



INCORPORATING HUMAN IMPACTS INTO HABITAT SUITABILITY MODELS: A LITERATURE REVIEW

Report Prepared for

The Taku River Tlingit First Nation

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EXECUTIVE SUMMARY

I reviewed more than 150 articles on the impacts of human disturbance on five focal species; woodland caribou, grizzly bear, moose, thimblehorn sheep, and mountain goats. Human impacts on each species are divided into the direct and indirect effects attributable to human development and infrastructure, predator-prey dynamics, logging and forestry, habituation, increased human access and human harassment. Habitat suitability models incorporating variables of human disturbance are reviewed and human use variables are described. I have made recommendations for the best ways of incorporating human disturbances into habitat suitability models specific to each species.

Habitat suitability models (HSM) are an important tool used by managers and wildlife scientists to predicting the quality or suitability of a habitat for a specific organism. HSM utilize data on critical nutritional, reproductive, and refuge requirements of species based on personal experience, literature, expert opinion and empirical evidence. Habitat suitability index models (HSI) are a type of HSM that quantify the relative quality of wildlife habitat on a scale from 0 to 1. If the value of an index is high there is a better chance that the species occurs in a habitat than if the value is near zero. Habitat variables can include a variety of landscape indicators such as vegetation type, vegetation structure, canopy cover, and human disturbance. Subjective HSI models have recently been replaced by empirically derived modeling techniques which allow resource selection to be examined at a broader suite of spatial and temporal scales.

Human influence on natural systems is drastically increasing as the world population grows and the pace of industrialization and consumption progress. The total land area impacted by human activities is projected to increase from 12-20% to 50-90% worldwide in the next 50 years. Northern ecosystems are experiencing a rise in anthropogenic activities as the demand for energy sends humans into the hydrocarbon and mineral rich biomes of the arctic and sub-arctic. Resource extraction brings with it human developments such as roads, pipelines, power lines, and other infrastructure that can cause a range of effects on wildlife including overt behavioral responses, local avoidance, decreased survival or fecundity, and even regional extinctions. The potential impact of human disturbance on wildlife has been extensively studied in conservation biology. Quantifying the responses of wildlife to disturbance is extremely species specific and may vary by season, disturbance type, habitat, and other environmental factors.

Caribou show high levels of avoidance to many types of human activity and development including: roads, seismic lines, oil well sites, human settlements, tourist resorts and cabins, power lines, hydroelectric developments, mine sites, logging clearcuts, and snowmobile traffic. Caribou also avoid habitats that have high densities of moose or wolves. In general, caribou reduce their use of areas within 5,000m of human disturbance by 50-90%. Levels and distances of avoidance can vary by season, sex, level of disturbance, and other environmental and demographic variables. Generally, females are the most sensitive to disturbance and avoided human infrastructure at greater distances. Roads have also been shown to prevent caribou movement and may fragment

populations. Caribou also demonstrate overt behavioral reactions to a number of human disturbances such as recreation, low altitude aircraft, and snowmobile traffic.

Grizzly bears are extremely sensitive to human development and the vast majority of bear mortality is caused by humans and the indirect effects of human access. The extent of impact can vary based on season, terrain, sex, age, level of habituation and other environmental and demographic variables. Overall, female bears with cubs are the most sensitive to human disturbance. In general, bears avoid areas within 500m of roads and other human development though the distance of avoidance may be dependent on the traffic volume, time of day and the relative human presence. Roads, especially high traffic highways, may act as barriers to movement and may isolate subpopulations. In some cases grizzly bears may select for areas of human disturbance that contain important food sources, such as roadside clearings and logging clearcuts. Habituation usually increases bears vulnerability to legal hunting, management control kills, defense of life kills and illegal poaching. A large proportion of human caused grizzly bear mortality occurs within 500m of roads.

Moose populations have shown high adaptation to human development and activities and may benefit from certain aspects of human disturbance. The impact of direct mortality from vehicle collisions has a strong negative effect on moose, especially in areas of high moose density, on roads with high traffic volumes, at night, and near roadside salt pools. A handful of studies suggest that moose may avoid roads and in some cases highways may act as barriers to migration. In contrast, other research reports that moose densities actually increase in the proximity of high human development. Moose may take advantage of early successional growth associated with regenerating logging clearcuts. There is growing evidence that moose may utilize human activity and development as a shield against predators such as wolves and grizzly bears. Moose demonstrate overt behavioral reactions to human disturbance though no long term demographic effects have been linked to behavioral modifications.

Bighorn and thinhorn mountain sheep demonstrate varying degrees of sensitivity to human impact. In general, mountain sheep avoid roads with high traffic volumes and in some cases may even abandon habitat following disturbance events. Research suggests that roads may act as a barrier to movement, especially when highways bisect routes between important seasonal mineral lick sites. Mountain sheep exhibit a number of overt behavioral reactions in response to human disturbance. Industrial mining may disturb the foraging efficiency of sheep by increasing time spent vigilant. Overall, approach by humans on foot elicits a stronger behavioral reaction than vehicle traffic. Aircraft overflights increase movement rates, heart rates, and interrupt foraging and resting behaviors. Helicopters have been shown to produce the greatest response. Evidence for potential habituation to jet overflights has been proposed.

Mountain goats are exceptionally susceptible to human disturbance. Roads may act as barriers to movement and disrupt traditional routes to mineral licks. While some studies suggest that mountain goats may be able to habituate to disturbance when events are predictable other research has found that mountain goats avoid areas up to 3000m

from disturbance and survival may decline in correlation with heightened human activity. Industrial activity and helicopter disturbances associated with recreation, mining, and logging may have severe consequences on goat populations. Low altitude overflights increase energetic costs, decrease forage efficiency, interrupt activity schedules, split up social groups and decrease survival. Helicopters are especially detrimental when within 500m of goats. Disturbance events have been shown to force mountain goats to abandon parts of their range.

Human impacts are most often incorporated into HSM as a variable of distance from human disturbance. More complicated modeling methods include variables that integrate the population size of human communities, travel time from human settlements to remote areas, density of roads or linear corridors, relative affect of different road classes, probability of human recreational use and other indicators of human influence on the landscape. Many models designate buffers around human disturbances that are based on the ecological effects of avoidance behavior reported in the literature. Human development and activity can reduce habitat suitability to varying degrees. The simplest models designate a linear decrease in habitat suitability with decreasing distance to human developments. Other models utilize disturbance coefficients that attempt to standardize the percent decrease in habitat value in different buffer zones of influence. Limitations of HSM models include a general lack of validation efforts.

The inherent complexity of ecological systems makes modeling relationships between habitat selection and human influence difficult. HSMs often assume that habitat quality decreases linearly with increasing distance to human activity. While these general distance variables may be the easiest to apply to models they may not be the most predictive of actual animal distribution. Evidence suggests that avoidance is not a linear reaction, but rather asymptotic where response decreases gradually as the distance from human disturbance increases until resource selection is no longer influenced by the anthropogenic factor. Though empirical evidence from actual animal locations on the landscape cannot be easily replaced by subjective HSI models, some complex models are generally predictive of species occurrence. Many of these models utilize complicated techniques that take into account a wide range of human influences on the landscape, but may not always be the best option. Other models hold predetermined buffers and disturbance coefficients constant which allows for easy replication and is especially beneficial when empirical data on animal locations are not available. Expert opinion and local knowledge of ecosystems can also be valuable tools when modeling complex relationships between human impacts and wildlife populations. For each species in this review, I recommend several important factors be taken into account when incorporating human impacts into HSM.

INTRODUCTION

Understanding species abundance and distribution is a fundamental objective of ecology. Habitat suitability models (HSM) are a tool for predicting the quality or suitability of a habitat for a given species based on personal experience, literature, and expert opinion of species occurrence. HSM must take into account the vital nutritional, reproductive, and refuge requirements of each species and may include environmental conditions and human activities and developments (Allen et al. 1987). Maps of habitat characteristics are used to produce expected species distributions, which can be constructive in informing wildlife management decisions (Larson et al. 2004).

Habitat suitability index models (HSI) are a type of HSM that have been used since the early 1980s to determine the relative quality of wildlife habitat. HSI models utilize an index value between 0 (least suitable habitat) and 1 (optimal habitat) that represents the probability of species occurrence. If the value of an index is high there is a better chance that the species occurs in a habitat than if the value is near zero. Habitat variables can include a variety of landscape indicators such as vegetation type, vegetation structure, canopy cover, and the presence or absence of seasonal food sources (Dijak et al. 2007). Subjective HSI models have recently been replaced by empirically derived modeling techniques. Use of geographic information system (GIS) technology allows the quantitative utilization of more complex land cover, vegetation and habitat data which allow resource selection to be examined at a broader suite of spatial and temporal scales (Roberts 2000, Larson et al. 2003).

Habitat selection can be measured by examining an organism's use or avoidance of a particular feature in the landscape relative to its availability. When an animal is observed using a feature in the landscape disproportionate to its availability, selection is assumed. When use is less than availability, the model predicts avoidance of that feature. Resource selection functions (RSF) are a form of HSI models that utilize increased statistical rigor and empirical data to determine the probability of resource use by an organism. Boyce et al. (2002) explain that "a RSF usually is estimated from observations of (1) presence/absence (used-vs.-unused), or (2) presence/available (used-vs.-available)

resource units.” Habitat use is most often founded on telemetry data locations. Scale can vary from geographic home ranges to micro-habitats. RSF models provide a valuable and efficient way of monitoring the impact human disturbance has on the way animals utilize their environment. Human impacts are most often incorporated into RSF models as variables representative of human disturbance such as road density, clearcuts, or distance to human settlements (Roberts 2000, Boyce et al. 2002, Johnson et al. 2005). There are many important applications of RSF models in management and conservation and in the development of cumulative effects assessments, population viability analyses and determining the impacts of human activities on wildlife populations (Boyce et al. 2002).

Anthropogenic activities such as oil and gas exploration, mineral exploration, mining, and tourism have increased dramatically in northern ecosystems. In the next 50 years infrastructure development is projected to critically affect 50-80% of arctic through fragmentation, disturbance, and avoidance of developments by wildlife (Fig. 1., UNEP 2001). The expansion of the global human footprint will challenge wildlife management with unpredictable and unprecedented effects on natural systems. Human developments such as roads, pipelines, power lines, and increased access associated with tourism can cause a range of effects on wildlife from local avoidance to decreased survival or fecundity, and even regional extinctions. The indirect effects on wildlife of infrastructure (i.e. effects extending to the surrounding area) is extremely species specific, and may vary by season, disturbance type, habitat, and other environmental factors (UNEP 2001).

The objective of this literature review is to provide assistance in the development of HSMs for woodland caribou (*Rangifer tarandus caribou*), grizzly bear (*Ursus arctos*), moose (*Alces alces*), thinhorn sheep (*Ovis dalli stonei* and *O. dalli dalli*), and mountain goat (*Oreamnos americanu*). Specifically, I focus on quantifying the meaningful ecological effects of numerous forms of human impacts on individual species habitat selection and I provide recommendations for the incorporation of direct and indirect human effects into HSMs that are being developed for these five focal species in the traditional territory of the Taku River Tlingit First Nation (TRTFN, Figure 2) of northern British Columbia. In some cases I draw upon information from other large mammals in similar ecosystem types. Specifically, this report includes:

- 1) The types of human impacts with the most significant effect on each species.

- 2) The relative importance of the indirect effects of human impact on each species, particularly in respect to displacement or avoidance.
- 3) A review of how human impacts have been incorporated into HSM.
- 4) A synopsis of the parameters that have been used to inform HSM.
- 5) Examples of validation efforts that have been attempted.
- 6) Recommendations of the best methods for incorporating human impacts into habitat suitability models.

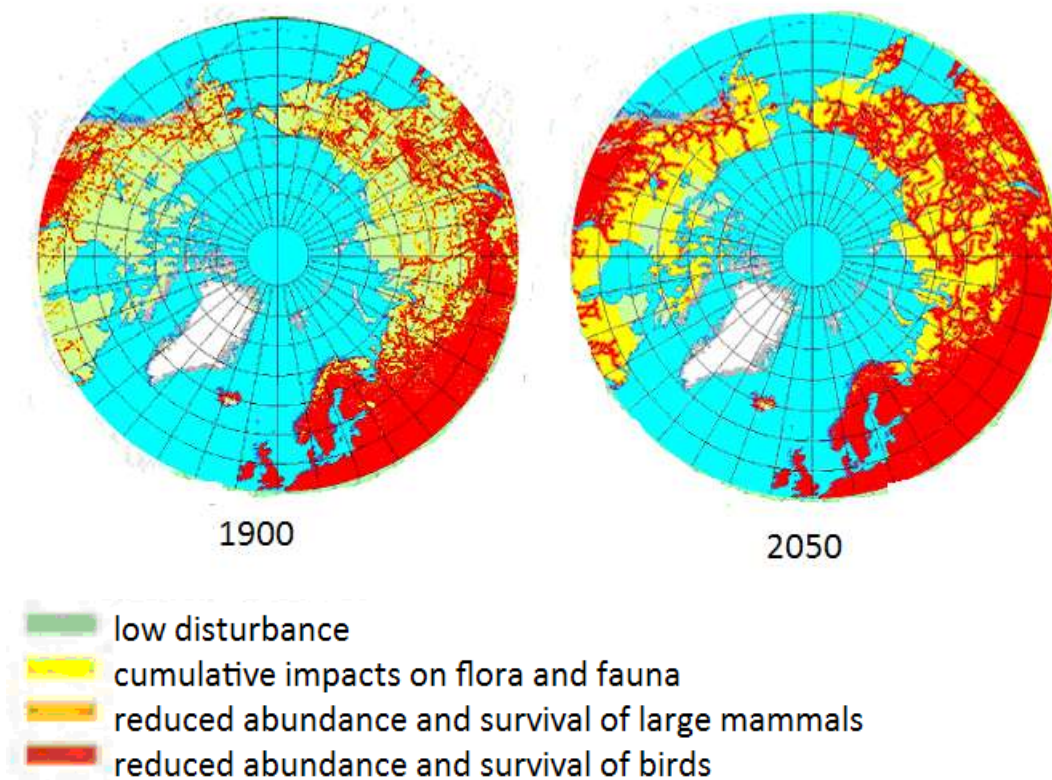


Figure 1. Changes in human impact on biodiversity and ecosystems between 1900 and 2050 using 100% rate of growth in infrastructure and resource utilization compared to 1940-1990 (UNEP 2001).

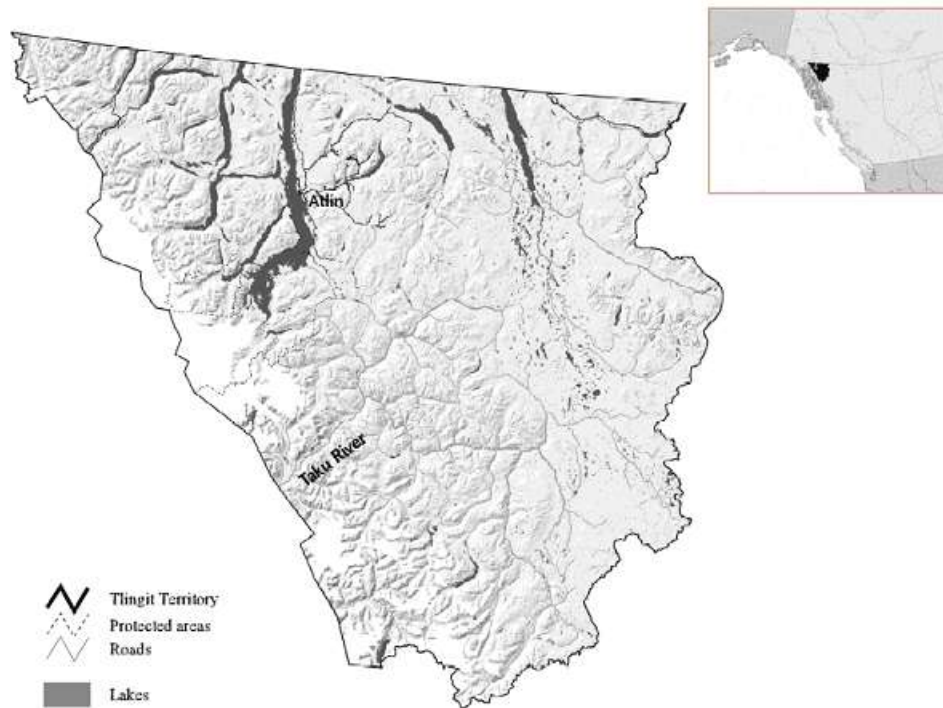


Figure 2. Territory of the Taku River Tlingit, Northern British Columbia. The territory covers approximately 4 million hectares (Heinemeyer et al. 2003).

METHODS

I conducted a literature review of the effects of human impacts on five focal species using a variety of electronic resources including: ISI Web of Knowledge, Zoological Record, CSA Biological Sciences, CSA Illustrata: Natural Sciences, Google Scholar, and Biological Abstracts. I used a combination of the following keywords: habitat suitability, habitat model, HSI, RSF, resource selection, human impacts, habitat degradation, development, roads, vehicle, oil well, gas, petroleum, mine, gold mine, overflight, aircraft, helicopter, snowmobile, habituation, caribou, reindeer, Dall's sheep, Stone's sheep, moose, grizzly bear, mountain goat, British Columbia, Alberta, arctic, and boreal. I focused on studies that incorporated human impacts into habitat models as well as studies on the effects of specific anthropogenic sources on wildlife.

In order to summarize the literature I recorded information on the following categories for each article: authors, year of publication, description of article title, species, peer review status, study area size, length of study, type of human impact, study design (observational, modeling, review, experimental, or comparative), study sample size, data type, general results and management recommendations. These summaries can be found in appendix A at the end of this report.

RESULTS

I reviewed 151 papers on the effects of specific anthropogenic sources on wildlife (Table 1). Of these articles, 80% were peer reviewed (122). Peer reviewed publications included scientific articles published in academic journals. Non-peer reviewed articles were mostly reports and conference proceedings as well as a few graduate theses. Caribou were the most common species in the review with 49 articles, grizzly bear followed with 43 studies. Moose and mountain sheep had 25 and 22 studies respectively while mountain goat literature was the least available with 12 studies. The majority of studies (62%) were observational and correlated animal response to human developments or activity. Several articles were specific modeling approaches to understanding human impacts on species distribution and abundance (22). Literature reviews (16) were included as they often provided insights into the field. Few studies utilized experimental (13) or comparative (6) study designs to document human impacts on wildlife. Articles reviewed on species other than caribou, grizzly bears, moose, mountain sheep and mountain goats were not included in the literature review summaries.

Table 1. Summary of literature reviewed by species.

Species	Number of Articles						
	Total	Peer Review	Observational	Modeling	Review	Experimental	Comparative
Caribou	49	46	26	8	7	4	4
Grizzly Bear	43	31	27	12	3	1	0
Moose	25	24	17	2	2	3	1
Mt. Sheep	22	15	15	0	2	4	1
Mt. Goat	12	6	9	0	2	1	0
Total	151	122	94	22	16	13	6

Various types of human disturbance were included in the literature review. The effects of roads on wildlife were the most commonly studied (Table 2). Of the studies on caribou, the most frequently included human disturbances were roads (28%), followed by

petroleum exploration (17%). Articles on human caused mortality were the least represented in the caribou literature (1%). Grizzly bear literature was also dominated by research on effects of roads (37%) though studies including human caused mortality (37%) were equally represented. Articles on the effects of logging on grizzly bears made up 20% of the literature. Moose were studied the most in relation to roads (43%) and human caused mortality (27%). Literature on mountain sheep and mountain goats both included a large proportion of studies on the effects of aircraft, 40% and 43% respectively.

