ENVIRONMENTAL IMPACTS
FROM SNOWMOBILE USE

Scientific evidence indicates that over-snow vehicles (OSVs) produce significant impacts on animals, plants, soils, air and water quality, and the ecology of entire winter ecosystems. OSV impacts to wildlife and wildlands represent a negative cycle where one impact leads to and compounds the next, and where the synergistic impacts cascade into major, long-term, and potentially cumulative adverse impacts. While the severity of OSV impacts will differ depending on the site-specific characteristics of an area, OSV use clearly impacts any winter ecosystem on which it occurs.

WHAT’S INSIDE

- **IMPACTS TO WILDLIFE**
  Snowmobile noise and activity disturbs wintering wildlife - causing stress, elevated energy expenditures, and changes in habitat use. In turn, these impacts can displace wildlife from their preferred habitat or even reduce an animal’s chances of surviving the winter.

- **IMPACTS TO AQUATIC AND TERRESTRIAL ECOSYSTEMS**
  Pollution from snowmobile exhaust accumulates in the snowpack and is released during spring snowmelt, elevating the acidity of nearby surface waters.

- **SOIL AND VEGETATION DAMAGE**
  Snowmobiles cause significant damage to land cover through direct physical injury to plants and increased erosion in areas with inadequate snow cover. Snowmobiles compact the snow, affecting vegetation growth and development later in the year.

- **IMPACTS TO AIR AND WATER QUALITY**
  Snowmobile exhaust contains dangerous levels of airborne toxins including nitrogen oxides, carbon monoxide, ozone, aldehydes, butadiene, benzenes, and extremely persistent polycyclic aromatic hydrocarbons. These pollutants degrade air quality and alter snow chemistry.

- **NOISE POLLUTION**
  Snowmobiles are loud and can be heard across vast distances, severely affecting the winter soundscape. This noise disturbs wildlife and is a primary factor in non-motorized/motorized user conflict.
IMPACTS TO WILDLIFE

Over Snow Vehicles can cause mortality, habitat loss, and harassment of wildlife (Boyle and Samson 1985, Oliff et al. 1999). While most animals are well adapted to survival in winter conditions, the season creates added stress to wildlife due to harsher climate and limited foraging opportunities (Reinhart 1999). Deep snow can increase the metabolic cost of winter movements in ungulates up to five times normal levels (Parker et al. 1984) at a time when ungulates are particularly stressed by forage scarcity and high metabolic demands. Disturbance and stress to wildlife from snowmobile activities during this highly vulnerable time is dire. Studies of observable wildlife responses to snowmobiles have documented elevated heart rates, elevated glucocorticoid stress levels, increased flight distance, habitat fragmentation as well as community and population disturbance (Baker and Bithmann, 2005).

In addition to the direct physiological stress of snowmobiles, evidence suggests that popular winter trails can fragment habitat and wildlife populations. Winter trails through surrounding wilderness areas or other core areas create more “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 (Baker and Bithmann 2005).

In Yellowstone, Aune (1981) reported that heavy snowmobile traffic inhibits free movement of animals across roads to preferred grazing areas and temporarily displaces wildlife from areas immediately adjacent to the roads. Cole and Knight (1991) have also noted the displacement of elk along the roads during periods of fairly continuous travel by snowmobiles in the Madison and Firehole River Valleys of Yellowstone.

In many instances, snowmobiles induce animal flight, causing increased energy expenditures. In Yellowstone National Park, for example, evasive maneuvers in response to snowmobiles have been documented in a number of species, including elk and mule deer. These maneuvers result in increased energy expenditures for the affected wildlife. For example, Aune (1981) reported flight distances of 33.8 meters for elk and 28.6 meters for mule deer in response to snowmobiles in Yellowstone. The energy cost estimates calculated for these impacts were 4.9 to 36.0 kcal in elk and 2.0 to 14.7 kcal in mule deer per disturbance (Parker et. al., 1984). These energy expenditures are roughly equivalent to the necessary additional consumption of 4.3 - 31.7 grams of dry forage matter by elk and 1.8 - 12.9 grams by mule deer each time a disturbance occurs. Severinghaus and Tullar (1978) theorize that for white-tailed deer, during a 20-week winter with snowmobile harassment each weekend, “food enough for 40 days of normal living would be wasted just escaping from snowmobiles.”
It has been widely documented that snowmobile activity disturbs wintering ungulates through physiological stress (Canfield et al., 1999) resulting in increased movements (Dorrance et al., 1975; Eckstein et al., 1979; Aune 1981, Freddy et al., 1986; Colescott and Gillingham 1998) and higher energy expenditures (Canfield et al., 1999).

