds.): Martens, sables and fishers: biology and conservation. Ithaca, New York, USA: Cornell University Press. 484 pp.

Larson, C.L., Reed, S.E., Merenlender, A.M., and Crooks, K.R. 2016. Effects of recreation on animals revealed as widespread through a global systematic review. PLoSONE 11(12): e0167259.

Lesmerises, F., Déry, F., Johnson, C. J., and St-Laurent, M. H. 2018. Spatiotemporal response of mountain caribou to the intensity of backcountry skiing. Biological Conservation 217:149-156.

Linnell, J.D.C., J.E. Swenson, R. Andersen, B. Brain. 2000. How Vulnerable are Denning Bears to Disturbance? Wildlife Society Bulletin 28(2):400-413.

Litvaitis, J. A. 1992. Niche relations between coyotes and sympatric Carnivora. Pages 73-85 in A. H. Boer, editor. Ecology and management of the eastern coyote. University of New Brunswick Wildlife Research Unit, Fredericton, New Brunswick, Canada.

Longshore, K. And D.B. Thompson. 2013. Detecting short-term responses to weekend recreation activity: Desert bighorn sheep avoidance of hiking trails. Wildlife Society Bulletin 37:698–706.

Macarthur, R.A., R.H. Johnston and V. Geist. 1979. Factors influencing heart rate in free-ranging bighorn sheep: a physiological approach to the study of wildlife harassment. Canadian Journal of Zoology 57:2010–2021.

Magoun, A. J., and J. P. Copeland. 1998. Characteristics of wolverine reproductive den sites. Journal of Wildlife Management 62:1313–1320.

May, R., A. Landa, J. van Dijk, J.D.C. Linnell, and R. Andersen. 2006. Impact of infrastructure on habitat selection of wolverines Gulo gulo. Wildlife Biology 12: 285–295.

McClure, C.J.W., H.E. Ware, J. Carlisle, G. Kaltenecker, and J.R. Barber. 2013. An experimental investigation into the effects of traffic noise on distributions of birds: Avoiding the phantom road. Proceedings of the Royal Society B 280:20132290.

McDaniel, M. and B. Zielinska. 2015. Polycyclic aromatic hydrocarbons in the snowpack and surface water in Blackwood Canyon, Lake Tahoe, CA, as related to snowmobile activity. Polycyclic Aromatic Compounds 35(1):102-119.

McKay, R. 1991. Biological assessment and inventory plan for the North American lynx (Lynx canadensis) in the Uinta Mountains. Prepared for Ashley National Forest and Utah Natural Heritage Program, Salt Lake City.

Mech, D.L. 1970. The wolf: the ecology and behavior of an endangered species. Natural History Press for the American Museum of Natural History, New York.

Menge CW and Ross JC. 2000. Measurement and modeling of snowmobile noise and audibility at Yellowstone and Grand Teton National Parks. In Noise-CON: Noise-CON 2000. Newport Beach, CA. December 3-5, 2000. Noise-CON.

Miller, A.B. King, D., Rowland, M., Chapman, J., Tomosy, M., Liang, C., Abelson, E.S. and Truex, R. 2020. Sustaining wildlife with recreation on public lands: a synthesis of research findings, management practices, and research needs. General Technical Report PNW-GTR-993. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 226 p.

Moriarty, K.M. 2014. Habitat use and movement behavior of Pacific Marten (Martes caurina) in response to forest management practices in Lassen National Forest, California. Ph.D. dissertation, Oregon State University. 145 pages.

Mullet, T. C., S.H. Gage, J.M. Morton, and F. Huettmann. 2016. Temporal and spatial variation of a winter soundscape in South-Central Alaska. Landscape Ecology 31(5):1117-1137.

Mullet, T.C and J. M. Morton. 2021. Snowmobile effects on height and live stem abundance of wetland shrubs in South-Central Alaska. Journal of Outdoor Recreation and Tourism (33): 100347.

Mullet, T.C. 2014. Effects of snowmobile noise and activity on a boreal ecosystem in southcentral Alaska. Thesis (Ph.D.) University of Alaska Fairbanks. 262 pgs.

Mullet, T.C., J.M. Morton, S.A. Gage and F. Huettmann. 2017. Acoustic footprint of snowmobile noise and natural quiet refugia in an Alaskan wilderness. Natural Areas Journal 37(3): 332-349.

Murray, D. L. and S. Boutin. 1991. The influence of snow on lynx and coyote movements: does morphology affect behavior? Oecologia. 88:463–469.

Murray, D. L., S. Boutin, M. O'Donoghue, and V. O. Nams. 1995. Hunting behavior of sympatric felid and canid in relation to vegetative cover. Animal Behavior 50:1203–1210.

Musselman, Robert & Korfmacher, John. 2007. Air quality at a snowmobile staging area and snow chemistry on and off trail in a Rocky Mountain subalpine forest, Snowy Range, Wyoming. Environmental Monitoring and Assessment. 133: 321-34.