Table 2. Human disturbance types by species (some studies included more than one impact).

Species	Number of Articles									
	roads	seismic lines	hydro	petro exploration	mines	logging	human approach	aircraft	snow-mobile	human caused mortality
Caribou	20	6	3	12	3	11	5	6	4	1
Grizzly Bear	22	1	0	1	1	12	1	0	0	22
Moose	13	0	2	0	0	4	1	1	1	8
Mt. Sheep	5	1	0	0	3	0	6	10	0	0
Mt. Goat	1	1	0	4	0	0	2	6	0	0
Total	61	9	5	17	7	27	15	23	5	31

Woodland Caribou



Woodland caribou (*Rangifer tarandus caribou*) are extremely sensitive to human activity (Figure 4). In Canada the northern mountain ecotype occurs in local populations throughout the Yukon, Northwest Territories and northwestern British Columbia (Figure 3) and is listed as a species of special concern by the Species at Risk Act (SARA) and the Committee on the Status of Endangered Wildlife in Canada (COSEWIC, <http://www.sararegistry.gc.ca/>). Both the southern mountain and boreal populations are listed as threatened across Canada, presumably due to habitat loss and fragmentation as well as to changing predator-prey relationships, most likely facilitated by human activities, and greater motor vehicle access (COSEWIC 2002b, Alberta woodland caribou recovery team 2005).

Recent literature reviews on the effects of human development on caribou and reindeer have documented a spatial and temporal shift in human impact studies from local behavioral scales to regional population level scales (UNEP 2001, Hebblewhite 2008, Vistnes and Nellemann 2008). In a literature review of 85 studies on reindeer and caribou across the Arctic, Vistnes and Nellemann (2008) found that studies that included wider spatial and temporal scales were more likely to conclude that human impacts had a significant effect on caribou and reindeer habitat use. Furthermore, as the spatial scale of research shifted from local to regional in the 1990s, more data revealed avoidance by caribou of roads, pipe lines, power lines, resorts, logging operations, and industrial development, where earlier local behavioral studies had found negligible or indecisive effects. A high percentage of regional studies concluded that *Rangifer tarandus* will reduce use of areas within 5 km of infrastructure and human activity by 50-95%. These results strongly suggest that the scale of assessment influences the probability of detecting impacts.

In a literature review on the effects of energy development on ungulates, Hebblewhite (2008) also tracked the shift in caribou research from short term behavioral investigations to population dynamic analyses to large scale cumulative effect

assessments. His findings highlight the importance of cumulative effect studies, which require wider temporal and spatial scales in order to describe population level effects. The assessment challenges the current management policy which attempts to mitigate impacts by restricting development through timing or seasonal restrictions. Instead, caribou persistence is unmistakably dependent on available habitat – habitat which is quickly being compromised by extensive oil, gas, and forestry development in the Canadian arctic and boreal forests. Several recent studies suggest that the most detrimental factor to caribou populations is loss of habitat due to avoidance of high quality habitat in the proximity of human development (Schneider et al. 2003, Weclaw and Hudson 2004, Sorensen et al. 2008).

Impacts on caribou attributable to human disturbance of caribou habitat include direct mortality (Stuart-Smith et al. 1997, Kinley and Apps 2001), energetic costs (Bradshaw et al. 1997, 1998) altered predator-prey relationships (James and Stuart-Smith 2000, James et al. 2004), barrier effects (Curatolo and Murphy 1986, Dyer et al. 2002) and avoidance and displacement (Nellemann and Cameron 1996, 1998, Dyer et al. 2001, Nellemann et al. 2001, Nellemann et al. 2003, Cameron et al. 2005, Joly et al. 2006, Schaefer and Mahoney 2007, Weir et al. 2007, Vistnes and Nellemann 2008). Identifying the ecological effects of these impacts is a challenge. Studies have proposed that functional habitat loss due to avoidance could have demographic consequences. Displacement from optimal foraging grounds could lead to less suitable habitats and cause crowding and overgrazing (Nellemann et al. 2003). Avoidance may influence individuals' ability to circumvent harsh snow conditions and local habitat variables. Decreased forage availability and lower nutrient intake have been shown to reduce reproductive rates (Nellemann and Cameron 1996, Cameron et al. 2005). Displacement also has the potential to alter predation risk by making caribou locations more predictable and thus more vulnerable to hunting by animal predators and humans (Stuart-Smith et al. 1997, James and Stuart-Smith 2000, Dyer et al. 2001).

However it is important to consider several caveats. Very few studies directly correlate behavioral responses to their ultimate population level implications (Wolfe et al. 2000) . Caribou may be able to habituate to human disturbance at certain levels (Duchesne et al. 2000). Insect harassment may intensify or lessen caribou response to

human activities (Reimers and Colman 2006, Vistnes and Nellemann 2008).

Observational studies with low sample sizes and a lack of controls or treatments do not explain the possible cumulative effects on survival or reproduction. Validation efforts and replication of human impact studies are sorely missing from the literature. Finding a meaningful way to link productivity parameters and avoidance behavior remains a challenge that has yet to be thoroughly explored in the scientific literature.

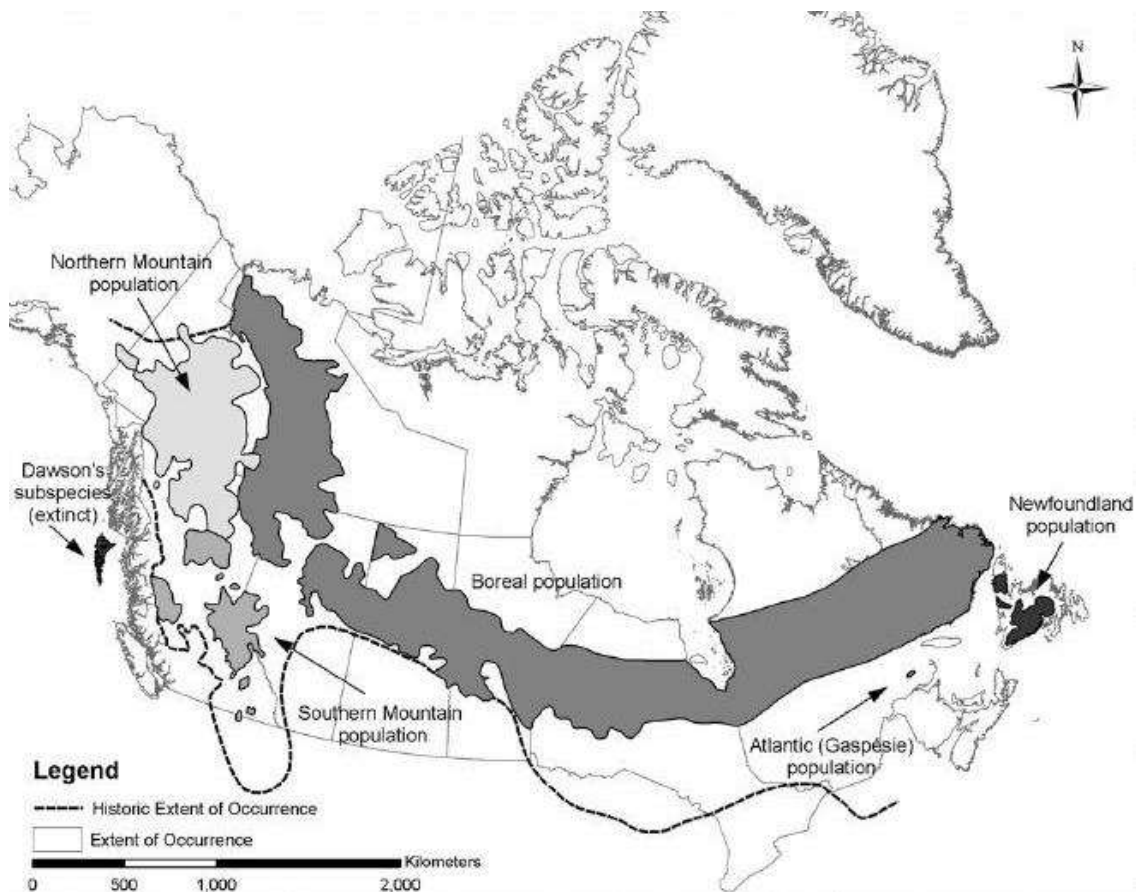


Figure 3. Current (solid lines) and southern limit of historical (dashed line) extent of occurrence of woodland caribou in North America in 2001 (COSEWIC 2002b).

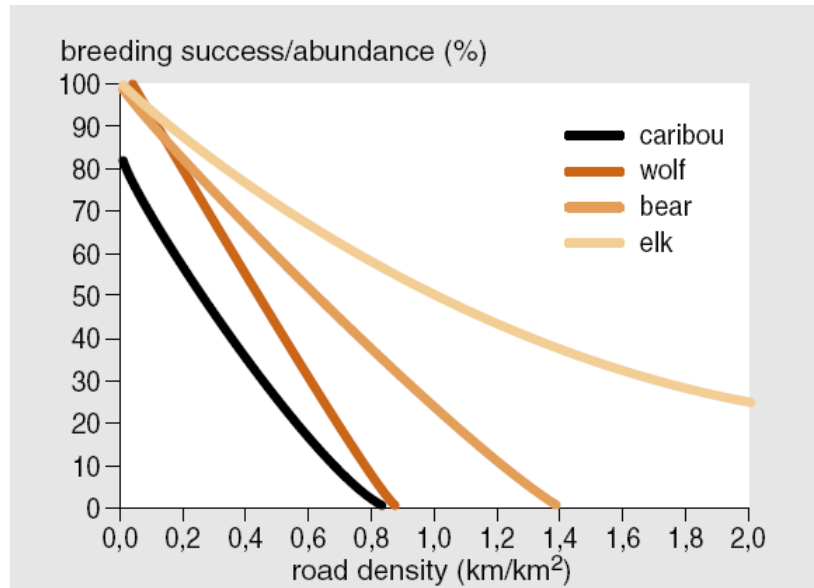


Figure 4. Reproductive success or abundance of caribou/reindeer, wolves, bears and elk as a function of distance from infrastructure or road density, as estimated from 20 studies (UNEP 2001).

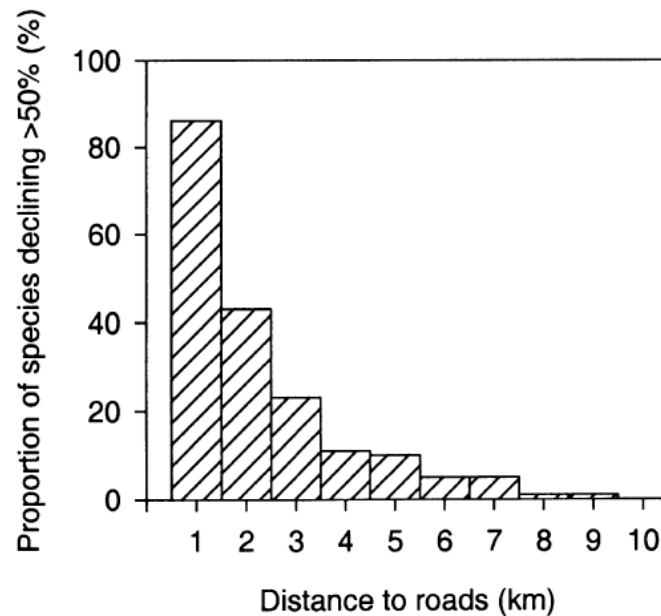


Figure 5. Generalized effect of infrastructure on wildlife: The proportion of 204 species reviewed that decline > 50% in abundance at 1-km segment intervals to infrastructure (Nellemann et al. 2003).

Human Development and Infrastructure

Linear developments such as roads, trails, pipelines, power lines, fence lines, railroads and seismic lines are common infrastructure associated with energy development and human activity. Industrial infrastructure generates diverse and systemic ecological results on the landscape (Jaeger et al. 2005). Of the many human corridor types, **roads** have the most significant impact on wildlife (Figure 5., Nellemann et al. 2003). Mortality due to vehicle collisions has become the leading source of human caused wildlife death, but direct mortality has a far less substantial ecological impact than the indirect cumulative effects associated with road avoidance (Forman and Alexander 1998). The zone of avoidance in the vicinity of road corridors can lead to an extensive loss of habitat effectiveness (Jalkotzy et al. 1997, Eigenbrod et al. 2008). Avoidance can be defined as a reduction in use of areas near human activity or development compared to areas farther from development. Patterns of avoidance vary by sex, age, season, density dependence, and size of the area affected. Other indirect impacts of roads include: the facilitation of additional human activities such as hunting, resource extraction, and recreation; the spread of invasive species; barriers to movement; habitat fragmentation; soil erosion and sedimentation; and foreign chemical transport, all of which cause further habitat degradation to the local system (Forman and Alexander 1998, Trombulak and Frissell 2000).



The response of barren ground caribou (*Rangifer tarandus granti*) to infrastructure associated with oil-fields has been well documented in the arctic (e.g., Curatolo and Murphy 1986, Murphy and Curatolo 1987, Cameron et al. 1992, Nellemann and Cameron 1996, Pollard et al. 1996, Nellemann and Cameron 1998, Noel et al. 2004, Haskell et al. 2006, Joly et al. 2006), with mixed conclusions regarding the ecological effects of human development (see reviews by Cronin et al. 1998, Cronin et al. 2000, Klein 2000, Wolfe et al. 2000). In this review I will attempt to limit the discussion to the response of woodland caribou (northern mountain, southern mountain and boreal

ecotypes, Figure 3) to infrastructure, most notably energy exploration in Canada, but I will also include a few key studies on reindeer (*Rangifer tarandus tarandus*) in Norway (see review by Reimers and Colman 2006).

Dyer et al. (2001) studied the distribution of woodland caribou in association with human infrastructure in the Athabasca oil sands deposit of northern Alberta. Their results established that caribou used areas near infrastructure significantly less than expected in all seasons and at varying levels of human activity. The maximum avoidance distance was 250m from roads and seismic lines and 1000m from oil well sites. This avoidance behavior diminished the use of up to 296,258ha in their study system, suggesting habitat loss can act cumulatively across the landscape and potentially lead to population level consequences.

Vistnes and Nellemann (2001) also documented avoidance of human infrastructure in semi-domesticated reindeer in northern Norway. Reindeer density was 78% lower within 4km of a tourist resort complex and 73% lower within 4km from high voltage power lines. Forage availability also decreased significantly with increasing distance from human impacts, increasing the potential competition for forage in non-avoided zones. Wild reindeer demonstrated comparable avoidance behavior of roads and power lines in southern Norway in a 13 year survey of local distribution. Nellemann et al. (2001) found that density was 79% lower within 2.5km of power lines compared with background areas and that areas within 5km of development were avoided in all years. Lichen cover declined 15-30 fold with increasing distance from infrastructure and was lowest in undisturbed sites that had the highest intensity of grazing by reindeer. Lichen height can be used as an indirect measure of reindeer avoidance of human infrastructure. In central Norway, reindeer avoidance of a highway was indicated by a 35% decrease in lichen height more than 8km away from the road (Dahle et al. 2008). Overgrazing in remote areas has the potential to decreased nutrient intake, decrease maternal female body condition and lead to decreased calf survival, and hence, reproductive success.

Because woodland caribou are more sedentary than migratory barren-ground caribou, it has been suggested they are more sensitive to barriers like roads and have less motivation to cross corridors. Dyer et al. (2002) found that roads can act as substantial barriers to caribou movement in northeastern Alberta. This barrier effect was most

evident in late winter, during the season of highest vehicle traffic, when caribou crossed roads 6 times less frequently than simulated control roads. Roads were also crossed less frequently than controls in summer when traffic was considered low. **Seismic lines** (5-10m wide swaths cut during the process of conventional oil and gas exploration) did not act as barriers to caribou movement. Caribou may have an aversion to the physical barrier of roads, to the vehicle traffic/noise, or to the associated predation risk from humans or other predators. Barrier effects have the potential to influence individual dispersal to new populations which may be essential to survival of local populations in Alberta (Dyer et al. 2002). These results suggest that reindeer and caribou avoid human infrastructure even at low levels of associated human traffic.

In a comparative study before, during, and after the construction of a **hydroelectric development** in west-central Newfoundland, Mahoney and Schaefer (2002) studied the movements and space-use of radio-collared caribou. Caribou use within 3km of the construction site diminished during the first year of construction and persisted after building was complete. The development was built in a migratory pathway between summer and winter grounds and construction disrupted the consistency of individual migration timing and patterns. In a similar comparative study documenting the construction of a large hydroelectric reservoir in southwestern Norway, Nellemann et al. (2003) examined the cumulative effects of power lines, roads, reservoirs and dams on wild reindeer distribution. Over a 10 year period, reindeer density within 4km of infrastructure declined 92% in winter. Areas more than 4km from roads and power lines experienced a 217% increase in reindeer use. After development, 75% of the study area was located within 4km of roads though the surface area physically altered was less than 1% of the total area. Cow:calf ratios declined as habitat was lost, most likely due to loss of high quality summer range.

Petroleum exploration is both temporally and spatially unpredictable and can affect caribou movement and behavior differently than permanent infrastructure. Bradshaw et al. (1997) showed that caribou displayed faster movement rates and crossed more habitat boundaries than controls when exposed to loud noise simulating geophysical surveys. Though it is difficult to infer population level effects from short term behavioral studies, increased movement rates could disrupt the delicate balance between winter

energy expenditure and forage availability. In order to estimate population effects Bradshaw et al. (1998) constructed a model to estimate the energy cost associated with loud noise disturbance. Their model predicted that caribou would have to encounter an average of 27 disturbance events during the winter to lose more than 15% of their mass. When compared to real exploration intensities that exist in the landscape, there were 10 occasions from 1988-1993 when caribou had the potential to encounter enough disturbance events to significantly impact female body condition and possibly calf production and survival.

Weir et al. (2007) studied the effects of **mining development** on the distribution of woodland caribou in southwestern Newfoundland. Construction of a gold mine resulted in 1.78km² of direct habitat loss within important winter and calving/post-calving habitat. Aerial surveys of caribou distribution pre-development and during mining operations showed that caribou avoided areas within 4km of the mine site in all seasons during mine operations. Distribution pre-development was not correlated to distance from mine center. Avoidance resulted in close to 50km² of indirect habitat loss.

Predator-Prey Dynamics



There is considerable evidence that woodland caribou populations are limited by predation (Stuart-Smith et al. 1997, Bergerud and Elliott 1998, McLoughlin et al. 2003). Human impacts caused by oil and gas development and forestry have the potential to increase the vulnerability of caribou to predation. Caribou use an “isolation” strategy to avoid predators by spatially segregating themselves from other prey species and predators. By maintaining low population densities caribou may reduce their risk of incidental detection by predators (Stuart-Smith et al. 1997).

James et al. (2004) tested the spatial separation hypothesis between woodland caribou, moose (*Alces alces*) and wolves (*Canis lupus*) in northeastern Alberta and found that caribou select against well-drained habitat while moose and wolves select for it during all seasons. Caribou on average were found 439m further from well drained sites in the calving season when calf predation is most likely. Furthermore, analysis of wolf scats

revealed that caribou were not killed in proportion to their availability, implying that spatial separation reduced wolf predation pressure on caribou, though it did not provide a complete refuge.