The flight response of ungulates to snowmobiles has been documented in a number of species (Aune, 1981; Hardy, 2001; Sevinhause and Tullar, 1978; and Freddy et al., 1986). In one study bison and elk responded to over-snow vehicles in Yellowstone National Park by increasing vigilance (looking around) and running away from approaching machines (Borkowski et al. 2006). Elk were more likely than bison to respond to OSVs and the intensity of both species’ response increased the closer they were to roads, the smaller the size of the group they were in, when actively approached by humans, or when herded by vehicles (Borkowski et al. 2006). Snowmobile activity has been shown to displace mule deer as well (Dorrance et al. 1975). A study conducted in Minnesota found that deer responded to even low intensities of snowmobile activity and as the amount of time that snowmobiles were in an area increased deer were more likely to change their behavior or flee. This disturbance resulted in displacement of deer from areas near snowmobile trails and increased home range sizes. However, there is evidence that wildlife may become habituated to snowmobiles if the activity is controlled, predictable, and does not cause physical harm (Dorrance et al. 1975, Borkowski et al. 2006).

Some species are more sensitive to disturbance than others. For example, mountain caribou have been almost completely displaced from high quality habitat in areas with intensive snowmobile activity. While other studies have shown smaller, localized, and short-duration displacement of wildlife due to snowmobiles (Dorrance et al. 1975, Borkowski et al. 2006), Seip et al. (2007) documented seemingly permanent displacement from an entire mountain block. Seip et al. (2007) postulated that this may be because the zone of influence of snowmobiles is larger than their actual footprint on the landscape and thus intensive use would effectively eliminate the habitat potential of an entire area. For example, other studies have shown that ATVs have an outsized impact on wildlife and can cause disturbance behavior in elk from over 1,000 meters away (Preisler, Ager, & Wisdom, 2006).

Of course, skiers and hikers also displace wildlife to some degree. In one study researchers found mule deer to be more disturbed by people walking down a trail than they were by a snowmobile on the same trail (Freddy et al. 1986). This paper is heavily cited by pro-snowmobile advocates, however, they usually fail to note the caveats: the researchers did not evaluate the effects of snowmobiles traveling at higher speeds and the study was confined to snowmobiles traveling in a predictable manner down an established trail. In addition, the researchers noted that deer likely had a longer response to people walking than a snowmobile because when walking it takes longer to pass the deer. In another study (Neumann et al. 2009) 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. Neumann et al. 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. They did not examine the effect of snowmobiles.

Norwegian scientists have documented the effect of both skiers and snowmobiles on wild reindeer behavior. Reindeer were displaced in both situations but fled further when approached by a skier (Reimers et al. 2003). Like in the mule deer study, however, the snowmobiles in this study moved slowly and predictably down an established trail. In addition, the study took place in an area where reindeer are hunted by humans on foot and where hunting from a vehicle is prohibited. Thus, the scientists postulated that reindeer associate people on foot with hunting and respond accordingly. Regardless of the source of the disturbance, Reimers et al. (2003) warned that increased human activity in reindeer habitat would lead in increased disturbance events and result in significant energy loss.
In addition to showing physical signs of disturbance, physiological indicators of snowmobile-induced stress have been documented in wildlife. Researchers have found that stress hormones in elk living in Yellowstone National Park fluctuated weekly, rising and falling in direct correlation with snowmobile activity (Creel, 2002). While snowmobile-caused stress has not yet been documented to be a chronic issue in wildlife, chronically elevated stress hormone levels can have a deleterious effect on wildlife and result in health and fitness costs (Creel et al. 2002).