Naney, R. H., L. L Finley, E. C. Lofroth, P. J. Happe, A. L. Krause, C. M. Raley, R. L. Truex, L. J. Hale, J. M. Higley, A. D. Kosic, J. C. Lewis, S. A. Livingston, D. C. Macfarlane, A. M. Myers, and J. S. Yaeger. 2012. Conservation of Fishers (Martes pennanti) in South-Central British Columbia, Western Washington, Western Oregon, and California–Volume III: Threat Assessment. USDI Bureau of Land Management, Denver, Colorado, USA. 65 pp.

Naylor, L. M., Wisdom, M. J., and Anthony, R. G. 2009. Behavioral responses of North American elk to recreational activity. The Journal of Wildlife Management 73(3):328-338.

Nelson, M.E., and Mech, L.D. 1986. Relationship between snow depth and gray wolf predation on white-tailed deer. Journal of Wildlife Management. 50(3): 471–474.

Nepal, N. 2014. A geospatial approach to wildlife and wilderness management. Dissertation, University of New Mexico, Albuquerque, New Mexico, USA.

Neumann, P.W. and H.G. Merriam. 1972. Ecological effects of snowmobiles. The Canadian Field Naturalist. 86: 207-212.

Neumann, P.W., Merriam, H.G. 1972. Ecological effects of snowmobiles. The Canadian Field Naturalist 86: 207-212.

Neumann, W., G. Ericsson, and H. Dettki. 2009. Does off-trail backcountry skiing disturb moose? European Journal of Wildlife Research 56:513–518.

Olliff, T., K. Legg, and B. Kaeding, editors. 1999. Effects of winter recreation on wildlife of the Greater Yellowstone Area: a literature review and assessment. Report to the Greater Yellowstone Coordinating Committee. Yellowstone National Park, Wyoming. 315 pages.

Olson, L.E.; Squires, J.R.; Roberts, E.K.; Ivan, J.S., and Hebblewhite, M. 2018. Sharing the same slope: behavioral responses of a threatened mesocarnivore to motorized and nonmotorized winter recreation. Ecology and Evolution 8:8555–8572.

Ortega, C.P. 2012. Effects of noise pollution on birds: A brief review of our knowledge. Ornithological Monographs 74:6-22.

Ozoga, J. J. and E. M. Harger. 1966. Winter activities and feeding habits of northern Michigan coyotes. Journal of Wildlife Management 30:809–818.

Papouchis, C.M., F.J. Singer and W.B. Sloan. 2001. Responses of Desert Bighorn Sheep to Increased Human Recreation. The Journal of Wildlife Management 65:573–582.

Paquet, P. C., Alexander, S., Donelon, S., and Callaghan, C. 2010. Influence of anthropogenically modified snow conditions on wolf predatory behavior. In The World of Wolves: New Perspectives on Ecology, Behavior, and Management, p.157-174.

Parker, K.L., Robbins, C.T. and Hanley, T. A. 1984. Energy expenditures for locomotion by mule deer and elk. Journal of Wildlife Management 48:474–488.

Peacock, Synte. 2011. Projected 21st century climate change for wolverine habitats within the contiguous United States. Environmental Research Letters 6.1: 014007.

Pederson, G.T., L.J. Graumlich, D.B. Fagre, T. Kipfer and C.C. Muhlfeld. 2010. A century of climate and ecosystem change in Western Montana: what do temperature trends portend? Climatic Change 96: DOI 10.1007/s10584-009-9642-y, 22pp.

Penner, D. F. 1988. Behavioral response and habituation of mountain goats in relation to petroleum exploration at Pinto Creek, Alberta. Proceedings of the Biennial Symposium of the Northern Wild Sheep and Goat Council 6:141-158.

Podruzny, S., S. Cherry, C. Schwartz, and L. Landenburger. 2002. Grizzly bear denning and potential conflict areas in the Greater Yellowstone Ecosystem. Ursus 13:19-28.

Portier, C., M. Festa-Bianchet, J.M. Gaillard, J.T.J orgenson and N.G. Yoccoz. 1998. Effects of density and weather on survival of bighorn sheep lambs (Ovis canadensis). Journal of Zoology 245:271–278.

Powell, R.A., and W. J. Zielinski. 1994. Fisher. Pages 38-73 in L.F. Ruggeiro, K.B. Aubry, S.W. Buskirk, L.J. Lyon and W.J.

Zielinski (tech. eds.): The scientific basis for conserving forest carnivores: American marten, fisher, lynx, and wolverine in the western United States. U.S. Department of Agriculture, Forest Service, General Technical Report RM-254.

Pozzanghera, C. B., Sivy, K. J., Lindberg, M. S., and Prugh, L. R. 2016. Variable effects of snow conditions across boreal mesocarnivore species. Canadian Journal of Zoology 94(10):697-705.

Richard, J. H., and S. D. Coté. 2016. Space Use Analyses Suggest Avoidance of a Ski Area by Mountain Goats. The Journal of Wildlife Management 80(3):387-395.