Forest harvesting and cutting associated with petroleum exploration provides young seral forests that are preferred by moose. Increased moose abundance, in turn, supports higher populations of wolves. This apparent competition between caribou and moose and associated landscape composition was studied in British Columbia by Wittmer et al. (2007). Their results suggest that adult female caribou survival is lowest in areas with a higher proportion of young and mid-seral forests and that caribou were killed by predators more often in areas with low old forest composition. These results provide a link between caribou vital rates and the decline of caribou populations in the presence of elevated moose and wolf population throughout British Columbia and Alberta (Bergerud and Elliott 1998, Wittmer et al. 2005).

There is also concern that the spatial segregation tactic used by caribou to decrease predation risk is not sufficient in human altered systems. Stotyn et al. (2007) studied the spatial relationships between caribou, moose and wolves following the recent expansion of moose into the north Columbia Mountains of British Columbia. Habitat selection between caribou and wolves was spatially segregated in all seasons. The relationship was especially strong in late winter and weaker in the spring when caribou moved down to valley bottoms during the green-up. Caribou and moose used different habitats creating a high level of spatial segregation in all seasons. On the other hand, wolves and moose had low levels of spatial separation, especially in summer. As moose densities increased in the study area, wolf predation on caribou increased from 0% to 21% suggesting a failure of spatial separation that is only expected to increase.

Linear developments such as roads and seismic lines may increase the mobility of wolves. In northeastern Alberta, James and Stuart-Smith (2000) found that while caribou avoided linear corridors (mostly seismic lines), wolves were more often found near corridors. Their results indicate that caribou have higher risk of predation from wolves near linear corridors. Seismic lines, which have low human use, may be preferentially used by wolves, increasing their travel efficiency and the ease of caribou detection. Legal and illegal harvest of caribou is also associated with corridors that allow hunters easier

access into caribou habitat. Even a small increase in predation through altered spatial relationships between caribou, predators, and alternate prey could lead to population level effects in herds with low growth rates.

Logging and Forestry

Logging alters the composition and structure of forests, creates direct habitat loss and opens large areas to increased access. Each year, more than 8,000km² are logged in Canada, of which approximately 90% is clearcut (<http://cpaws.org/>). Smith et al. (2000) studied radio-collared caribou distribution over a 16 year period in west-central Alberta during a large scale timber harvest. Their results show that caribou avoided clearcuts and were 1.2km farther from newly harvested cut blocks than random locations in the study area. On average caribou avoided a zone of approximately 11km surrounding cut blocks. Furthermore, mean winter range size and daily movement rates were negatively correlated with harvest. Two studies in east-central Newfoundland have also documented caribou avoidance of clearcuts. Chubbs et al. (1993) and Schaefer and Mahoney (2007) examined caribou habitat selection in relation to clearcuts during spring and summer. Female caribou avoided cutovers both pre and post harvest and maintained an average of 9.2km (Schaefer and Mahoney 2007) and up to 15km (Chubbs et al. 1993) from active logging. Neither found significant effects of forest harvest on male caribou.



Courtois et al. (2007) monitored caribou in habitats disturbed by logging and fire in central Québec. Caribou density was significantly lower in disturbed landscapes and caribou exhibited avoidance of human activities. In areas with high disturbance caribou increased home range size and decreased fidelity to both seasonal and annual home ranges. Their study connected female survival to the extent which caribou home ranges overlap with disturbed landscapes. Female caribou that occupied disturbed home ranges were more likely to be killed by both humans and other predators. In another recent study, Vors et al. (2007) used a model to demonstrate caribou extirpation based on different disturbance types. Forest cutovers were determined to be the best predictor of

caribou occupancy. The model predicted that caribou avoid cutovers by 13km providing strong support for the negative response of caribou to logging and forest disturbance.

Human Harassment



Human-related harassment of caribou can be broken into two categories: pedestrian approach and vehicular stimuli (aircraft, snowmobiles, and automobiles). Response can vary from minor increased vigilance to panicked flight depending on numerous variables such as prior disturbance and habituation,

season, quality of cover, distance from stressor, visibility and other environmental stimuli (Webster 1997). Flight responses in caribou may reduce feeding time as well as increase movement costs, both of which have the potential to reduce body condition and possibly reproductive success and survival. Reimers et al. (2006) studied the response of reindeer in Norway to **human approach** on foot or on skis. They found that the farther away the person was when first sighted, the greater the distance of flight. Humans were able to approach closer when the herd size was larger, likely reflecting safety in numbers. Reindeer with domesticated origin also show less response to humans than reindeer with wild origins, highlighting the importance of previous levels of domestication and habituation to humans (Reimers and Colman 2006). Reindeer response was greatest in July and least in September-October during rut. They recommend that humans stay 350m away from reindeer from March-July and 200m in September-October. Human approach did not appear to cause substantial energy costs to reindeer in this system. Duchesne et al. (2000) examined woodland caribou response to ecotourists in a Provincial Park in southeastern Québec. Groups of 5-19 ecotourists and guides interrupted caribou foraging and increased time spent vigilant and standing. As winter progressed, impact of human

presence was reduced, suggesting that caribou are able to habituate to low levels of human disturbance.

Though normal high altitude aircraft (900-3000m above ground) probably have no effect on ungulates (Reimers and Colman 2006), the increase in military training exercises in the Arctic have raised concerns over caribou response to low-altitude **overflights by aircraft**. Harrington and Veitch (1991) studied the overt behavioral response of woodland caribou to overflights by NATO forces stationed at Canadian Forces Base in Labrador. The most common response to jet overflights passing within 30m of the ground was a startle reflex in response to the sound of the aircraft. Upon hearing the jet caribou bolt for several meters, but rarely run for more than 10 seconds. **Helicopters**, which have slower flight speeds and thus longer overpass times, caused caribou to run farther and for longer periods than jet aircraft did. Daily activity levels did not vary significantly between control caribou that were not disturbed and caribou exposed to overflights. Studying the same system in Labrador, Harrington and Veitch (1992) also investigated the potential for long-term effects on population dynamics and behavior. They found that female caribou exposed to overflights had lower calf survival than those not disturbed. This significant negative correlation between a female caribou's exposure to overflights and her calf's survival has serious demographic consequences and the authors recommend that aircraft maintain an altitude of 300m above ground level during the calving season. Maier et al. (1998) studied barren-ground caribou response to overflights by U.S. Air Force jets in Alaska and concluded that female caribou with calves were the most sensitive to aircraft disturbance, though Lawler et al. (2005) found no effects of overflights on calf survival in a short term study during the calving period.

Recreational use of **snowmobiles** has increased in recent decades as new roads provide easier access and improved technology enhances snowmobiles ability to reach new areas. Caribou may suffer increased stress from the use of snowmobiles on winter ranges. Running through deep snow in winter conditions can leave caribou susceptible to predation as well as deplete energy stores crucial for winter survival (Webster 1997). Reindeer fright and flight response to snowmobiles has been documented by Reimers et al. (2003) in southern Norway. They found snowmobiles were on average 164m further away from reindeer than skiers at the moment of initial reaction. Mean flight distances

were 281m from skiers and 264m from snowmobiles. Total distance moved was greater in response to skiers than to snowmobiles, which supports other evidence that humans on foot elicit greater responses than vehicles, most likely because humans hunting ungulates normally approach on foot (Reimers and Colman 2006). Their results also estimate that reindeer burned up to 590kJ per disturbance which is approximately 3% of normal daily energy expenditure.

In Gros Morne National Park of Newfoundland, where snowmobile encounters with caribou can be high, Mahoney et al. (2001) tested caribou response to approaching snowmobiles. They found that snowmobiles displaced caribou 60-237m from their initial locations. Time spent running was greater for animals that were resting than for animals already running or walking. Snowmobile approach interrupted feeding behavior and had the largest impact on groups of adults. Seip et al. (2007) used resource selection functions to demonstrate caribou displacement from preferred winter habitat by snowmobile use in south-eastern British Columbia. Caribou were not found in areas of high snowmobile use over several years in mountain blocks. Habitat modeling indicated that significantly lower numbers of caribou were using snowmobile habitat than expected based on habitat quality. Displacement may force caribou to use inferior habitats and suffer increased predation risk. Furthermore, snowmobiles create trail networks that provide easier access to remote winter ranges and hard packed snowmobile tracks might also increase mobility of carnivore predators disrupting predator/prey relationships.

Summary of Human Impacts on Caribou

Woodland caribou are extremely sensitive to human development. Of the 49 articles on caribou and human impacts that I reviewed, 30 demonstrated varying levels of avoidance behavior. Caribou show high levels of avoidance to many types of human activity and development including: roads, seismic lines, oil well sites, human settlements, tourist resorts and cabins, power lines, hydroelectric developments, mine sites, logging clearcuts, and snowmobile traffic. Caribou also avoid habitats that have high densities of moose or wolves. Based on a literature review of 85 studies on reindeer and caribou across the Arctic, Vistnes and Nellemann (2008) suggest that regional studies on caribou and reindeer find a reduction in use of areas within 5km of human disturbance

by 50-90%. Levels and distances of avoidance can vary by season, sex, type of disturbance, terrain and other environmental and demographic variables. Generally, females are the most sensitive to disturbance and avoided human infrastructure at greater distances than males. Many authors reported quantifiable distances of avoidance from various human developments and activities (Table 3). Roads have also been shown to prevent caribou movement and may fragment populations.

Caribou also demonstrate overt behavioral reactions to a number of human disturbances though these behaviors are rarely correlated with demographic consequences. Overall, caribou are more reactive to humans approaching on foot than to vehicles. Low altitude aircraft can elicit a response from caribou; with helicopters having a greater effect than fixed-wing aircraft. In some cases decreased calf survival has been linked to military overflights. High levels of human recreation and snowmobile use may cause displacement from suitable habitat. Finding a meaningful way to link productivity parameters and avoidance behavior remains one of the greatest challenges of research on the effects of human impacts on caribou. Cumulative effect studies are needed to analyze the impacts of human disturbance on larger temporal and spatial scales.

Table 3. Summary of caribou studies showing avoidance of human developments.

Author	Avoidance distance (m)							
	roads	seismic lines	well sites	resort or cabin	power line	hydro	mine	clear-cut
Dyer et al. (2001)	250	250	1000					
Vistnes & Nellemann (2001)				4000	4000			
Nellemann et al. (2001)				5000	2500			
Mahoney & Schaefer (2002)						3000		
Nellemann et al. (2003)						4000		
Weir et al. (2007)							4000	
Smith (2000)								1200
Schaefer & Mahoney (2007)								9200
Chubbs et al. (1993)								15000

Grizzly Bear



Grizzly bears (*Ursus arctos*), the world's largest terrestrial carnivore, have lost an estimated 50% of their range world-wide since the mid 1800s. In Canada, grizzly bears occur throughout Nunavut, Yukon, Northwest Territories, Alberta and British Columbia (Fig. 6) and are listed as a species of special concern

by COSEWIC (COSEWIC 2002a). Grizzly bears are extremely sensitive to human development and the vast majority of bear mortality is caused by humans (McLellan et al. 1999, Benn and Herrero 2002) and the indirect effects of human access (Nielsen et al. 2004b). Large carnivores in general pose a unique dilemma for conservation due to their immense spatial requirements and life history traits that cause conflict with humans (Noss et al. 1996). Bears have been persecuted for centuries resulting in extirpation in all but the northern part of their original range in North America (Herrero 2005). Behavioral and spatial overlap with people often has severe consequences for bears including hunting, poaching, accidents and nuisance kills. Habitat fragmentation and increased human encroachment lead to increased mortality, decreased reproduction, smaller isolated populations and ultimately lower population viability (COSEWIC 2002a).

Humans are grizzly bears' only known competitors for habitat. Roads, logging, resource extraction, industrial development, human settlement, agriculture, and recreation all conflict with the continuous undisturbed habitat essential to grizzly bear productivity. Low reproductive rates, late weaning age, delayed implantation and large spatial requirements (individual home ranges can encompass up to 3,885 km²) enhance the demographic consequences of individual responses such as avoidance and displacement (U.S. Fish and Wildlife Service 1993). Female survival in particular is the most sensitive parameter for population demographics and management of bear populations often focus on protecting breeding females (Mace and Waller 1998, Wiegand et al. 1998, McLellan et al. 1999, Wielgus et al. 2001). The plethora of grizzly bear habitat studies highlight the importance of fluctuations in season, topography, habitat size, intra-specific competition,

gender, age, reproductive status, temperament, level of habituation, stochastic environmental effects and a large complement of human variables that can make predicting general grizzly bear behavior extremely difficult (Fig. 7). Cumulative effect studies are needed to piece together the many confounding influences on grizzly bear behavior, abundance and distribution with regards to human impacts.

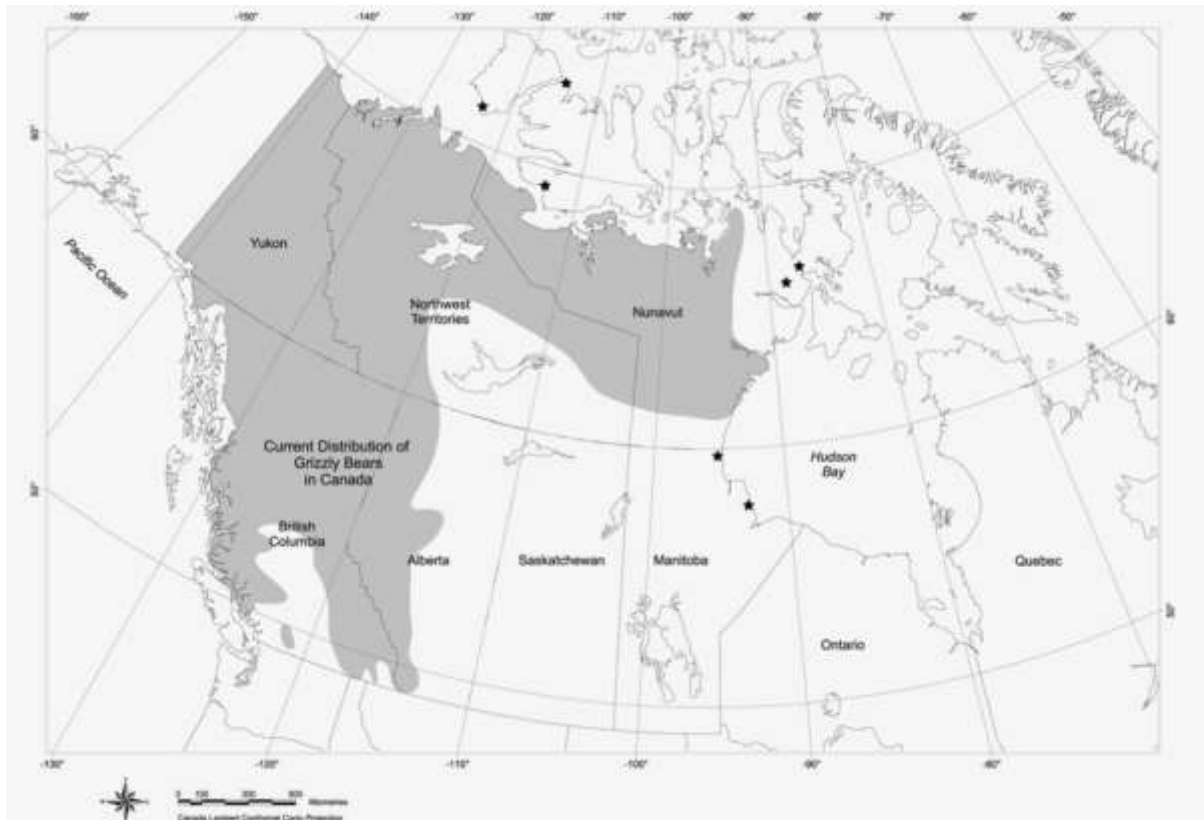


Figure 6. Current distribution of grizzly bears in Canada. Confirmed observations outside of normally occupied range are identified by stars (Herrero 2005).

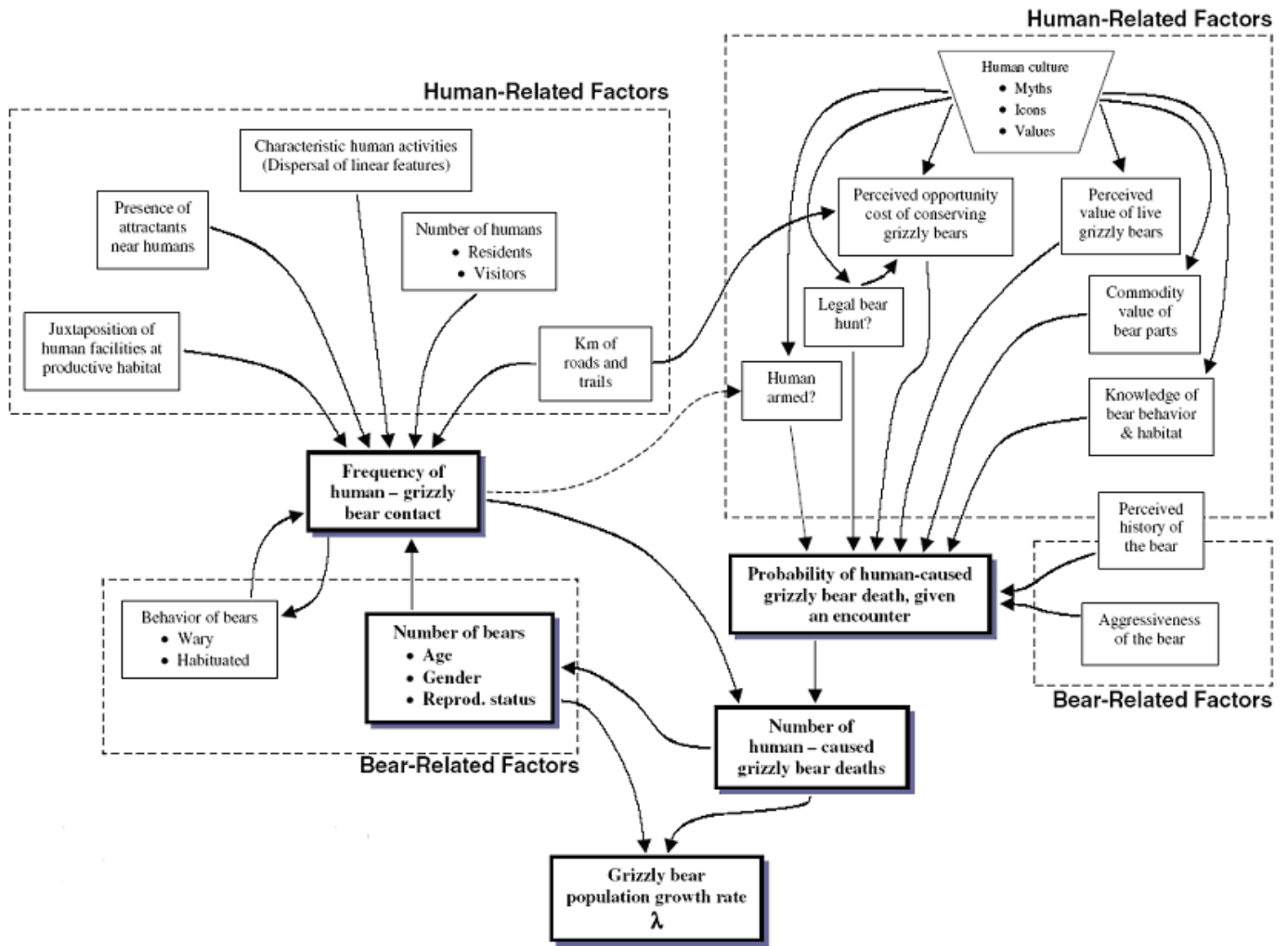


Figure 7. A descriptive model of the nature and consequences of human-grizzly bear conflict in the eastern slope of the Canadian Rockies (Herrero et al. 2000).