Compaction of snow by snowmobiles may cause significant increases in energy costs by ungulates digging to access vegetation (Fancy and White 1985). Fancy and White (1985) reported that the amount of energy expended by caribou digging in snow to access forages was, on average, 118 J, 219 J, and 481 J per hoof stroke in uncrusted, hard crusted, and snowmobile compacted snow, respectively.

**Gray Wolf**

Snowmobiling has been shown to cause stress in wolves. In Minnesota fecal analysis was used to compare the hormone levels of wolves in Isle Royale, where there are no snowmobiles, to those of wolves in Voyageurs, where snowmobiling is pervasive. The Voyageurs wolves consistently exhibited higher levels of stress hormones (Creel, 2002). In addition, the scientists noted another direct relationship between snowmobiles and stress. When snowmobile use declined 37 percent in Voyageurs between the winters of 1999 and 2000, fecal stress hormone levels also dropped in the park’s wolf population by 37 percent (Creel, 2002).

**Grizzly Bear**

Though only a few National Forests are occupied by grizzly bears, it is important to consider how snowmobiles can impact this iconic species. Grizzly bears are most vulnerable to disturbance during hibernation and there is some evidence that both snowmobilers and backcountry skiers can disturb denning bears. However, scientists have been unable to fully quantify the extent of this problem (Podruzny et al. 2002, Goldstein et al. 2010). When bears are disturbed during hibernation they expend more energy than in their normal resting state. This is a concern as bears must live off of their energy reserves until they emerge from their dens in the spring. In addition, disturbances may cause bears to abandon their dens. In cases of females with cubs, den abandonment can lead to cub mortality if the cubs are left in the abandoned den or the new den is insufficient to protect the cubs from the elements. Finally, repeated or frequent disturbances can lead to total displacement from denning areas (Goldstein et al. 2010). It is suspected that snowmobile activity would have a detrimental effect on bears if use increases in denning areas. Therefore it is advisable to restrict snowmobile activity in areas that provide suitable denning habitat.

**Wolverine**

There is scientific uncertainty about the exact effects of snowmobiles on wolverines. However, compelling anecdotal evidence suggests snowmobile use displaces wolverines and may reduce reproductive success, especially when it occurs within potential wolverine denning habitat. Wolverine parturition primarily occurs mid-winter during the month of February (WCS, 2007). Six of the seven natal dens located in the Greater Yellowstone Ecosystem by the Wildlife Conservation Society (2007) were in areas without motorized use, i.e., designated wilderness, areas inaccessible by vehicle, or national park.
Other wolverine biologists have suggested refuge from human activity is important for wolverine reproduction (Banci, 1994; Magoun and Copland, 1996). Female wolverines appear to be quite sensitive to human disturbance in the vicinity of natal and maternal dens, and may abandon dens and move their kits a considerable distance if they detect human presence in the area (Copeland 1996, Magoun and Copeland 1998). In general it appears that wolverines are sensitive to human disturbance and are less likely to occur in areas with anthropogenic activity (Fisher et al. 2013).

**CANADA LYNX**

OSV trails that are created by winter recreation and forest management activities may enable coyotes to access lynx habitat not normally accessible to them (Koehler and Aubry 1994, Buskirk, 2000, Brannel, et. al., 2006). Coyotes aggressively compete with, or prey upon, a number of different vertebrate species, including Canada lynx, that are adapted and limited to deep snow (Buskirk et. al., 2000). Koehler and Aubry (1994) determined that inter-specific competition during late winter, a time when lynx are already nutritionally stressed, may be especially detrimental to lynx.

Snowmobile trails facilitate coyote movement into lynx habitat and may increase competition with, or predation of, lynx. However, snowmobile trails do not necessarily guarantee that interspecific competition between coyotes and lynx will increase. Coyotes travel on snowmobile trails, like many wildlife species, but the presence of trails does not necessarily affect coyote movements, presence, or foraging success (Kolbe et al. 2007). However, other researchers found that snow compaction from snowmobiles did influence coyote movements. They documented that coyotes intentionally traveled on snowmobile trails, particularly as snow depth and penetrability increased (Gese et al. 2013). Overall, snow characteristics appear to be the primary factor influencing whether coyotes use snowmobile trails (Gese et al. 2013).