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

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

Ruggiero, L. F., K. S. McKelvey, K. B. Aubry, J. P. Copeland, D. H. Pletscher, and M. G. Hornocker. 2007. Wolverine conservation and management. Journal of Wildlife Management 71:2145–2146.

Sanecki, G. M., K. Green, H. Wood, and D. Lindenmayer. 2006. The implications of snow-based recreation for small mammals in the subnivean space in south-east Australia. Biological Conservation 129:511–518.

Seip, D.R.; Johnson, C.J. and G.S. Watts. 2007. Displacement of mountain caribou from winter habitat by snowmobiles. Journal of Wildlife Management 71(5):1539–1544.

Simpson, K. and Terry, E. 2000. Impacts of backcountry recreation activities on mountain caribou–management concerns, interim management guidelines and research needs. British Columbia Ministry of Environment, Lands and Parks, Wildlands Branch, Victoria, BC. Wildlands Working Report Number WR-99. 11pp, 3.

Slauson, K. M., Zielinski, W. J., and Schwartz, M. K. 2017. Ski areas affect Pacific marten movement, habitat use, and density. The Journal of Wildlife Management 81(5):892-904.

Slauson, K.M. and K.M. Moriarty. 2010. Synthesis of Marten Ecology and Multi-Scale Habitat Selection. Public presentation at the Truckee Ranger District Office, Truckee California.

Squires, J. R., L. E. Olson, E. K. Roberts, J. S. Ivan, and M. Hebblewhite. 2019. Winter recreation and Canada lynx: reducing conflict through niche partitioning. Ecosphere 10(10): e02876. 10.1002/ecs2.2876.

Stankowich, T. 2008. Ungulate flight responses to human disturbance: A review and meta-analysis. Biological Conservation 141:2159–2173.

Switalksi, T.A. and A. Jones. 2012. Off-road vehicle best management practices for forestlands: A review of scientific literature and guidance for managers. Journal of Conservation Planning 8(2012): 12 – 24.

Switalski, A. 2016(a) Snowmobile Best Management Practices for Forest Service Travel Planning: A Comprehensive Literature Review and Recommendations for Management – Water Quality, Soils, and Vegetation. Journal of Conservation Planning 12: 8-12.

Switalski, A. 2016(b). Snowmobile Best Management Practices for Forest Service Travel Planning: A Comprehensive Literature Review and Recommendations for Management – Wildlife. Journal of Conservation Planning 12: 13-20.

Tomeo, M.A. 2000. Fecal measurement of stress responses to snowmobiles in moose (Alces alces). Thesis in partial fulfillment of the requirements for the Master of Science in Environmental Science degree Alaska Pacific University. 48 pgs.

U.S. Fish and Wildlife Service. 2019. Final Rule for Endangered Species Status for Southern Mountain Caribou Distinct Population Segment. Federal Register 84(191):52598-52661.

Vittersø, J., R. Chipeniuk, M. Skår, and O. I. Vistad. 2004. Recreational Conflict Is Affective: The Case of Cross-Country Skiers and Snowmobiles. Leisure Sciences 26:227–243

Wanek, W. J. 1974. The ecological impact of snowmobiling in northern Minnesota.In: D. F. Holecek (Ed.), Proceedings of the 1973 Snowmobile and Off the Road Vehicle Research Symposium, Michigan State University. pp. 57–76.

Weaver, J. 1993. Lynx, wolverine, and fisher in the western United States: research assessment and agenda. U.S. Forest Service Intermountain Research Station Contract Number 43-0353-2-0598.

Wengert, G.M., M.W. Gabriel, S.M. Matthews, J.M. Higley, R.A. Sweitzer, C.M. Thompson, K.L. Purcell, R.H. Barrett, L.W. Woods, R.E. Green, S.M. Keller, P.M. Gaffney, M. Jones, and B.N. Sacks. 2014. Using DNA to describe and quantify interspecific killing of fishers in California. Journal of Wildlife Management 78(4):603-611.

Whiteman, J.P. and Buskirk, S.W. 2013. Foot load influences wildlife use of compacted trails in the snow. Wildlife Biology 19(2):156–164.

Wiedmann, B.P. And V.C. Bleich. 2014. Demographic responses of bighorn sheep to recreational activities: A trial of a trail. Wildlife Society Bulletin 38:773–782.

Wisdom, M. J., Ager, A. A., Preisler, H. K., Cimon, N. J., and Johnson, B. K. 2004. Effects of off-road recreation on mule deer and elk. In: Transactions of the 69th North American Wildlife and Natural Resources Conference: 531-550.

Witmer, G. W., S. K. Martin, and R. D. Sayler. 1998. Forest carnivore conservation and management in the interior Columbia basin: issues and environmental correlates. General Technical Report PNW--GTR--420. Portland, OR: USDA Forest Service, Pacific Northwest Resear

WINTER WILDLANDS ALLIANCE

Winter Recreation Impacts Report

BEST AVAILABLE SCIENCE, MAY 2021

Photo: Josh Metten