Human Development and Infrastructure

Human infrastructure poses both direct and indirect threats to grizzly bears. Though direct mortality due to traffic and train collisions has been documented for grizzly bears (Gibeau et al. 1996, Chruszcz et al. 2003), indirect effects of **roads** have much more severe consequences. These effects can include loss of habitat effectiveness due to avoidance (Hood and Parker 2001), barriers to movement, increased habituation to human activity and human caused mortality facilitated by increased human access (U.S. Fish and Wildlife Service 1993, Noss et al. 1996). Grizzly bears are especially vulnerable to the effects of roads because their large spatial requirements and ability to travel great distances necessitates contact with infrastructure. Roadside clearings also regularly contain high quality forage, especially in the spring and autumn, putting grizzly bears in direct conflict with humans during their most critical foraging periods. Roads are most often placed in high-quality valley-bottom habitat and riparian areas which are often frequented by bears (McLellan and Shackleton 1988). Avoidance of roadside habitat due to human activity can lead to increased competition for similar undisturbed habitats and an overall loss of habitat effectiveness.



Wildlife overpass on the Trans Canada Highway in Banff

In their 1988 study, McLellan and Shackleton documented that grizzly bears used habitats within a 100m of roads significantly less than expected in southeastern British Columbia and northern Montana. This avoidance was most pronounced in adult males and was less obvious for sub-adult females and adult females with cubs. Bears avoided all roads, regardless of traffic levels. This produced approximately 8% effective habitat loss in the study area. In the Swan Mountains of Montana, Mace et al. (1996) found that most bears avoided a 500m buffer surrounding roads. Female grizzly bears showed high selection for unroaded home ranges. All grizzly bears avoided roads with greater than 60 vehicles per day and most avoided roads that had more than 10 vehicle passes per day.

Similarly, on the Kenai Peninsula of Alaska the probability of female bear occurrence decreased with increasing density of roads and human developments (Suring et al. 2006).

In order to investigate the relative importance of varying road traffic levels on grizzly bear habitat use, Wielgus (2002) studied open, closed and restricted roads in southeastern British Columbia and the northern United States. They found that both male and female bears selected against open roads, and only females avoided closed roads. Females avoided an area within 250m of open roads. Neither sex selected against restricted roads which had moderate human use. This may be because restricted roads were used exclusively by forestry workers who rarely left their vehicles. Bears may have learned and habituated to the fact that there was no danger from humans on restricted roads contrary to the high human threat near open roads where most poaching mortality took place.

Research has also documented conflicting data that illustrates selection by grizzly bears of areas of human disturbances. In a novel approach, Wasser et al. (2004) used domestic dogs trained to detect bear scat, along with telemetry and hair snare data to determine grizzly and black bear habitat use in Alberta along the boarder of Jasper National Park. Scat, telemetry and hair data all illustrated grizzly bear avoidance of areas of high human use within the park, while conversely, black bears occupied areas of high human activity. Outside the park, both species concentrated use in areas most heavily disturbed by human-use, though grizzly bears also used areas of low human use. Bears may respond to higher concentrations of food resources where human land use created a variety of seral stages and high ungulate populations.

Gibeau et al. (2002) studied the relationship between grizzly bears' attraction to high quantity habitats near roads and their avoidance of various human developments in Alberta. Almost all grizzly bears avoided the Trans Canada Highway (TCH) in Banff National Park, where traffic can reach 21,000 vehicles per day. Sub-adult males were found closer to the highway when in the proximity of high quality habitat. This cohort utilized habitat in the vicinity of the highway during low periods of human activity, mostly at night, and near ample cover. Females avoided the highway regardless of habitat quality or time of day. In fact, only one radio collared female crossed the highway during the study using a wildlife crossing structure, and only 2 radio collared males crossed on a

regular basis. Paradoxically, females were found closer to human development and places where people might be encountered than males. This may be because adult female bears are the most risk adverse sex-age group and might be forced to select habitats away from adult males, regulating them to habitats closer to people. In the same study system, Chruszcz et al. (2003) found that grizzly bears were more likely to cross roads with low traffic volumes than the TCH. They also found that males used areas closer to low traffic roads than females. Interestingly, females crossed low traffic roads more than males, especially during the berry season. The TCH was a barrier to movement for both sexes and most crossings were motivated by movements into better quality habitat. Physical barriers to movement have the potential to decrease genetic diversity, especially in small isolated subpopulations of grizzly bears.

Increased human presence on the Kenai Peninsula of Alaska may affect the isolation of female grizzly bears. Graves et al. (2006) found that the Sterling and Seward highways (peak traffic levels reach 17,115 vehicles daily) have the strongest barrier effect on adult females with cubs. Bears were less likely to cross roads in areas of high road density, high traffic volumes and during daylight. Movement rate increased during highway crossings compared to travel through other landscapes, suggesting bears try to minimize their exposure to human activities. GPS data of grizzly bear road crossings in northwestern Montana were studied by Waller and Servheen (2005). Their results indicate that grizzly bears cross highway US-2 less frequently than expected when compared to random movements and that bears avoid a zone of 500m from roadsides. Adult females with cubs of the year were the most sensitive to vehicle traffic. Most successful crossings occurred at night (85%) and coincided with faster and longer movement patterns. The authors suggest that highways act as a barrier to movement when traffic exceeds 2,400 vehicles per day.

As oil and gas exploration and production increase in Canada's northern ecosystems, an increasing proportion of landscapes have become fragmented by **seismic cutlines**. Linke et al. (2005) studied the effect of seismic lines on grizzly bear habitat use in west-central Alberta. Though no direct relationship was found between the proportion of seismic lines and population level landscape use, seismic lines did modify the landscape in a way that might functionally decrease grizzly bear use. In the study system

bears selected for consistent large landscape patches and broad inter-patch distances. Seismic lines alter this configuration by creating non-uniform inter-patch distances and smaller patches of continuous forest. Their results highlight the importance of habitat configuration on landscape selection and distribution of species.

Logging and Forestry



Logging drastically alters the spatial composition of forests. In Canada, clearcut logging devastates hundreds of thousands of hectares each year as well as promoting the construction of new roads which provide increased access to humans. Shortly after logging, clearcuts may reduce habitat effectiveness for grizzly bears. In southeastern

British Columbia and northern Montana, McLellan and Hovey (2001) found that planted or naturally regenerating cut blocks less than 40 years old were rarely used by grizzly bears in any season. Little bear forage was available in these clearings, which had been logged in response to insect outbreaks. Alternatively, timber harvests may have the potential to create a mosaic of early seral-staged forests across the landscape, which in certain phases of revegetation might be selected for by grizzly bears responding to new growth and increased forage (COSEWIC 2002a). In southeastern British Columbia and the northern United States, Wielgus and Vernier (2003) examined grizzly bear habitat selection in managed and unmanaged forests. They determined that bears neither selected for nor avoided clearcuts but did select for natural openings. In west-central Alberta where natural openings are rare due to fire suppression, Nielsen et al. (2004a) found that grizzly bears did actively select for clearcuts. This selection was especially strong during mid-summer (15 June to 7 August) when bears fed on green herbaceous material and ants, both of which had higher frequencies of occurrence in clearcuts compared with upland forest stands. Clearcut use decreased in late summer during the berry period when fruits occurred in high proportions in the forest (Nielsen et al. 2004c). Furthermore,

grizzly bears selected for the edge of irregularly shaped clearcuts more often and used clearcuts more frequently at night.

The importance of essential spring and summer forage that becomes available in clearings such as avalanche chutes and burn sites, as well as grizzly bears' selection for natural burn sites (McLellan and Hovey 2001), highlights the significance of allowing a natural fire regime to occur in grizzly bear habitat (Gibeau et al. 1996). Furthermore, it may also be possible to utilize timber harvest activities to duplicate the ecological processes of natural fire regimes. If managed correctly, cut blocks have the potential to provide grizzly bears with essential habitat, food resources, and den sites (Herrero et al. 2000).

Habituation

Habituation is the loss of a wild animal's wariness towards humans and can be viewed as an indirect effect of human activities on wildlife. A gradual adaptation to human caused stimuli can be especially dangerous when dealing with large, powerful animals like grizzly bears. Individual variation in bears' level of habituation makes predicting behavior and response difficult. While



increased tolerance to human proximity may benefit some bears by allowing them to exploit lush open habitats near roadsides or human developments, habituated bears generally experience higher mortality rates than wary bears (Benn and Herrero 2002, Herrero et al. 2005). Proximity to human activity also makes habituated bears more vulnerable to illegal killings as well as management control kills when associated with damage to property or human injury (U.S. Fish and Wildlife Service 1993). Mattson et al. (1992) found that grizzly bears in Yellowstone used areas near roadsides with higher frequency during years of poor whitebark pine seed crops. Low levels of natural food at higher elevations and away from human facilities forced grizzly bears to utilize areas within 5-8km of roads. They found a corresponding increase in mortality risk for adult

females and sub-adult males during years of small seed crops. Data from management kills also suggest that habituated bears were 3-4 times more likely to be killed by humans compared to nonhabituated bears.

A unique case of habituation is demonstrated by the growing tourist industry of grizzly bear viewing along coastal Alaska and British Columbia. If managed correctly, bear tolerance to humans can provide considerable benefits to both the people and bears involved. In salmon systems, bears demonstrate increased habituation to other bears, and exist at much higher concentrations than inland bears. This bear-to-bear tolerance allows a large number of animals to exploit an important food resource, and most likely sets the stage for greater bear-to-human habituation. Positive experiences with bears may lead people to support conservation and promote habitat protection. In contexts where habituation may lead to high mortality risk such as near highways and roads, habituation should be discouraged, yet in other systems habituation has the potential to allow humans and bears to coexist (Herrero et al. 2005).

Increased Human Access



Extensive effort has gone into documenting the cause and location of grizzly bear deaths across Canada. Most deaths can be attributed to humans (Mace and Waller 1998, McLellan et al. 1999, Benn and Herrero 2002, Herrero 2005) and include legal hunting, management control, defense of life, and illegal poaching. Many populations of grizzly bears are legally hunted in Canada with approximately 450 bears harvested each year. Numerous studies have addressed the effects of harvest mortality on population demographics (Wielgus and Bunnell 2000, Wielgus et al. 2001, Wielgus 2002). The success of grizzly bear hunts can vary widely between years based on variables such as annual variation in cohort size, survival, reproductive success and weather during the hunting season (Reynolds and Ver Hoef 2000). Nearly 2.5% of the Canadian grizzly bear population is killed by humans annually

(COSEWIC 2002a) which may be unsustainable in certain populations when in conjunction with the estimated 2.2% of the population that die from natural deaths and other unknown mortality attributed to illegal poaching incidents and defense of life kills (McLoughlin 2002, Peek et al. 2003, Benn et al. 2005). A large proportion of human caused grizzly bear mortality occurs within 500m of roads (Benn and Herrero 2002, Benn et al. 2005, Ciarniello 2006). Backcountry road use is often variable, which makes it difficult for bears to develop avoidance patterns in relation to unpredictable human activities. Grizzly bear mortality risk is dependent on several factors ranging from previous human contact, habituation level, amount of road access, frequency of human encounters, and varying levels of human tolerance toward bears (Ciarniello 2006).

There is growing concern that areas near roads and human developments may be attractive population sinks for grizzly bears. Attractive sinks are areas where grizzly bears are likely to be present (most likely due to high quality forage, for example; near roadsides) but suffer increased mortality rates (Schwartz et al. 2005, Nielsen et al. 2006, Ciarniello et al. 2007). Many studies have correlated high rates of grizzly bear mortality to road access and illegal killings (Mace et al. 1996, Benn and Herrero 2002, Ciarniello et al. 2007). In Banff and Yoho National Parks, humans caused 119 of 131 known grizzly bear mortalities from 1971-98. Most of these (71%) were management control kills of problem bears. Highway mortalities accounted for 19% of deaths. All human caused mortalities were within 500m of roads or 200m of trails (Gibeau et al. 1996, Benn and Herrero 2002). In the areas of Alberta and British Columbia surrounding Banff and Yoho National Parks (known as the Central Rockies Ecosystem) where some hunting is allowed, Benn et al. (2005) collected similar data. They found that in Alberta from 1972-2002, a total of 229 grizzly bears were killed by humans. Of these, 48% were legally harvested, 18% were management control kills, 16% were illegal kills and 11% were self defense kills. In British Columbia from 1976-2002, a total of 397 grizzly bears were killed by humans. Legal harvest accounted for 81% of deaths, followed by management control kills (16%), and illegal kills (3%). A large proportion of these deaths (98% in Alberta and 56% in BC) occurred within 500m of roads and 200m of trails.

Reported mortalities may underestimate the actual number of natural mortalities that are usually only detected with radiotelemetry information. McLellan et al. (1999)

suggest that without radio collar data management agencies would miss up to half of all grizzly bear deaths. Their study also investigated causes of grizzly bear death over a period of 22 years in the Rocky and Columbia mountains of the United States and Canada. They established that people killed approximately 85% of the 99 grizzly bears that died while radio collared. Similarly, in the Greater Yellowstone Ecosystem 85.5% of known bear mortalities were caused by humans over a period of 18 years (Schwartz et al. 2005).

Summary of Human Impacts of Grizzly Bears

Grizzly bears have suffered from a negative public image due to their dangerous nature as an apex carnivore. Wildlife biology has recently begun to shed light on the important ecosystem functions that grizzly bears provide, from seed and nutrient transport to acting as an umbrella species whose conservation supports the habitat needs of a diversity of organisms (Noss et al. 1996, Peek et al. 2003). Grizzly bears are extremely sensitive to human development and the vast majority of bear mortality is caused by humans and the indirect effects of human access. The extent of impact can vary based on season, terrain, sex, age, level of habituation and other environmental and demographic variables. Overall, female bears with cubs are the most sensitive to human disturbance. Grizzly bears demonstrate varying levels of avoidance of human infrastructure that has been quantitatively defined in several studies (Table 4). Avoidance may be dependent on the traffic volume, time of day and the relative human presence. Roads, especially high traffic highways, may act as barriers to movement and may isolate subpopulations. In some cases grizzly bears may select for areas of human disturbance that contain important food sources, such as roadside clearings and logging clearcuts.

Though habituation to human disturbance may benefit bears by allowing them to utilize high quality habitat near human developments, it also increases the likelihood of fatal conflict with humans. Grizzly bears are susceptible to legal hunting, management control kills, defense of life kills and illegal poaching. A large proportion of human caused grizzly bear mortality occurs within 500m of roads. Balancing the important economic assets of grizzly bear hunting with their intrinsic value to the environment and

society will be an important challenge in grizzly bear conservation in the coming decades.

Table 4. Summary of grizzly bear studies showing avoidance of human developments.

Author	Avoidance distance (m)			
	roads	high-ways	trails	develop- ment
McLellan & Shackleton (1988)	100			
Mace et al. (1996)	500			
Wielgus (2002)	250			
Gibeau et al. (2002)	1050	1790	890	2115
Waller & Servheen (2005)	500			

Moose



Moose are widely distributed across Canada and the northern United States in boreal habitats (Fig. 8., Timmermann 2003). Currently moose are expanding and re-establishing their range in several New England states and portions of central and southern British Columbia (Timmermann 2003, Stotyn et al. 2007). This may be due to numerous factors including low predator

abundance, declining deer populations, increased logging and fire disturbance, conservation and protection, global warming, and reduced harvests (Peek and Morris 1998, Timmermann 2003). There are thought to be approximately 1,000,000 moose in North America. Human hunting has the largest anthropogenic effect on moose populations with the annual collective harvest totaling approximately 82,500 moose in 2000-2001 (Timmermann 2003), including 14,000 in British Columbia alone (British Columbia Ministry of Environment 2000a). Moose are a principle game species in Canada and provide more meat than all other ungulates combined. In some areas hunting pressure may lead to local declines (Ericsson 2003, Heinemeyer et al. 2003, Parker 2003).

In a review of how human dimensions are incorporated into moose research and management, Erricsson (2003) found that in the past 10 years there has been a decline in research on moose-human interactions. Furthermore, hunting and vehicle collisions studies made up the majority of the literature that dealt with the effects of human impact on moose. Moose populations have shown high adaptation to human habitation. For example, in Anchorage, Alaska moose numbers in the city can increase to over 1,000 in the winter and moose are becoming an escalating hazard to drivers (Rozell 1999). Urban moose have even developed a taste for human garbage (Fig. 9., Sinnott 2008). Moose may benefit from certain aspects of human settlement, such as increased forage in areas of human disturbance and decreased hunting pressure near developments from human hunters and non-human predators (Schneider and Wasel 2000).



Figure 8. 2000-2001 post-hunt moose population estimates for 28 North American jurisdictions (Timmermann 2003).



Figure 9. Cow moose teaching her calf to eat improperly stored garbage in an Anchorage trailer park (Sinnott 2008).

Human Development and Infrastructure

Direct mortality due to vehicle collisions has a large negative effect on both moose and humans involved in accidents. Hundreds of moose are killed on **roads** each year in Canada, resulting in high monetary costs and safety concerns for motorists (L-P Tardif & Associates Inc. 2003). A number of variables increase the likelihood of moose-vehicle collisions. These include; high to intermediate traffic levels, relatively high speed limits, areas of high moose density, hot days with high atmospheric pressure, dry roads, nighttime, summer months, high quality habitat close to the road and in valley bottoms (Belant 1995, Garrett and Conway 1999, Joyce and Mahoney 2001, Seiler 2005, Dussault et al. 2006b).



Salt used to de-ice roads during the winter often builds up in roadside pools in spring and early summer. Moose congregations at these sites can result in increased collision rates. Dussault et al. (2006b) found that accidents in Québec were 80% more frequent in the vicinity of segments of road that included salt pools. A management attempt to drain pools in 1979 failed to reduce moose abundance or moose mortality at these sites (Jolicoeur and Crete 1994). In 2004 the Québec Ministry of Transportation drained the most problematic pools and also filled them with rocks to prevent moose from reaching the water. Leblond et al. (2007) documented the abundance and distribution of moose utilizing these pools before and after management intervention. They found that moose gradually reduced use and frequency of visits to altered pools during the night. They suggest that decommissioning roadside pools has the potential to decrease vehicle collisions with moose, though their results did not directly correlate collision risk with pool use within the timeframe of their study.

In the same study area of Québec, Leblanc et al. (2006) examined several environmental variables and their relative influence on the number and location of moose vehicle collisions. Contrary to the results of Dussault et al. (2006) they did not find a relationship between the location of salt pools and moose mortalities. Rather, their results

suggest that moose collisions occur more often in areas moderate topographic variation, in areas of high moose density where forage quality and abundance were high, and when rivers and streams are within 250m of the road. Moose accidents were less likely to occur in areas where steep embankments or deep ditches paralleled the roadway.