**SUBNIVEAN MAMMALS**

Wildlife such as coyotes, bison, and elk utilize snowmobile trails because snow density is significantly higher, making travel easier. While this can benefit wildlife who travel on top of the snow, compacted snow fundamentally alters habitat quality in the subnivean zone (Keddy et al. 1979, Sanecki et al. 2006). Small mammals that remain active during the winter depend on the insulated space between the snowpack and ground for winter survival.

Winter temperatures, even with snow cover, are stressful to small mammals (Mezhzherin 1964, Schwartz et. al., 1964, Fuller 1969, Fuller et al. 1969, Brown 1970). Many small mammal species depend on the space between the frozen ground and the snow to live. When snow compaction from snowmobiles occurs, the subnivean (below snow) space temperatures decrease, which can lead to increased metabolic rates in these small mammal species. If the subnivean 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 (Neumann and Merriam, 1972).

Jarvinen and Schmid (1971) determined through controlled experiments that compaction due to snowmobile use reduced rodent and shrew use of subnivean habitats to near zero, and attributed this decline to direct mortality, not outmigration. In a study in Minnesota, Rongstad (1980) found that intensive snowmobiling on an old field eliminated the small mammal population in the layer between the ground and snow. Likewise, Sanecki et al. (2006) documented a decline in small mammals following destruction of the subnivean zone following snowmobile activity. Killing of subnivean species could well reduce the population of species preying upon them -- hawks, owls, foxes (Brander 1974). Population declines of small mammals undoubtedly impacts the species that prey upon them, creating ecosystem level disturbance.
Pollutants from snowmobile emission, including the highly persistent polycyclic aromatic hydrocarbons (PAH), are stored within the snowpack (Ingersoll, 1998). During spring snowmelt, these accumulated pollutants are released causing elevated acidity levels in surrounding waterways and resulting in higher death rates for aquatic insects and amphibians (Charette et. al., 1990). The impact of the spring release of pollutants may have far-reaching consequences for surrounding watersheds. Acidity fluctuations can disable a watershed's ability to regulate its own pH level, which could trigger system-wide problems and result in a long-term alteration of an entire ecosystem (Shaver et. al., 1998).

When two-stroke engines were used in Yellowstone toxic raw fuel and air emissions accumulated in the Park's snowpack along rivers, streams and lakes and roads where snowmobile use occurred. Ingersoll et. al., (1997) found increased levels of sulfates and ammonium in Yellowstone's snowpack compared to baseline conditions. Pollutants "locked" in the snowpack are released very rapidly during the first few days of snowmelt. Researchers found that 80 percent of acid concentrates are released in the first 20 percent of snowmelt, and that this acid pulse is a major cause of death for aquatic insects and amphibians (Hagen and Langeland, 1973). This acid pulse may also reduce the acid neutralizing capacity of aquatic systems, particularly those found at high elevations which typically are less capable of neutralizing acid deposition. In one study, Charette et al. (1990) determined that "during the spring melting, the massive liberation of atmospheric pollutants accumulated in the snow cover is connected to a very important increase of acidity, which may be more than 100 times higher than the usual acidity level in surface water."

Pollution from OSV exhaust contains a number of elements which are damaging to vegetation. While the amount of pollutants emitted by two-stroke engines are greater than those emitted by four-stroke engines, the elements in the emissions, except for the unburned fuel emitted by two-stroke engines, are similar and include: 1) carbon dioxide which may act as a fertilizer and cause changes in plant species composition (Bazzaz & Garbutt 1988, Ferris and Taylor 1995); 2) sulfur dioxide which is taken up by vegetation and can cause changes in photosynthesis (Iqbal 1988); 3) oxides of nitrogen which may be harmful to vegetation or may act as a fertilizer, causing changes in plant species composition (Rogers and Campbell 1979, Falkengren-Grerup 1986); 4) organic gases such as ethylene, to which plants may be extremely sensitive (Gunderson and Taylor 1988, Taylor et. al., 1988); and 5) heavy metals which may cause phytotoxic damage (Atkins et. al., 1982).

Shaver et. al., (1988) reported that the effects of pollutants can be both biological and ecological, and both acute and chronic. Such effects on plants include foliar injury, reduced productivity, tree mortality, decreased growth, altered plant competition, modifications in species diversity, and increased susceptibility to diseases and pests. Alterations to the vegetative community are also likely to result in implications to herbivores and other ecosystem components. In addition, ingestion by herbivores of trace elements deposited on leaf surfaces may lead to other impacts to the individual organism and throughout the food chain.
Soil and Vegetation Damage

Snowmobiles cause significant damage to land cover through direct physical injury as well as indirectly through snow compaction. Impacts on soil and vegetation include retarded growth, erosion, and physical damage (Baker and Bithmann, 2005). These impacts are exacerbated on steep slopes (Stangl, 1999) or in areas with inadequate snow cover (Stangl, 1999; Baker and Bithmann, 2005). This erosion can lead to increased soil runoff resulting in sedimentation and turbidity in the immediate area and throughout the watershed (Stangl, 1999). Rongstad (1980) reported delayed flowering in some plants in spring, lower soil bacteria, and elimination of some plants due to snow compaction.

Snow compaction from snowmobiles can lower soil temperatures and reduce the survival of plants and soil microbes (Wanek, 1973). A natural, un-compacted snowpack greater than 45 cm deep will prevent frost from penetrating the soil (Baker and Bithmann, 2005). However, the thermal conductivity of snow, when compacted by snowmobiles, is greatly increased, resulting in both greater temperature fluctuations and overall lower soil temperatures (Baker, and Bithmann, 2005). This in turn inhibits soil bacteria that play a critical role in the plant food cycle (Stangl, 1999). Thus the growth and reproductive success of early spring flowers is retarded and reduced (Wanek, 1973).

Vegetation in riparian areas is highly susceptible to damage from snowmobiles (Stangl, 1999). In their study of snowmobile impacts on old field and marsh vegetation in Nova Scotia, Canada, Keddy et.al. (1979) 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 subnivean rodents.

When snowmobiles are riding over the snow, abrasion and breakage of seedlings, shrubs, and other exposed vegetation is common (Stangl, 1999). Neumann and Merriam (1972) showed that direct mechanical effects by snowmobiles on vegetation at and above snow surface can be severe. After only a single pass by a snowmobile, more than 78 percent of the saplings on the trail were damaged, and nearly 27 percent of them were damaged seriously enough to cause a high probability of death. Young conifers were found to be extremely susceptible to damage from snowmobiles. Wanek (1971a), in a study in Minnesota, reported that 47 percent of pines and over 55 percent of white spruce sustained damage by snowmobiles traversing his study site. In 1973, with reduced snowfall, Wanek (1973; undated) documented that 92.6 percent of white spruce were damaged, with 45.4 percent receiving heavy damage and 8 percent perishing altogether within his snowmobile study site.
Impacts of OSV use include the degradation of both air and water quality. Two-stroke engines, which represent the vast majority of OSV use on NFS land, are particularly onerous. A two-stroke snowmobile can emit as many hydrocarbons and nitrogen oxides as 100 cars and create up to 1,000 times more carbon monoxide (EPA, 2002). In addition, snowmobiles, like other combustion engines, emit significant amounts of carbon dioxide (USDI 2000), which is classified as an air pollutant under section 302(g) of the Clean Air Act and is well-documented to contribute to climate change.

Two-stroke engines emit many carcinogens and pose a danger to human health (Eriksson et al. 2003, Reimann et al. 2009). Two-stroke engines emit dangerous levels of airborne toxins including nitrogen oxides, carbon monoxide, ozone, aldehydes, butadiene, benzenes, and extremely persistent polycyclic aromatic hydrocarbons (PAH). Several of these compounds are listed as "known" or "probable" human carcinogens by the EPA. Benzene, for instance, is a "known" human carcinogen and several aldehydes including butadiene are classified as "probable human carcinogens." All are believed to cause deleterious health effects in humans and animals well short of fatal doses (EPA 1993).