Indirect effects of roads may also be important to moose distribution. Avoidance of habitat in the vicinity of roads can decrease habitat effectiveness and roads may also act as barriers to movement. Furthermore, roads allow people to reach secluded areas and may enhance hunting and poaching pressure on local populations (Snaith et al. 2002, Parker 2003). A few studies have demonstrated weak levels of road avoidance by moose. In Nova Scotia, Snaith et al. (2002) found that road density was a strong predictor of the presence of moose fecal pellets. As road density increased the probability of finding moose pellets decreased, indicating that moose avoid areas of high road density. In fact, road density explained more variation in moose habitat selection than many other habitat composition variables included in their HSI model. Results from a study by Yost and Wright (2001) along a road corridor in Denali National Park in Alaska propose that moose avoid areas within 300m of the road. Moose sightings were significantly lower than expected near the road in areas of high traffic than in the backcountry. The authors caution that this result may also be due to higher forage availability more than 600m from the roadside. Roads may also constrain the movement of large mammals and act as barriers to migrations and dispersal. In northern Sweden, Ball and Dahlgren (2002) examined the browsing intensity of moose in relation to a major highway. They found that moose density and browsing pressure increased within 3km of the road. They suggest that moose may be hesitant to cross the highway and thus form population aggregations along the road corridor during migration between summer and winter ranges.

Not all impacts of human development affect moose negatively. In Alberta, a study by Schneider & Wasel (2000) suggests that certain human disturbances, such as fragmentation and increased edge habitat may promote moose density as a consequence of improved high quality forage. Aerial moose surveys of almost all of northern Alberta identified higher moose densities in areas of high agricultural use and human settlement (0.40 moose/km^2) compared to areas comprised of boreal forests with few human developments (0.25 moose/km^2). Their results indicated that on a regional scale moose

density is positively correlated with high road density and high levels of legal hunting. They suggest that regional selection for areas of high human settlement is more important than small scale avoidance of anthropogenic infrastructure.

Hydroelectric development and its associated power lines, roads, reservoirs and dams has the potential to decrease moose habitat. In a literature review on the effects of hydroelectric developments on moose, Meth et al. (2000) found very few studies that actually document changes in moose habitat selection or demography due to hydroelectric infrastructure. In Norway, Andersen (1991) studied the effects of a large reservoir created in association with hydroelectric development on moose migration and summer habitat use before and after construction. They found only minor effects on migration patterns and no significant changes in home range size, though home range site fidelity did decrease between years. Similarly, Ricard and Doucet (1999) were unable to document avoidance or selection by moose of power line corridors associated with Hydro Québec. Their results indicated that moose density was not significantly different beneath power lines or in control habitats. Other studies have suggested that moose may utilize transmission lines as winter travel corridors (Northcott et al. 1996) and that increased habitat edges may provide young browse for moose (Meth et al. 2000).

Logging and Forestry



Logging and forest management practices are prevalent across Canada and affect large areas of moose habitat. As mentioned previously, forest disturbance has the potential to increase moose habitat by creating a mosaic of forest patches and early successional types which supply the new willow and shrub growth

that is the primary source of moose forage (Hjeljord and Histol 1999, British Columbia Ministry of Environment 2000a). Moose densities have been shown to increase following wildfires, floods, insect outbreaks, windfalls and clearcuts (Collins and Schwartz 1998). When timber harvest is managed in order to create high levels of hardwood regeneration through soil scarification, site preparation and good seedling establishment, new forage

can increase moose carrying capacity by up to 45 times more than that of mature forests (Collins and Schwartz 1998). However, clearcuts may only benefit moose during the first 20 years post logging, and may even be detrimental to moose in the first few years following harvest (Courtois et al. 1998). Courtois et al. (2002) studied moose habitat selection in northwestern Québec in an region of intense forest harvest at two spatial scales. They found that on a coarse scale clearcuts did not affect home range selection and cutovers were not related to increased mortality. Conversely, at a fine scale, moose tended to avoid clearcuts during most seasons, and selection was strongest for mixed stands. They suggest that logging and moose populations can co-exist, but that behavioral trade-offs between foraging and undesirable environmental conditions and predation may manifest as avoidance of recent clearcuts.

Predator-Prey Dynamics

Human developments can be attractive to ungulates due to the inherent avoidance of human infrastructure by predators such as wolves and grizzly bears. In Anchorage, moose may exploit the city for protection from nearby wolf packs in the winter (Garrett and Conway 1999). In the Greater Yellowstone Ecosystem,



Berger (2007) evaluated the hypothesis that female moose select for areas in the vicinity of roads as a shield against predation by grizzly bears. Data on the distribution of moose birth sites indicate that when threatened by grizzly bear predation, female moose chose sites closer to roads to give birth. Preference for roads increased in correlation with the increase in grizzly bear density. Non-reproductive females and moose in areas of low predation risk did not shift their birth site locations. In southeastern British Columbia Kunkel and Pletscher (2000) compared sites where moose were killed by wolves to random locations from radio collared moose. Their results suggest that moose were less likely to be killed by wolves in areas of high road density. Though wolves use roads to enhance travel and searching speeds, the risk of encountering humans on roads may have

offset any hunting efficiency benefits. Subsequently, moose were safer in areas with roads. Incidentally, moose were more likely to be killed by wolves near trails and streams. The lack human use on these types of linear corridors may improve hunting success for wolves. Clearcuts in the study area were not correlated to higher rates of moose mortality by wolves. These results provide strong evidence of the use of human refugia to decrease predation risk.

Human Harassment



Human recreation and vehicular stimuli from aircraft, snowmobiles, and automobiles can affect moose distribution, and may cause short term behavioral changes that have the potential to result in survival and reproductive consequences (Canfield et al. 1999). In New Hampshire, moose response to human **wildlife viewing** was monitored at a

roadside salt lick. Most moose were highly tolerant of quiet viewers at a viewing stand and fled less than 4% of the time (Silverberg et al. 2003). Moose were most sensitive to cars stopped and trucks passing as well as multiple combinations of several stimuli. Leblonde et al (2007) also observed moose flight response in reaction to passing cars at roadside salt licks in Québec. Similar to other ungulates, moose reactions to **human approach** on foot appears to be greater than vehicular stimuli. In Norway, Andersen et al. (1996) found that moose elicit flight responses at much greater distances from pedestrian approach on foot or skis than from mechanical stimulus (including tracked all-terrain vehicles, a snowscooter, a four-wheel motorcycle, a helicopter, a F-16 fighter jet, and canon fire). Heart rate also returned to normal sooner after disturbance by mechanical stimuli than from direct human disturbance. They suggest that increased fear of humans is related to a ban on human hunting from vehicles. No long term effects of military disturbance were observed during the study, though the authors advise that winter disturbance has the potential to cause greater detrimental effects.

In Wyoming, Colescott & Gillingham (1998) recorded the reactions of moose to **snowmobile traffic**. They found that moose within 300m of the trail altered their behavior in response to passing snowmobiles. Moose reactions were most pronounced when within 150m of a snowmobile, but behavioral changes were not significantly harmful and moose did not reduce use of the study area. Trimper et al. (1996) found very low densities of moose ($0.1/\text{km}^2$) in the areas surrounding the Canadian Forces Goose Bay facility in south central Labrador and northeastern Québec. This area is used for training and is subject to low level **overflights by jet aircraft**. Aerial surveys documented an absence of moose from regions of apparently suitable habitat. The authors did not study the correlation between aircraft use and moose densities and rather suggest that low population size is attributable to bad winters, illegal harvest and wolf predation.

Summary of Human Impacts on Moose

Moose populations have shown high adaptation to human development and may benefit from certain aspects of human disturbance such as increased food resources and decreased predation pressure near human settlements. Reduced moose harvests, low predator abundance and increased forestry disturbance may all be contributing to an overall increase in moose abundance. The impact of direct mortality from vehicle collisions has a strong negative effect on moose, especially in areas of high moose density, on roads with high traffic volumes, at night, and near roadside salt pools where moose congregate. A handful of studies suggest that moose may avoid areas within 300m of roadsides and in some cases highways may act as barriers to migration. In contrast, other research reports that moose densities actually increase in proximity to areas of high human development. Similarly, moose may take advantage of the high quality early successional growth associated with regenerating logging and forestry clearcuts. There is growing evidence that moose may utilize human activity and development as a shield against predators such as wolves and grizzly bears. The use of human refugia to decrease predation risk is an interesting unintended indirect effect of human influence on natural systems. Moose demonstrate overt behavioral reactions to human disturbance. In general, approach by humans on foot elicits a stronger reaction than vehicle traffic. No long term

demographic effects have been linked to behavioral modifications in response to human disturbance. In general, moose have a high tolerance of human presence and seem to be able to coexist with the current pace of industrialization.

Thinhorn Sheep



Thinhorn sheep (*Ovis dalli*) occur primarily in Alaska, the Yukon Territory, western Northwest Territories, and north of 56° latitude in British Columbia (Fig. 10., Demarchi and Hartwig 2004). Rocky mountain bighorn sheep (*O. canadensis canadensis*) have larger curled horns than thinhorn sheep and are distributed along the

Rocky Mountains from central British Columbia and Alberta to New Mexico (Demarchi et al. 2000). Two subspecies, the Sierra Nevada bighorns (*O. c. sierrae*) and the desert bighorn (*O. c. nelsoni*) occur throughout the desert southwest of the United States and in the central Sierra Nevada range. Among thinhorn sheep there are two subspecies classified by coat color: the white Dall's sheep (*O. d. dalli*) and the darker Stone's sheep (*O. d. stonei*) which only occur in the Yukon and northern British Columbia (Fig. 10., Worley et al. 2004). Fannin sheep are thought to be a hybrid between Stone's and Dall's sheep where their ranges overlap (Paquet and Demarchi 1999, Demarchi and Hartwig 2004).

Thinhorn sheep inhabit most of their historic range, and have likely maintained a population level of approximately 130,000 sheep since before European contact (Worley et al. 2004). Because British Columbia has only a small, concentrated population of Dall's Sheep, the population is on the blue list as a species of special concern in the province. Stone's Sheep are on the yellow list and are not considered to be at risk (<http://a100.gov.bc.ca/pub/eswp/>). Predation and malnutrition are likely the most common causes of natural mortality in thinhorn sheep populations (Paquet and Demarchi 1999). Mature males with a full curl are an important trophy animal in British Columbia with 250-500 Stone's sheep rams and 8 Dall's sheep rams harvested per year (Demarchi

and Hartwig 2004). Thinhorn sheep have not been affected by human encroachment to the same extent as bighorn sheep. In the last century bighorns have been extirpated from much of their former range and have suffered from competition with domestic livestock, hunting and disease (Armentrout and Boyd 1994). However, as oil and gas development expands into northern Canada, thinhorn sheep are likely to experience many of the same disturbances and consequences as bighorn sheep. In preparation for the foreseeable human impacts on thinhorn sheep and because of the lack of current research specific to thinhorns, I will review effects of human disturbance on all subspecies of wild mountain sheep in North America.

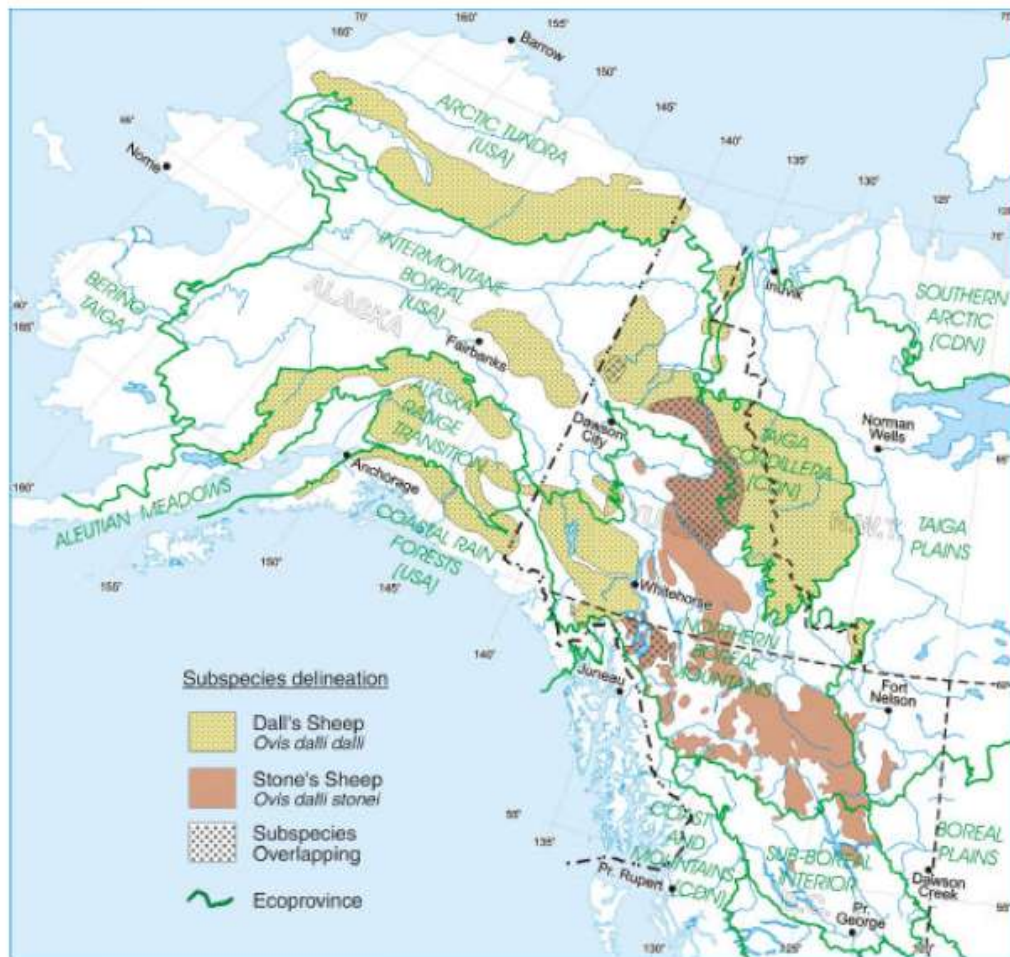


Figure 10. Distribution of thinhorn sheep (Dall's Sheep, Stone's Sheep and Fannin Sheep) in North America, including British Columbia, Yukon, Northwest Territories and Alaska (Demarchi and Hartwig 2004).

Human Developments and Infrastructure

Roads and other infrastructure can impact wild sheep populations. Direct mortality due to vehicle collisions is probably not a widespread problem, though there are reports of Stone's sheep hit by cars on the Alaska highway



(British Columbia Ministry of Environment 2000b). The indirect effects of **roads** may have demographic consequences as a result of avoidance and displacement from key habitats. Roads can act as barriers to movement and may fragment habitat between important seasonal sites such as mineral licks. In Colorado, Keller and Bender (2007) observed attempts of bighorn sheep to cross a road in order to access an essential mineral site. They found that when traffic was high and people were present at the site, bighorn sheep made more attempts and took longer to cross the road. Furthermore, the number of bighorn sheep utilizing the mineral lick declined from nearly 800 sheep in 1996 to only 243 during the summer of 2003. The authors suggest that the decline may be due to avoidance of the road. This could decrease reproduction and survival because of the importance of mineral licks to bighorn health (Tankersley 1984). Roads may act as barriers to migration and annual movements. In Denali National Park, unsuccessful road crossings by Dall's sheep have been observed. Sheep that occupy ranges more than 1000m from the road are less likely to habituate to human presence and roads may act as substantial barriers to migrations (Dallemolle and Vanhorn 1991).

Avoidance of roads may also lead to loss of functional habitat. Papouchis et al. (2001) studied desert bighorns response to roads and vehicles in Canyonlands National Park, Utah. They found that bighorns fled from vehicles in 17% of encounters. Heavy traffic caused greater avoidance and sheep fled most often when within 200m of the road and did not respond if they were more than 800m from the road. In general, most bighorn sheep avoided roads and were on average 39% farther from roads than other areas. This avoidance produced a 20-36% decrease in the use of suitable habitat along the road corridor within the study area.

The effects of human infrastructure and **mining development** on mountain sheep behavior, abundance and habitat selection have been studied where sheep home ranges overlap with mines or other developments. In the Mojave Desert of California, a heap-leach gold mine was placed near a critically important spring used by bighorn sheep in the summer. Oehler et al. (2005) measured the influence of mining activity on habitat selection, home-range dynamics and foraging ecology of two subpopulations of bighorn sheep; one that occupied an area within the vicinity of the mine, and a control population in a non-mined area. They recorded few changes in sheep activity that could be directly correlated with mining. Their results did suggest that female sheep near the mine spent more time vigilant during the summer and fall and consequently spent less time foraging. This result was also documented for bighorn sheep within the perimeter of an active copper mine in Arizona. Sheep in the presence of vehicles and blasting associated with mine activity foraged up to 6% less than sheep in non-mined areas (Jansen et al. 2006, Jansen et al. 2007). Oehler et al. (2005) proposes that even a small decrease in forage intake could affect survival in populations of desert bighorns that must persist in marginal environments.

Mountain sheep can be extremely sensitive to human development and may abandon habitat following disturbance events (Armentrout and Boyd 1994). On the Rocky Mountain Front in Montana, **seismic lines** caused a significant decline in home range size of bighorn sheep. In the year following four large scale cutlines, bighorns were excluded from 28% of their traditional fall range (Hook 1986). In the Santa Catalina range of Arizona, bighorn abandonment of 206km² of historic habitat has been correlated to human disturbance and fire suppression (Etchberger et al. 1989). The 1988 Winter Olympics in Calgary, Alberta caused local bighorn sheep populations to abandon parts of their range adjacent to the “ladies downhill start area” at the downhill skiing venue on Mt. Allan. After the ski area was opened in 1986, Jorgenson (1988) observed an 18% decline in the population due to decreased lamb survival and hunting pressure. Human activities such as snowmaking, helicopter flights, and avalanche blasting probably contributed to the decline and range abandonment. Parasite levels also increased following human disturbance, and later returned to pre-development levels.

Human Harassment



Mountain sheep are a highly vigilant species and spend a large portion of time in open habitats in order to watch for potential predators or danger (Demarchi and Hartwig 2004). Human disturbance due to recreation and aircraft overflights can severely stress wild sheep. Aircraft disturbance is especially crucial to wild sheep which are often found on exposed mountain sides where cover is scarce. In California, Bleich et al. (1990, 1994) monitored the distribution and movements of bighorn sheep following disturbance by **helicopter** surveys. They found that during surveys and in the days following surveys, adult sheep moved 2.5 times farther than on non-survey days. In the spring, sheep were more likely to move into a new vegetation type in response to surveys. They also found that some animals abandoned the study area following disturbance. The authors suggest that increased movement may lead to altered foraging rates, increased susceptibility to predators and increased stress. Bighorn sheep in western Arizona also demonstrated increased movements 19% of the time when exposed to low-level overflights from fixed wing aircraft. When aircraft approached within 50m of the ground sheep left the area (Krausman and Hervert 1983). In Grand Canyon National Park, Stockwell et al. (1991) found that desert bighorns were especially sensitive to helicopter disturbance during the winter. Disturbance resulted in a 43% reduction in foraging efficiency. During the spring when sheep were closer to the valley bottom and further from helicopters, disturbance was not detected. The authors propose a threshold disturbance distance of 250-450m.

Aircraft disturbance of thinhorn sheep may be especially important considering the rapid expansion of oil and gas development that often necessitates aircraft to access remote sites. Site seeing helicopter tours are also an expanding industry in the Canadian north that has the potential to influence thinhorn sheep behavior and abundance. Several studies have examined the effect of experimental overflights on Dall's sheep behavior in the Yukon Territory. Results suggest that **fixed-wing aircraft** overflights are less disturbing to Dall's sheep than helicopters (Frid 2000a, 2003). Helicopter overflights

caused sheep groups to flee 100% of the time when the trajectory was <0.6km while in contrast fixed-wing aircraft only caused 53-58% of groups to flee (Frid 2000b). When sheep were further from rocky slopes and when aircraft approach directly, sheep were more likely to flee or disrupt resting. Sheep that were bedded down at initiation of disturbance took longer to return to pre-disturbance behavior than sheep that were active, indicating that the energetic costs of interrupted rumination time may be more substantial than decreased forage and increased locomotion. There was no evidence of habituation to overflights (Frid 2000a, b, 2003).

Habituation to **jet overflights** was observed in two studies that monitored bighorn sheep heart rate and behavior before, during and after being disturbed by loud noise associated with F-16 fighters. Krausman et al. (1998) found that in Nevada, the heart rate and behavior of bighorn sheep in a large enclosure flown over by jets did not change significantly. They found that heart rate only increased in 21 of 149 overflights and returned to preflight levels within 120 seconds. In a lab setting, Weisenberger et al. (1996) observed that bighorn sheep and mule deer (*Odocoileus hemionus*) were able to habituate rapidly to noise from a simulated jet overflight. They recorded 34 incidents of increased heart rate in bighorns during 112 overflights and heart rate returned to normal within 60-180 seconds. These results suggest that bighorn sheep do not view overflights by jet aircraft as a threat.

Similar to other ungulates in this review (caribou and moose), approach by **humans on foot** tends to illicit a greater response in mountain sheep than that of vehicular stimuli. In Utah, Papouchis et al. (2001) found that bighorn sheep fled three times more often in response to hikers (animals fled in 61% of encounters) than to vehicles. They suggest that the high unpredictability of hiker locations caused sheep to have stronger reactions when surprised by people compared to the much more predictable traffic on roads. Loehr et al. (2005) studied the response of Dall's sheep to human presence in the Yukon Territory. They found that female sheep were more sensitive than males and decreased bedding and increased foraging when humans were present, whereas rams had no behavioral changes. Adults also seemed to react more to human presence than juveniles. Mountain sheep may also be more reactive to human approach when people are accompanied by a dog. MacArthur et al. (1982) found that in southwestern

Alberta, cardiac and behavioral responses of bighorn sheep were greatest when humans approach with a dog or approached from over a ridge.

Summary of Human Impacts on Sheep

Bighorn sheep were once distributed continuously across western North America. Human encroachments, competition with domestic livestock, and diseases have all contributed to the current fragmentation of local populations. As humans expand into northern Canada and Alaska, the formally isolated and secluded habitats of thimhorn sheep are under increasing pressure from human disturbance. Bighorn and thimhorn mountain sheep demonstrate varying degrees of sensitivity to human impact. Where human development intersects sheep range roads may act as a barrier to movement, especially when highways bisect routes between important seasonal mineral lick sites. Other research suggests that mountain sheep avoid roads with high traffic volumes and in some cases may even abandon habitat following disturbance events.

Mountain sheep exhibit a number of overt behavioral reactions in response to human disturbance. Industrial mining may disrupt foraging efficiency by increasing time spent vigilant in the proximity of the mine, though few studies have linked behavioral changes to long term demographic consequences. In general, approach by humans on foot elicits a stronger behavioral reaction than vehicle traffic. Aircraft overflights may increase movement rates, heart rates, and interrupt foraging and resting behaviors. The extent of the response may depend on the trajectory of the aircraft and the availability of escape terrain. Helicopters have been shown to produce the greatest response. Evidence for habituation to jet overflights has been proposed in certain situations. Protection and maintenance of thimhorn sheep habitat is essential to prevent extirpations similar to those observed in bighorn sheep populations in the past century.

Mountain Goat



Mountain goats (*Oreamnos americanus*) are among the least-understood ungulate in North America (Cote and Festa-Bianchet 2003). Mountain goats occur throughout the Rocky Mountains in British Columbia, Alberta, Northwest Territories, Alaska, and several northern states in the United States (Fig. 11). They have recently been reintroduced into parts of Colorado, Oregon, Nevada, South Dakota and Wyoming where populations are highly successful (Cote and Festa-Bianchet 2003). Because mountain goats inhabit some of the most inhospitable terrain in North America, their

habitat does not overlap with humans as much as species that live at lower elevations.

Predation by grizzly bears, wolves and cougars (*Puma concolor*) probably has a significant effect on mountain goat population growth, though few studies have quantified predation rates (Cote and Festa-Bianchet 2003).

Mountain goats in native populations have demonstrated extreme sensitivity to over-harvest by human hunters (Smith 1988). A late age of first reproduction and low kid production may increase their susceptibility to increased mortality (Cote et al. 2001). Trophy hunting occurs throughout much of their range, with an annual harvest of 902 goats in British Columbia alone. Harvest management is complicated due to the difficulty in distinguishing male and female goats (Cote et al. 2001). Skewed sex ratios may affect female abundance and population demographics. Interestingly, reintroduced populations seem less sensitive to hunting. In Montana, the goat harvest can eliminate 7-9% of the population annually with few negative consequences (Cote and Festa-Bianchet 2003). Mountain goats also seem to be exceptionally susceptible to human disturbance and the indirect effects of roads and increased access. Industrial activity and helicopter disturbances associated with recreation, mining, and logging may have severe consequences on goat populations especially since recruitment is often low (Cote and Festa-Bianchet 2003).



Figure 11. Distribution of mountain goats in North America (Cote and Festa-Bianchet 2003).

Human Development and Infrastructure

Mountain goats are likely sensitive to industrial activities such as mining, logging, and energy exploration in their range, but information on the influence of human developments on goat behavior and long term demographic consequences is scarce (Wilson and Shackleton 2001, Cote and Festa-Bianchet 2003). In Montana, Singer (1978) observed the behavior and movements of mountain goats that had to cross a **road** to reach an important mineral lick. During the summer he observed 87 successful crossings and 31 unsuccessful attempts. Crossing success was related to the size of the group (large groups had greater success than individuals), the difference in motivation when arriving or departing from lick (all arrivals were successful while 42% of departures were not), and the amount of visitor activity and passing vehicles. Goats often fled from the road when trucks or cars passed, though they were able to habituate to a low level of visitor activity and noise from a train across the river. In a subsequent study of mountain goats in Glacier National Park, Pedevillano and Wright (1987) found that after the implantation of underpasses to allow goats to reach the mineral lick, all crossings were eventually successful. Traffic and people standing above the overpass caused alarm responses, hesitation and flight. Habituation allowed goats to utilize the mineral lick in the presence of people. Goats also exhibited habituation to predictable and continuous stimuli related to **petroleum exploration** activities in Alberta. Penner (1988) found that goats were able to tolerate noises that mimicked the potentially disturbing noise stimuli associated with seismic activity. Results suggest that goats were most reactive during the rutting, kidding and post-kidding seasons. Unpredictable stimuli and sudden disturbances such as helicopter overflights caused the greatest reactions.



Demographic population variables of mountain goats along the Rocky Mountain front of Montana were monitored by Joslin (1986) during a period of intense energy exploration. From 1981-1985, 579km² of **seismic lines** were cut within mountain goat habitat. Results indicate that a decline in adult female numbers, kid numbers and

productivity coincided with the peak of seismic activity in the study area. Kid:adult ratios dropped 81% in one year for the population that was most effected by human disturbance. In British Columbia, mountain goats avoided an area 1-3km from drilling disturbances in association with hydroelectric development. When the rig was removed goats returned to their pre-disturbance distribution (Foster and Rahs 1985).

Human Harassment

Human recreation has the potential to disrupt mountain goat behavior and movements, though contact may be rare due to the spatial segregation of goats in remote rugged topography (Varley 1998). The literature suggests that mountain goats are more sensitive to helicopter disturbance than other ungulates (Wilson and Shackleton 2001). Like mountain sheep, habitat ranges of mountain goats provide little cover and protection from disturbances such as aircraft. Use of helicopters in energy development and exploration can impact mountain goats in secluded areas where few other human disturbances exist. Cote (1996) measured the overt responses of mountain goats to **helicopter overflights** by exploration companies by in Alberta. During the study, 32% of groups observed were greatly affected by the presence of helicopters, 26% were moderately disturbed and 42% were lightly disturbed. Distance between goats and the helicopter had the biggest impact on response. Goats were highly disturbed 85% of the time when helicopters approached within 500m of the animals compared to only 9% when aircraft was more than 1,500m away. Helicopter disturbance also split up social groups of goats during 25 overflights. In a few incidents goats were subjected to several hours of consistent helicopter disturbance while seismic lines were cut. Goats under continuous stress did not forage, indicating the potential consequences of disturbance on energy intake. Coupled with enhanced energy expenditure due to increased movements, helicopter overflights have the potential to influence mountain goat physiological condition, survival and reproduction. In the same



study area of Alberta, female and kid survival was influenced by helicopter overflights and other forms of human disturbance such as ATVs and oil and gas exploration.

Disruptions of social groups lead to 22 temporary and permanent separations of nannies from their kids. Kids that were separated from their mothers had a lower survival rate than their non-separated conspecifics (Cote and Festa-Bianchet 1996).

Recreational helicopter use has also increased in the past decade. Sight-seeing tours, heli-skiing, heli-hiking, and glacial tours have increased human access in the backcountry and the number of helicopters flying over mountain goat habitat (Wilson and Shackleton 2001). Goldstein et al. (2005) studied mountain goat response to commercial and experimental helicopter overflights similar to recreational flight-seeing in Alaska. Comparable to Cote (1996), they found that distance from goats to helicopters influenced the probability of overt responses, with the likelihood of disturbance inversely related to distance. Goats responded to overflights 30% of the time and 25% of the 773 individual goats observed were alert, vigilant or fled when helicopters approached. Goats with prior experience to helicopters demonstrated the most tolerance for aircraft. In coastal British Columbia, helicopters are increasingly used to access previously inaccessible trees to supply a growing demand for timber. Gordon and Wilson (2004) studied the impact of industrial forestry helicopter disturbance on coastal mountain goats. They found that during the second year of the study, mountain goats increased their use of forest cover or moved away and spent less time bedded when helicopter activity was most intrusive. There was no evidence of mountain goat habituation to helicopter disturbance.

In British Columbia, Foster and Rahe (1983) documented mountain goats response to aircraft and ground disturbances associated with **hydroelectric exploration**. They found that goats respond 80% of the time to disturbance events and 33% of responses were severe flight behaviors to escape terrain or cover. Most severe responses occurred when the disturbance was within 100m of the goats. Goats were more likely to respond when the disturbance was close, when the source of the disturbance was visible, and when cover or escape terrain were farther away. Some goats temporarily abandoned their range in response to disturbance events. Rather than demonstrate habituation to aircraft, goats tended to become sensitized, where each successive disturbance event

produced an additive level of response to the point where some goats began to react to natural events such as thunder.

Summary of Human Impacts on Mountain Goats

Mountain goats appear exceptionally susceptible to human disturbance and the indirect effects of roads and increased access. Roads may act as barriers to movement and disrupt traditional routes to mineral licks. While some studies suggest that mountain goats may be able to habituate to disturbance when events are predictable or when goats are motivated to use mineral licks, other research has found that mountain goats avoid areas up to 3000m from disturbance and survival may decline in correlation with heightened human activity. Industrial activity and helicopter disturbances associated with recreation, mining, and logging may have severe consequences on goat populations. Low altitude overflights increase energetic costs by producing flight responses, decrease forage efficiency through vigilant behavior, interrupt activity schedules, split up social groups and decrease survival. Helicopters are especially detrimental when within 500m of goats. Disturbance events may cause mountain goats to abandon parts of their range.

INCORPORATING HUMAN IMPACTS INTO HSM



Conservation planning often uses measures of habitat quality as a tool to inform management decisions. Habitat suitability models (HSM) may employ various sources in order to create a conceptual understanding of the suitability and capability of habitats (Johnson and Gillingham 2005, Doswald et al. 2007). Expert knowledge, published scientific literature, local observations and empirical data can all be used to determine where animals occur in the landscape. Habitat selection can be generated by understanding which habitats are important sources of food and shelter and which habitats are avoided. Use often fluctuates by season, sex, age and in relation to other environmentally stochastic events. Habitat variables can include a variety of landscape indicators such as vegetation type, vegetation structure, canopy cover, and the presence or absence of seasonal food sources (Dijak et al. 2007). Many HSM do not incorporate human impacts into variables of habitat selection. For example, models developed for moose (Allen et al. 1987, Snaith et al. 2002, Dussault et al. 2006a), woodland caribou (Schneider et al. 2000, Johnson et al. 2004), bighorn sheep (Wockner et al. 2003), and white tailed deer (Short 1986) include only environmental variables such as vegetation type and a variety of landscape level features.

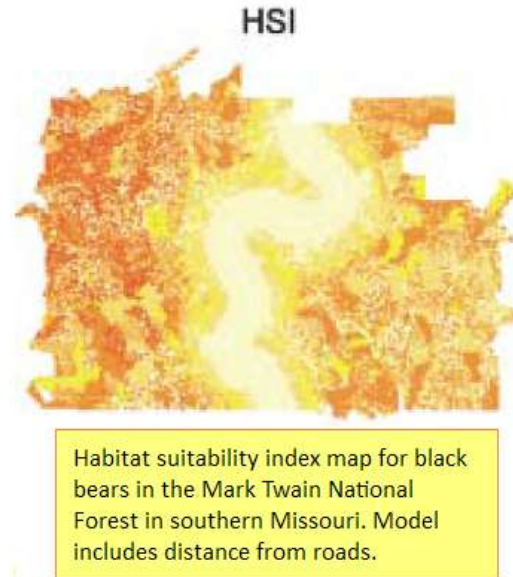
As human developments spread across the landscape, few ecosystems are not influenced by human presence to some extent. Infrastructure often conflicts with animals' use of habitat and HSM models can be an essential tool for combining wildlife habitat relationships with human impacts (Dussault et al. 2006a). Furthermore, incorporating human disturbance into HSMs can be especially important when the species of interest is highly sensitive to anthropogenic effects on the landscape. This is generally the case for several species reviewed in this report including; woodland caribou, grizzly bears, mountain sheep and mountain goats. In the following section, examples of habitat

suitability index models and resource selection function models that incorporate human impacts into model variables will be reviewed.

Example Models

Habitat Suitability Index Models

HSI models are used to determine the relative quality of wildlife habitat based on an index value between 0 (least suitable habitat) and 1 (optimal habitat) that represents the probability of species occurrence. If the value of an index is high there is a better chance that the species occurs in a habitat than if the value is near zero. When linked with GIS information, maps of ranked habitat units can be created. Because HSI models often utilize expert knowledge and published literature they are especially useful when quantitative data is too expensive to collect, difficult to obtain or does not exist (Johnson and Gillingham 2005). Several studies have compared predictions of HSI models to empirical data with positive results (Johnson and Gillingham 2004, Doswald et al. 2007). Limitations of HSI models include variation in expert opinion, the use of arbitrary classification schemes and a general lack of validation efforts (Johnson and Gillingham 2004). The following section details the numerous values and variables that are used to incorporate human impacts into HSI models. Due to the lack of HSI models specific to the focal species of this review, HSI models for various species of large mammals will be included.



Bears

Habitat suitability index (HSI) models developed for the U.S. Fish and Wildlife Service in the early 1980s utilize parameters such as percentage canopy cover, distance between cover types (e.g., forest edge to water, forest patch to forest patch) or other features that can be acquired from aerial imagery (Kapustka 2005). Few of these early HSI models incorporated human disturbance variables into model parameters. An exception is the HSI for black bears in the Upper Great Lakes Region (Rogers and Allen

1987). The model includes variables of quantity and quality of foods, cover type composition and the influence of human use and habitation on black bear habitat quality. The human use variable is based on a circular zone of influence surrounding habitation sites such as campgrounds, residences, resorts and agricultural areas. Buffers surrounding human settlements are derived from mortality rates associated with the area as well as generalized distances of 5.7km around towns, 3.5km around croplands, and 1.1km around residences. The model was not validated with empirical data. In Missouri, GIS data was used to create HSI maps for several species. Variables for selection primarily include tree species, tree age, and land type data. The HSI model for black bears also incorporates distance from roads in a distance algorithm. Distance of avoidance was based on published literature on black bear intolerance of human activity. The suitability index increases linearly from 0 when habitat is within 200m of a road to an index of 1 when more than 1000m from the road. No validation efforts were performed for this model (Larson et al. 2003).

Several HSI have been developed by the Foothills Model Forest research initiative in west-central Alberta. The black bear model incorporates components of habitat effectiveness that are based on distance from roads (distance from the edge of the nearest road, railroad, or trail with horse or motorized access) and distance from human activity (distance from industrial sites, active well sites, logging, settlements, ranches, camps, etc.). Black bears' food habitat is assumed to be less suitable when within 250m from roads and cover is less useful when within 5000m of human activity (Zapisocki et al. 1998).

Incorporating human related factors into grizzly bear HSI models is especially important since the most grizzly bear mortality is caused by humans. Merrill et al. (1999) developed a HSI model to aid in the reintroduction of grizzly bears to central Idaho. Their approach utilizes an index of habitat productivity (based on regional abundance of bear foods) and an index of habitat effectiveness that incorporated presence of humans and road and trail densities. The extent of human impact on the landscape is measured with several variables in addition to distance to roads. The numbers of human residents in an area come from the distance to and size of population centers as well as recreation visitor days data from the US Forest Service. Potential human activity is determined by

multiplying distance to centers by recreation visitor days. Finally, the density of road and trail access is incorporated into the model of actualized human impacts. Habitat suitability is determined by subtracting the actualized human presence index from the habitat productivity (bear food) index. This model is further scaled to a size that was comparable to grizzly bear home ranges and collaborated with empirical data from observations of grizzly bears in northern Idaho. The authors suggest that their approach “systematically translates qualitative information and sparse quantitative data into spatial representations of grizzly bear habitat based on a conceptual model” (Merrill et al. 1999).

A grizzly bear HSI has been developed for the Atlin Lake and Taku River watersheds in northwestern British Columbia. This model was initiated by the B.C. Ministry of Water, Land and Air Protection to investigate the potential impacts of the Tulsequah Mine and access road development (Wellwood 2003a, b). The HSI model is based on the suitability and availability of important seasonal food values and does not incorporate human impacts. Telemetry data was used to evaluate the accuracy of the HSI maps. Most high quality habitats were correctly classified, with the exception of high value spring habitats. This model has been used to produce an effects assessment of the Tulsequah Chief Mine Project on grizzly bear habitat (MacLeod et al. 2008). The effects assessment integrates the risk for habitat use and mortality into the HSI model. Direct effects of current or proposed infrastructure were mapped and GIS was used to merge human impacts with the map of high value habitat from the HSI model. Areas of high value that were affected by current or proposed infrastructure are assumed to have “no value”. An 800m buffer zone of influence was used to incorporate a reduction in habitat suitability where indirect effects of the mine extended into grizzly bear habitat. Disturbance coefficients were developed by AXYS Environmental Consulting that predict the percent reduction in habitat value for each infrastructure type and season of habitat use. The affected habitat value is found by multiplying the disturbance coefficient with the HSI value. High quality bear habitat is assumed to be lost if the affected habitat value is below 0.75.