In addition, two-stroke engines also discharge 25-30 percent of their fuel mixture unburned directly into the environment (Blue Water Network 2002). Unburned fuel contains many toxic compounds including benzene, toluene, xylene and the extremely persistent suspected human carcinogen Methyl Tertiary Butyl Ether (MTBE). Winter recreationists are especially at risk because the concentration of these emissions increases with elevation and cold (Janssen and Schettler, 2003).

In a study on the Medicine-Bow National Forest Musselman and Korfmancher (2007) documented a decline in air quality with increased snowmobile activity. They measured higher ambient concentrations of CO₂, NOₓ, NO, and NO₂ at a snowmobile staging site and found significantly higher concentrations of these air pollutants on days with significantly more snowmobile activity. The researchers concluded that snowmobile exhaust was degrading air quality.

Not only do snowmobiles increase air pollution – quite significantly in areas where many machines are concentrated – this pollution settles into the snowpack and affects snow chemistry. Musselman and Korfmancher (2007) found that many changes to snow chemistry on snowmobile trails when compared to untracked powder. These changes included elevated numbers of cations and some anions and a significant drop in pH. Other studies have shown that snowpack concentrations of ammonium and sulfate positively correlate with snowmobile activity (Ingersoll 1998). Concentrations of toluene and xylene in the snow are also positively correlated with snowmobile traffic (Ingersoll 1998). Likewise, snowpack concentrations of benzene are higher in areas with heavy snowmobile use (Ingersoll 1998). When the snow melts, these pollutants, which are stored in the snowpack throughout the winter, are released in a concentrated pulse and can seep into groundwater or enter surface water.
Silence is a valuable and fragile resource that can easily be shattered by snowmobiles (Vittersø et al. 2004). Natural soundscapes are intrinsic elements of the environment and are necessary for natural ecological functioning (Burson, 2008). Noise from snowmobiles severely affects the winter soundscape and impacts both wildlife and other visitors. Animals exposed to high-intensity sounds suffer both anatomical and physiological damage, including both auditory and non-auditory damage (Brattstrom and Bondello 1983). In addition, 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 (Vittersø et al. 2004).

Sounds can occur in both a continuous and intermittent manner. At high intensities, sounds can have a deleterious impact on human hearing if sustained for certain lengths of time (Brattstrom and Bondello 1983). Intermittent sounds or startle noises have been shown to have many effects on humans including annoyance, disruption of activity, increase in heart rate, vasoconstriction, increase in blood pressure, stomach spasms, headaches, stress, fetal convulsions, ulcers, and coronary disease (Baldwin and Stoddard 1973, Brattstrom and Bondello 1983). However, the larger, more sophisticated, better protected human ear is capable of withstanding high intensity sounds which easily damage smaller, more simplistic ears of many species of wildlife (Brattstrom and Bondello 1983) and thus animals may be more affected by noise compared to humans. Thus, a vehicle noise limit acceptable in urban areas may be capable of severely damaging the hearing of exposed wildlife populations (Brattstrom and Bondello 1983).

Indirectly, the noise generated by OSVs can adversely impact animals impairing feeding, breeding, courting, social behaviors, territory establishment and maintenance, increasing stress, and/or by making animals or their young more susceptible to predation (Luckenbach 1975, Wilshire et al., 1977, EPA 1971, Bury 1980, Vos et al., 1985, Baldwin 1970). According to the Environmental Protection Agency, noise acts as a physiological stressor producing changes similar to those brought about by exposure to extreme heat, cold, pain, etc. (EPA 1971).

A noise study from Yellowstone involving four-stroke machines, which are much quieter than two-stroke snowmobiles, found that under a “best case scenario” (upwind, no temperature inversion, soft snow) snowmobiles were audible at distances of up to a half mile (NPS, 2000). When there was a temperature inversion or firm snow, or for those downwind of a snowmobile, the machines could be heard more than two miles away (NPS, 2000). At Yellowstone’s Shoshone Geyser Basin, four-stroke snowmobiles were audible from 8 miles away (Burson, 2008).
REFERENCES