Ungulates

Many studies have examined the impact of roads and other human activities on elk habitat selection and behavior (Lyon 1979, 1983, Lyon et al. 1985, Cole et al. 1997, Phillips and Alldredge 2000, Cole et al. 2004, see review by Hebblewhite 2008). Accordingly, HSI models for elk usually reflect this collection of research. A habitat effectiveness index for elk winter ranges measured four variables to produce a model of potential elk habitat suitability in Oregon and Washington. The variables include size and spacing of cover and forage stands, cover quality, roads open to vehicular traffic and quantity and quality of forage. The road variable employs road density. Habitat effectiveness values decrease linearly from 1 when road density is 0 to a value of 0.2 when road density approaches 8km of road per km² of habitat (Thomas et al. 1988).

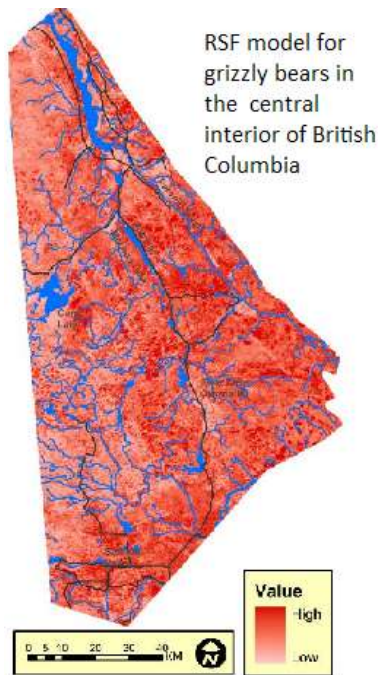
Several HSI models for elk have demonstrated poor predictive capability when validated with empirical data. A HSI for elk developed by Roloff (1998) which incorporates a combination of roads and security cover was later validated by Roloff et al. (2001). The road variable in the original HSI assumed that roads which bisected habitat with high-quality cover had less of a negative effect (160m zone of reduced quality) on habitat potential than roads that intersected low-quality cover (800m zone). Habitat quality increased with increasing distance from roads. The model was validated using 21 cow elk telemetry locations in Custer State Park, South Dakota. The evaluation study illustrated that Roloff's (1998) model did not perform consistently better than random. While some patterns did perform better than random more than 75% of the time, other aspects, such as the negative effects of roads predicted in the model, were not empirically supported by telemetry data. In another validation attempt, Jones et al. (2002) found that a HSI model for elk developed by Buckmaster et al. (1995) for the Foothills Model Forest did not perform well when compared with empirical telemetry use-availability data. Little attention was given to human use variables in the evaluation, but the original model did include distance variables that reduced the value of food resources when within 100m of permanent access such as roads. The locations used by elk did not correlate with areas of high habitat suitability values predicted by the model. The authors state that "the fact the model did not perform well is not surprising considering that elk

are generalists, widely distributed and highly adaptive to a variety of environments” (Jones et al. 2002).

A Foothills Model Forest HSI model for mule deer incorporated two variables of distance to human access (roads, trails, seismic lines, and gas pipeline corridors). Food and cover adjacent to human access were considered unsuitable and the value of the resource decreased linearly within 100m of roads. Habitats more than 100m from human access were considered optimal and given HSI values of 1 (Wood et al. 1999). The moose Foothills Model Forest HSI did not include human impact variables (Romito et al. 1999).

HSI models have been developed for moose, woodland caribou and mountain goats in the Atlin Lake and Taku River watersheds (woodland caribou: MacLean and Hawkes 2003, moose: Hawkes 2004, mountain goat: Hawkes and MacLean 2004, moose: MacLean and Hawkes 2004). Similar to the grizzly bear model, these HSI models identify key high quality habitats that can be used to determine the effects of the proposed Tulsequah Chief Mine Project on habitat selection and species distribution. The HSI models are based on vegetation and cover characteristics as well as important seasonal habitats such as calving and kidding grounds. The models do not incorporate human impacts and were evaluated with use-availability data from telemetry locations. The effects assessment developed for moose is comparable to the grizzly bear model (MacLeod et al. 2008). Where human impacts overlap high value habitat the value is reduced to “not high value”. Indirect effects were measured by including a 400m zone of influence buffer surrounding roads. The HSI values for woodland caribou, moose, grizzly, and mountain goat habitat were mapped in comparison to areas of proposed human impact in the conflict and risk report (AXYS Environmental Consulting Ltd 2004).

Resource Selection Function Models



RSF models utilize increased statistical rigor and empirical data to determine the probability of resource use by an organism. Habitat selection is measured by examining an organism's use or avoidance of a particular feature in the landscape relative to its availability. When an animal is observed using a feature in the landscape disproportionate to its availability, selection is assumed. When use is less than availability, the model predicts avoidance of that feature (Boyce et al. 2002). Animal locations are most often obtained through telemetry data.

Like HSI models, RSFs also produce coefficients that measure the strength of individual variables to predict species distribution. Maps of RSFs allow

comparisons between animal habitat relationships and human disturbances to be visualized. Statistical precision and ease of interpretation make RSFs a valuable tool when modeling habitat selection in relationship to human variables (Johnson and Gillingham 2005). RSF models are limited by the accuracy and spatial and temporal scales of data from animal locations. Radio collared individuals may not always be representative of the entire population and inferences of selection and avoidance may be based on individual bias when sample size is low (Doswald et al. 2007). Furthermore, occurrence may not always be the best way to predict habitat quality. Fitness is not always related to selection. In some cases high quality habitat may be associated with an increased risk of human caused mortality and ultimately decrease survival (Nielsen et al. 2006). Because RSF models are a specialized version of HSI models, examples of how human impacts are incorporated into model variables for grizzly bears and caribou are reviewed in this section.

Grizzly Bear

Ciarniello et al. (2003) used RSFs to quantify and predict high probabilities of bear use in the central interior of British Columbia. Covariates of the model included land cover categories, forest age classes, aspect, slope, greenness and distance to roads. GIS was used to calculate distances to nearest roads. The most parsimonious model of grizzly bear selection included distance to roads. Interestingly, grizzly bears selected for areas near secondary and deactivated roads, but avoided highways. The authors admit that the most problematic part of the analysis was incorporating biologically relevant human effects into the model. Factors such as commercial logging operations, number of hunters on roads and seasonally explicit human use variables are not available in GIS databases. These human impacts are most likely very important to grizzly bear survival and should be incorporated into model covariates when possible. In Alberta, Nielsen (2005) used an anthropogenic variable of the distance to the nearest motorized or non-motorized linear corridor, though exploratory seismic lines were not included. Grizzly bears tended to avoid anthropogenic factors and regenerating forests.

In southeast British Columbia Apps et al. (2004) used location information from DNA hair-trap sampling to model the distribution and abundance of grizzly bears in relation to human activities. Their probabilistic RSF model included several human factor variables. Human access was measured by calculating the time required to access any point along roads in the study area from nearby communities. A decay exponent of -1.45 was used to explain the decreased probability of human presence further from towns. Major cities were incorporated by finding the size of the community and the travel time required to reach roads within the study area. All communities were balanced on a 0-1 scale with 1 representing permanently occupied sites. The density of linear features and the Trans-Canada highway were also included. The model was validated with independent telemetry data from 55 radio collared grizzly bears. The study found that grizzly bears occurred more often in areas of low human accessibility and low linear corridor densities. A subset of human activity that included increasing linear disturbance and human access as well as the Trans-Canada highway accounted for 63% of the variation in the human influence variables. The authors suggest that “human access, as a

function of road networks, temporal proximity to human settlements, and the population of those settlements, may be an important factor in grizzly bear survival and thus distribution” (Apps et al. 2004).

Johnson et al. (2005) undertook a large scale cumulative effects assessment to predict the response of four species to variables of vegetation, interspecific interactions and avoidance of human developments in the arctic. They created RSF models for grizzly bears, barren ground caribou, wolves and wolverines (*Gulo gulo*). Human disturbance variables consisted of various buffers surrounding human use features that depended on the relative use and risk associated with each type of development. Buffers included 1000m around major disturbances (operating mines, communities, winter road camps), 500m around outfitter camps (seasonal guide-outfitter camps), 5000m around lake shorelines within 20km of camps (accounting for human caribou hunting), and 10km around mineral claims (areas of mineral exploration activities). Maps of resource selection depicted areas of high, good, low and poor quality habitats. These maps were modified with disturbance coefficients from GIS and telemetry data as well as a hypothetical disturbance coefficient based on published literature and local knowledge to generate a measure of habitat effectiveness. Hypothetical coefficients for major disturbances corresponded to a 50% decrease in habitat effectiveness within 5km and a 95% decrease in habitat effectiveness within 1km. Mineral exploration was assumed to decrease habitat value by 50% within 10km. Outfitter camps decreased habitat by 10% within a 500m radius and finally a 95% decrease in habitat values within 1000m buffer of roads was applied.

Model results indicated a large variation in strength of human influence across seasons and species, though human disturbance was a strong indicator of animal distributions. Habitat loss was most extreme for grizzly bears due to significant avoidance of human disturbance (habitat selection decreased up to 23km from mineral exploration sites and 12km from outfitter camps). Grizzly bears suffered from a 21% decrease in availability of high quality habitat in autumn. Caribou demonstrated the largest seasonal reduction in habitat with a 37% decrease in areas of high quality habitat and an 84% increase in areas of the lowest quality habitats during the post-calving season.

Caribou

Brown et al. (2007) developed a spatially explicit predictive model of habitat suitability for woodland caribou in Ontario and Québec using RSFs. Primary roads and clearcuts were included as a variable in the model. The RSF model was effective in identifying habitat selection patterns. Caribou selected for mature forests with large contiguous patches. Primary roads and cutovers were negative coefficients but had large conditional standard errors making predicting avoidance imprecise. In southeastern British Columbia, Apps and McLellan (2006) created an occupancy index of caribou locations based on 235 radio collared animals across 13 subpopulations. This index was compared to a predictive model that incorporated variables of forest overstory, land cover, terrain, climate and human influence in order to understand what natural and human factors limit caribou persistence and distribution. The human disturbance variables included: logged forests, urban areas (industrial developments, settlements and isolated developments), roads (density of corridors and relative impact of road classes), major highways, an index of remoteness (primitive to urban), primitive recreation opportunities, areas of high snowmobiling, heli-skiing and summer motorized use (based on inventories of recreational use). Results indicate that important characteristics of caribou distribution include a landscape with little human activity, low road densities and limited access to motorized recreation. Primary highways and extensive road networks may obstruct population contiguity.

Summary of Human Impacts in Habitat Suitability Models

Human impacts are most often incorporated into HSM as a variable of distance from human disturbance (Table 5). More complicated modeling methods include variables that incorporate the population size of human communities, travel time from human settlements to remote areas, density of roads or linear corridors, relative affect of different road classes, probability of human recreational use and other indicators of human influence on the landscape. Many models designate buffers around human disturbances that are based on the ecological effects of avoidance behavior reported in the literature. Human development and activity can reduce habitat suitability to varying

degrees. The simplest models designate a linear decrease in habitat suitability with decreasing distance to human developments. Other models utilize disturbance coefficients that attempt to standardize the percent decrease in habitat value in different buffer zones of influence. Limitations of HSM models include a general lack of validation efforts. In some cases validation exposes weaknesses in a model's predictive potential.

Table 5. Summary of human impact variables in HSI and RSF models.

Author	Generalized human variable included in model. Distance in meters.							
	spp	roads	town	homes	agra- culture	indust- rial	camps	mines
Rogers & Allen (1987)	b. bear		5700	1100	3500			
Larson et al. (2003)	b. bear	200						
Zapisocki et al. (1998)	b. bear	250	5000	5000	5000	5000		
Merrill et al. (1999)	g. bear	density	pop. size					
MacLeod et al. (2008)	g. bear	800				800		
Ciarniello et al. (2003)	g. bear	distance						
Nielsen (2005)	g. bear	distance						
Apps et al. (2004)	g. bear	time, distance, density	pop. size time, distance					
Johnson et al. (2005)	g. bear, caribou	1000	1000				500	10,000
MacLeod et al. (2008)	moose	400						
Thomas et al. (1988)	elk	density						
Roloff (1998)	elk	800						
Buckmaster et al. (1995)	elk	100						
Wood et al. (1999)	m. deer	100						
Brown et al. (2007)	caribou	distance						
Apps & McLellan (2006)	caribou	density	distance					

RECOMMENDATIONS AND CONCLUSIONS

Infrastructure has been considered the “the central nervous system of our modern world” (UNEP 2001). Globally the increase in roads, linear corridors, airports, pipelines, resource exploration, mines, power lines, utilities, hydroelectric plants and dams has progressively altered the distribution and abundance of wildlife. Human developments can have direct effects on wildlife through loss of habitat, collisions with vehicles, and changes to the physical and chemical environment. Indirect effects expand beyond the source of disturbance to include a much more extensive zone of influence on the landscape. The ecological effects of indirect impacts are difficult to quantify. Observations of behavioral responses to human presence are often used as proximate explanations for how disturbance affects population distribution, viability and productivity (Gill et al. 2001). These behavioral studies often measure specific species responses to particular human disturbances at varying temporal and spatial scales. Avoidance behavior is a central focus in the field of conservation biology. Avoidance has the potential to decreased foraging success, increased energetic costs, alter predator-prey relationships and generate functional habitat loss, all of which have assumed demographic consequences though direct mechanistic relationships between habitat disturbance and population productivity are rare.

The inherent complexity of ecological systems makes modeling relationships between habitat selection and human influence difficult. Suitability models are inevitably specific to the species and location of interest. Few models can be easily applied to a universal map of species occurrence. Variables of human impact are most often distance equations that are founded on the biological relevance of avoidance behavior (Table 3). The models often assume that habitat quality decreases linearly with increasing distance to human activity. While these general distance variables may be the easiest to apply to models they may not be the most predictive of actual animal distribution. Literature reviewed in this report implies that avoidance is dynamic in nature and varies by location, species, age, sex, motivation and a plethora of other environmental and demographic factors. Evidence suggests that avoidance is not a linear reaction, but rather asymptotic

where response decreases gradually as the distance from human disturbance increases until resource selection is no longer influenced by the anthropogenic factor (Johnson et al. 2005). Furthermore, animals do not avoid all areas of human presence in all situations. For example, grizzly bears may select for roads with low traffic volumes when forage availability is high. When modeling avoidance, ecological relationships of specific areas are extremely important.

Though empirical evidence from actual animal locations on the landscape can not be easily replaced by subjective HSI models, studies such as Merrill et al. (1999) and Apps et al. (2004) come closer to actual predictive capabilities by using complicated modeling techniques that take into account a wide range of human influences on the landscape. These modeling methods require a firm understanding of model theory and application and are not always the best option. Johnson et al. (2005) developed predictive models of species response to human developments by holding predetermined buffers and disturbance coefficients constant. This approach allows for an assessment of the effects of human disturbance that can be “easily replicated and may serve as a simple tool to evaluate a range of development impacts where information for actual animal responses is lacking” (Johnson et al. 2005). Expert opinion and local knowledge of ecosystems can also be valuable tools when modeling complex relationships of human impacts and wildlife populations. Doswald et al. (2007) found that local expert knowledge was very predictive of species occurrence and even outperformed scientific expert knowledge when mapping the distribution of local lynx populations in the Swiss Alps. In this section I will make recommendations for the best methods of incorporating human impacts into habitat suitability models for the five focal species included in this review. I will focus on the human impacts with the greatest effect on each species distribution and I will suggest potential buffer zones of influence and disturbance coefficients when the literature allows.

Woodland Caribou

The literature generally agrees that caribou populations are highly sensitive to human developments, activities and infrastructure. Across the arctic and sub-arctic empirical data from caribou studies provides evidence for numerous behavioral and demographic responses to anthropogenic disturbances. Woodland caribou are highly cryptic and attempt to isolate themselves from any potential predator or competitor. Caribou do not adapt well to human disturbances and tend to exist in lower densities near human presence than in areas of undisturbed habitat. Forestry operations, petroleum exploration, infrastructure and human activities have numerous indirect effects on caribou that range from avoidance and displacement to altered predator-prey relationships. These behavioral costs usually emerge as reductions in habitat effectiveness and demographic consequences when studied over large spatial and temporal scales. Other reviews of caribou literature suggest that caribou will reduce use of areas within 5 km of infrastructure and human activity by 50-95% (Vistnes and Nellemann 2008). Several points should be considered when modeling caribou habitat selection in relation to human disturbances:

- Habitat effectiveness decreases by 50-90% within 5000m of infrastructure.
- Low densities of caribou have been observed near roads, seismic lines, well sites, tourist resorts, power lines, hydroelectric developments, mines and clearcuts when compared to control areas away from development.
- Caribou exhibit the largest avoidance distances from concentrated developments and clearcuts (Table 3).
- Roads with high traffic volumes are stronger barriers to movement than back roads or seismic lines.
- Caribou can be negatively affected by altered predator-prey relationships.
- Females with calves are most sensitive to human disturbance especially during calving and post-calving seasons.
- Caribou display stronger reactions to humans on foot than to vehicles.
- Snowmobile recreation can cause caribou to avoid high quality habitats.

Grizzly Bear

The majority of grizzly bear mortality is caused by humans, making the indirect effects of increased human access and infrastructure very important to grizzly bear demographics. Because of this, almost all habitat suitability models generated for grizzly bears include some form of human impact variable. These models can be difficult to create because bears are highly mobile, travel large distances and can differ in selection or avoidance of human disturbance. The grizzly bear literature does not give explicit examples of disturbance coefficients for the reduction in habitat effectiveness near human developments. I suggest adopting Johnson et al.'s (2005) recommendations of 50% decrease in habitat effectiveness within 5000m and 95% decrease in habitat effectiveness within 1000m of major disturbances. In general grizzly bears tend to avoid human presence on the landscape and suffer increased mortality risk when associated with high levels of human activity or development. Several factors which influence grizzly bear habitat selection are described below:

- Habitats effectiveness decreases with increasing distance to human disturbances.
- Grizzly bears avoid habitat within 100-1000m of roads and 2000m of developments.
- Grizzly bears avoid roads, highways, trails and developments.
- Females with cubs of the year are most sensitive to human disturbance.
- Avoidance is strongest during the day, in areas of high road density and surrounding roads with traffic volumes over 60 vehicles per day.
- Traffic volumes greater than 2,400 vehicles per day may act as barriers to grizzly bear movement.
- Bears may select for clearcuts when natural clearings are scarce.
- The majority of grizzly bear mortality caused by humans occurs within 500m of roads and 200m of trails.

Moose

The majority of literature on the influence of human disturbance on moose distribution suggests that moose do not tend to avoid areas of human presence. On the contrary, moose may benefit from and even select for high levels of human development and activity. Clearcuts provided increased browse abundance, transmission lines may facilitate movement and human presence can shield moose from predators such as wolves and grizzly bears. Though moose mortality is high along roads due to vehicle collisions, especially when roads bisect high quality habitat or areas of high moose density, there is little evidence that moose change their distribution to avoid these areas of risk. In general, moose habitat suitability can change in response to several factors of human disturbances:

- Moose select for habitats closer to humans due to increased early successional growth along roads, developments and corridors.
- Moose congregate at roadside salt pools in spring and summer.
- Moose select for clearcuts in the first 20 years of regeneration.
- Human presence can decrease predation pressure on moose.
- Moose display stronger behavioral reactions to humans on foot than to vehicles.

Thinhorn Sheep

Little effort has gone into examining the effects of human disturbance on Dall's and Stone's sheep, most likely because these two species have not been directly affected by human presence to the same extent as bighorn sheep. The literature on mountain sheep response to human disturbance suggests that sheep demonstrate varying degrees of sensitivity to human developments. Roads may act as barriers to movement when they intersect important migration routes. High intensity disturbance events such as petroleum exploration have the potential to cause mountain sheep to abandon parts of their range. Most commonly, mountain sheep have been studied in relation to overt behavioral reactions to aircraft. Though these disturbances events increase movement rates, heart rates and cause sheep to flee they have not been linked to changes in distribution or

abundance. I did not review any examples of how to aircraft disturbance variables could be included in HSM. Several factors should be considered when modeling habitat suitability of thinhorn sheep:

- Sheep within 200m of roads display overt behavioral reactions to traffic.
- Roads that intersect traditional migration routes may act as barriers to movement.
- Range abandonment can occur following large scale disturbance events.
- Helicopter disturbance is more distressing to thinhorn sheep than fixed-wing aircraft.
- Helicopter distance disturbance threshold varies from 250-450m but overt reactions may occur as far away as 1500m.
- Aircraft are most disturbing when within 50m of the ground and when directly approaching sheep.
- Females are generally more sensitive to disturbance than males.
- Mountain sheep display stronger behavioral reactions to humans on foot than to vehicles.

Mountain Goat

Mountain goats have not been subjective to high levels of human disturbance due to the ruggedness and isolation of their habitats. Goats are exceptionally sensitive to aircraft disturbance and may abandon parts of their range in response to repeated disturbance events. In some cases, high levels of human activity have been correlated with avoidance and decreased productivity. When roads bisect seasonal migration routes they may act as barriers to movement. In general, several human impacts can influence mountain goat distribution and habitat suitability:

- Mountain goats avoid areas 1000-3000m from drilling disturbances in association with hydroelectric development.

- Mountain goats that cross roads to reach mineral licks are hindered by high traffic volumes and human presence.
- Mountain goats are the most sensitive ungulate to helicopter disturbance.
- Helicopter distance disturbance threshold is 500m but can cause overt behavioral reactions when as far as 2000m away.
- When disturbance stimuli are visible and within 100m goats had the most severe reactions.
- Mountain goats may abandon range in reaction to human disturbance.

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APPENDIX A: Summary of Articles Reviewed by Species

Table 6. Review of scientific literature of human impacts on caribou.

Key: Rtt - *Rangifer tarandus tarandus*, Rtc - *Rangifer tarandus caribou*, Rtg - *Rangifer tarandus granti*

						Alaska/arctic	Norway
Authors,Year, Title discription	Spp.	Peer Review	Study Area Size, Duration	Human Impact Type	Study design, size & data type	General Results	Management Recommendations
Alberta Caribou Recovery Team 2005, AB, boreal forest and foothills	Rtt	No	>100,000 km ² , endangered species recovery plan	Oil, gas, seismic, forestry, linear development	Review	Caribou populations declining across the province because of cumulative effects of energy development	Aggressive energy development restrictions and restoration activities required including reduced logging, road removal, rehabilitation of seismic lines, protected areas with no development, predator and ungulate control
Apps & McLellan 2006, factors influencing dispersion and fragmentation of mountain caribou pop.	Rtc	Yes	127,000 km ²	roads, traffic, hydro, highways	Modeling, n=235	Modeled landscape occupancy index with human factors as variables. Remoteness, low road density and little motorized access were important factors	Must maintain habitat connectivity and decrease human impacts.
Bradsaw et al. 1997, effects of petroleum exploration on woodland caribou	Rtt	Yes	20,000 km ² and 1years	Simulated Seismic explosions	Experimental, n=23	Exposed animals showed higher mean movement rate; no effect of distance from animal to canon vs. movement; exposed animals showed higher habitat patch change; exposure to sound reduced feeding time.	Total avoidance of winter petroleum exploration rather than shorter activity restrictions
Bradsaw et al. 1998, energetic implications of petroleum exploration	Rtt	Yes	20,000 km ² and 5years	Petroleum exploration	Modeling	Potential loss of mass and increased energy costs	Model may serve as a template for future research
Brown et al. 2007 forest management impacts	Rtc	Yes	10,139 km ² and 4 years	forestry	Modeling, n=27 radio collared	Used RSF and a patchwork model to predict effects of multiple forest management strategies on caribou occurrence.	Recommend using a combination of spatial and aspatial habitat supply targets to conserve caribou in managed forests.
Cameron et al. 2005, Central Arctic Caribou and petroleum development	Rtg	Yes	8,000 km ² and 22years	Petroleum development	Review	calving caribou avoided roads and caribou exposed to petroleum development may have consumed less forage during the calving period.	Assessments of cumulative effects of petroleum development on caribou must incorporate the complex interactions with a variable natural environment.

Chubbs et al. 1993. Responses of woodland caribou (<i>Rangifer tarandus caribou</i>) to clear-cutting in east-central Newfoundland	<i>Rtc</i>	Yes	2700 km ² and 4 years	clearcut logging	Observational, n=35 radio collared	3 males and 12 females were further away from clearcuts on two were closer. Females were 2-3 times further from clearcuts than males.	Clearcutting mature forests on summer ranges affects the movements and distributio of woodland caribou.
Cronin et al. 1998, 2000 Northern Alaska oil fields and caribou	<i>Rtg</i>	Yes	17,000 km ² and 20years	Oil fields, roads, well pads, infrastructure	Review	Herd-level impacts of the Prudhoe Bay oil fields are not apparent on the Central Arctic caribou herd.	Resource extraction and wildlife populations can be compatible when managed properly.
Courtois et al. 2007 Effects of forest disturbance on density, space use, and mortality of woodland caribou	<i>Rtc</i>	Yes	42,539 km ² and 4 years	clearcut logging and fire	Observational, n=20 radio collared and aerial surveys	Monitored caribou in disturbed and undisturbed habitats. Survival lower when homerange overlapped disturbed areas. Increased homerange size and decreased fidelity in disturbed areas. Avoided disturbed sites.	Protect 100-250km ² blocks of forest to favor caribou spacing away from humans and predators.
Dahle et al. 2008 reindeer avoidance of highways	<i>Rtt</i>	Yes	8,200 km ² and 2 years	highways and cabins	Observational, lichen sampling	lichen height decreased 35% over an 8km distance from the highway and cabin indicating avoidance of highway.	Wild reindeer tolerance towards human infrastructure varies spatially and is influenced by herd traditions and or motivation to follow established migration corridors.
Dryer et al. 2002 barrier effects of roads and seismic lines of woodland caribou	<i>Rtc</i>	Yes	6,000 km ² and 1 year	roads and seismic lines	Observational, n=36	Roads were barriers to movement especially in late winter and seismic lines were not barriers. Functional habitat loss through avoidance.	Approach useful in quantifying animal movements
Dyer et al. 2001, Avoidance of industrial development by woodland caribou	<i>Rtt</i>	Yes	6,000 km ² and 1years	roads, seismic lines, pipelines	Observational, n=36	Seismic lines were semipermeable barriers to caribou movements, roads were barriers with high traffic. Caribou avoided human development by 250 – 1000 meters (seismic vs wells). 22% - 48% of study area impacted by roads.	Semi-permeable barrier effects may exacerbate functional habitat loss through avoidance behavior. Effects great year round.

Duchesne et al. 2000 Responses of woodland caribou to winter ecotourism in the Charlevoix Biosphere Reserve, Canada	<i>Rtc</i>	Yes	310 km2 and 3 months	ecotourists	Observational, n=58 caribou observed	Groups of 5-19 ecotourists and guides interrupted caribou foraging and increased time spent vigilant and standing. As winter progressed, impact of human presence was reduced suggesting that caribou are able to habituate to low levels of human disturbance.	results suggest that with proper precautions caribou in Charlevoix can tolerate ecotourist visits.
Harrington and Veitch 1991 Short-Term Impacts of Low-Level Jet Fighter Training on Caribou in Labrador	<i>Rtc</i>	Yes	23,000 km2 and 2 years	low-altitude jet overflights	Experimental control/treatment, n=10 radio collared	Helicopters had a greater effect than jet aircraft and Daily activity levels did not vary significantly between control caribou that were not disturbed and caribou exposed to overflights.	caribou should be avoided.
Harrington and Veitch 1992 Calving success of woodland caribou exposed to low-level jet fighter overflights	<i>Rtc</i>	Yes	23,000 km2 and 3 years	low-altitude jet overflights	Experimental control/treatment, n=10 radio collared	the number of survey periods that a cow was accompanied by a calf was negatively correlated with the female's exposure to low level jet overflight during the calving and immediate post-calving period and again during summer.	jets should avoid overflying woodland caribou calving range at least during the last week of May and the first three weeks of June
Haskell et al. 2006, Dynamic responses of calving caribou to oilfields in northern Alaska	<i>Rtg</i>	Yes	700 km2 and 3years	Oil fields, roads, well pads	Observational, n=up to 12,000	Caribou habituate to active oilfield infrastructure during and after the calving period depending on the timing of the spring snowmelt. Groups with calves were distributed farther from infrastructure.	Development of calving period-specific mitigation measures that are effective and flexible is important because annual rehabilitation is correlated with timing of spring snowmelt.
James & Stuart-Smith 2000, Distribution of caribou and wolves in relation to linear corridors	<i>Rtt</i>	Yes	20,000 km2 and 7years	roads, trails, seismic lines, pipelines	Observational, n=98	Caribou mortalities attributed to wolf predation were closer to linear corridors.	Development of new corridors within caribou habitat should be minimized. Existing corridors should be made unsuitable as travel routes to reduce impacts.
James et al. 2004 spatial separation of caribou from moose and its relation to wolves	<i>Rtt</i>	Yes	20,000 km2, 4 years	Oil and gas, seismic lines	Observational	Caribou avoided habitats selected by wolves and moose, but moose preferred habitats impacted by forestry.	Limit overlap of energy and forestry development with spatial refuge areas for caribou.

Johnson et al. 2005, Cumulative effects of human developments on arctic wildlife	<i>Rtg</i>	Yes	190,000 km2 and 5 years	Energy exploration, hunting, mines.	Observational, n=28	Mines had the largest negative effect on species. During post-calving caribou had a 37% reduction in the area of the highest quality habitats and an 84% increase in the area of the lowest quality habitats.	Regional cumulative effects analyses serve as the coarsest framework for understanding the impacts of human developments on wide-ranging animals.
Joly et al. 2006, A reevaluation of caribou distribution near an oilfield road on Alaska's North Slope	<i>Rtg</i>	Yes	n/a and 23 years	Oil field, roads, infrastructure	Review	Calving caribou gradually abandoned the oilfield with a drop in abundance by at least 72% in spite of the fact that the total herd increased 4-5 fold.	
Kinley and Apps 2001 Mortality patters in a subpopulation of endangered mounain caribou	<i>Rtc</i>	Yes	6,000 km2 and 6 years	Roads and fragmentation	Observational, n=8-15 radio collared	higher road density and forest fragmentation in the southern part of the study area was spatially related to high mortality levels. Annual growth rates of 0.62 to 0.88. Low calf recruitment and high adult mortality due to predation from cougars.	Conducting research into relationships between predation and patterns of forest harvesting and reasons for low calf recruitment. Limit predation by reducing numbers of cougars and alternate prey.
Lawler et al. 2005 short term impacts of overflights on caribou	<i>Rtg</i>	Yes	n/a and 2 months	low-altitude jet overflights	Observational, n=52 cows and n=25 calves	Military overflights did not cause calf death and short term responses to overflights were mild.	Short term reactions to jet overflights were mild.
Mahoney et al. 2001 Caribou reactions to provocation by snowmachines in Newfoundland	<i>Rtc</i>	Yes	1,805 km2 and 5 years	snowmobiles	Observational, approached groups	snowmobiles displaced caribou from resting activities and initiated avoidance reactions that interrupted feed bouts and increased locomotion rates. Displaced 60-237m from initial locations.	variation in response by individuals and across years must be taken into account.
Mahoney & Schaefer 2002, Hydroelectric development and the disruption of migration in caribou	<i>Rtc</i>	Yes	12,000 km2 and 7 years	Hydroelectric development	Comparitive before, during, after development, n=51	Hydroelectric development caused a disruption of the migration timing during construction and longer-term diminished use of the range surrounding the project site.	Long-term studies of individually marked animals can aid in environmental assessments for migratory animals.
Maier et al. 1998 response of caribou to overflights by aircraft	<i>Rtt</i>	Yes	9,600 km2 and 1 year	Overflights by aircraft	Experimental control/treatment, n=10	Monitored activity and movement. Most responsive post calving and caribou moved further after overflight. Very low sample size and treatment groups mixed.	Female and young most sensitive to aircraft disturbance. Limit military flights during calving and post calving.

McLoughlin et al. 2003, Declines in populations of woodland caribou	<i>Rtt</i>	Yes	n/a and 10 years	human development	Observational, n=332	Wolf predation most common cause of death. Calf production 75-95%, mean annual recruitment was ~20 calves per 100 cows. 4 of 6 herds declining.	New land-use guidelines to promote caribou conservation
McLoughlin et al. 2005, Relating predation mortality to broad-scale habitat selection	<i>Rtt</i>	Yes	n/a and 11 years		Observational, n=195	Uplands present caribou with higher than expected levels of predation risk. Caribou should max selection of peatlands.	Linking fitness measures to multivariate resource selection will enable us to ask questions of evolutionary ecology once restricted to only the finest ecological scales.
Nellemann et al. 2001, Winter distribution of wild reindeer in relation to power lines, roads and resorts	<i>Rtt</i>	Yes	2900 km ² and 12 years	Roads, railroads, power lines	Observational, n=2500	Density of reindeer was 79% lower within 2.5 km from power lines compared with background areas. Areas within 5km of development were avoided in all years.	Construction of roads, power lines and cabin resorts endanger the available winter ranges of reindeer in southern Norway.
Nellemann et al. 2003, Progressive impact of piecemeal infrastructure development on wild reindeer	<i>Rtt</i>	Yes	1350 km ² and 10 years	Hydroelectric development	Comparative, before, during, after development n=>2000	Reindeer densities within a 4km radius to infrastructure declined during winter and summer with a 217% increase in use of the few remaining sites located >4km from infrastructure.	Controlling piecemeal development in infrastructure is critical for the survival of the remaining European populations of wild mountain reindeer.
Noel et al. 2004, Caribou distribution near an oilfield road on Alaska's North Slope, 1978-2001	<i>Rtg</i>	Yes	225 km ² and 23 years	Oilfield development, roads	Observational, n=up to 1,259	Caribou density after road construction was not lower < 1km of roads than pre-road. # calving caribou in the study area has declined since road construction. Distribution of caribou was not influence by presence of the road.	
O'Brien et al. 2006 Testing the importance of spatial configuration of winter habitat for woodland caribou: An application of graph theory	<i>Rtc</i>	Yes	900 km ² and 4 years	forestry and road development	Modeling, n=11	Strong relationship between large clusters of high-quality winter habitat patches and winter GPS telemetry locations from two herds in Manitoba	Results highlight importance of accounting for the spatial configuration of habitat on the landscape and the intervening land cover types when assessing range quality for woodland caribou.

Reimer et al. 2003 Behavior Responses of Wild Reindeer to Direct Provocation by a Snowmobile or Skier	<i>Rtt</i>	Yes	5700 km2 and	snowmobiles and skiers	Observational	reindeer responded to snowmobile disturbance on average 164m further away than skiers. Mean flight distances were 281m from skiers and 264m from snowmobiles.	Restrict recreational use of snowmobiles.
Reimers et al. 2006 flight by reindeer in response to approach on foot or skis.	<i>Rtt</i>	Yes	2,000 km2 and 1 year	Human approach	Observational, approach reindeer groups	the farther away the person was when first sighted, the greater the distance of flight. This response was greatest in July and least in September-October during rut.	humans stay 350m away from reindeer from March-July and 200m in September-October. Human approach did not appear to cause substantial energy costs to reindeer in this system.
Reimers & Colman 2006 Reindeer and caribou (<i>Rangifer tarandus</i>) response towards human activities	<i>Rtt, Rtc, Rtg</i>	Yes	n/a	human activity	Review	Review of many important articles on caribou response to a wide variety of human impacts.	future studies combine direct and indirect methodologies in order to combine the successful, robust attributes of both and simultaneously remove their respective weaknesses.
Schaefer & Mahoney 2007, Effects of progressive clearcut logging on Newfoundland Caribou	<i>Rtc</i>	Yes	2700 km2 and 9 years	clearcut logging	Observational, n=237 animal- years	Females avoided cutovers and maintained an average of 9.2km from active cutovers, males had no response to clearcuts.	Long-term investigations are needed to enhance our capacity to evaluate anthropogenic habitat changes.
Schneider et al. 2000 Habitat use by caribou in northern Alberta, Canada	<i>Rtt</i>	Yes	4 study areas (~29,000 km2 each) and 6 years	none	Modeling, n=172 radio collared	Habitat suitability map. polygons in the peatland map containing greater than 30% bog were selected by caribou. Fens were also selected, but not as strongly as bogs. Habitat polygons containing greater than 50% non-peat were avoided.	Based on the observed selection patterns, we reclassified the peatland map to reflect the potential suitability of habitat for caribou across northern Alberta.
Schneider et al. 2003, Managing the cumulative impacts of land uses in the Western Canadian Sedimentary Basin	<i>Rtt</i>	Yes	59,000 km2 and model dependent	energy and forestry development	Modeling	Model predicts caribou habitat availability will decline from present levels of 43 to 6% in 40 years.	Substantial improvement in ecological outcomes can be achieved through alternative management scenarios while still maintaining a sustainable flow of economic benefits.

Seip et al. 2007 Displacement of Mountain Caribou From Winter Habitat by Snowmobiles	<i>Rtc</i>	Yes	n/a and 4 years	snowmobiles use	Observational, n=28 radio collared	Caribou were not found in areas of high snowmobile use over several years in mountain blocks. Habitat modeling indicated that significantly lower numbers of caribou were using snowmobile habitat than expected based on habitat quality.	snowmobiling should be restricted from high-quality mountain caribou winter habitat, or at least limited to a small proportion of the total high-quality habitat for each herd.
Smith et al. 2000 winter distribution of woodland caribou in relation to clearcut logging in Alberta	<i>Rtc</i>	Yes	2,468km ² and 16 years	clearcut logging	Observational, n=45 radio collared	caribou avoided clearcuts and were 1.2km farther from newly harvested cut blocks than random locations in the study area. On average caribou avoided a zone of approximately 11km surrounding cut blocks.	Alternates to clearcutting should be examined for the purpose of maintaining habitat structure at the landscape scale.
Sorenson et al. 2008, Boreal forest	<i>Rtt</i>	Yes (In Press)	50,000 km ² , 10 years	Oil and gas development, forestry	Comparative, n=6 caribou herds	Compared the cumulative amount of all industrial development and natural disturbance (fire) against caribou population growth rates (λ) in 6 different herds. λ well predicted by % industrial development.	5 of 6 caribou herds declining in study because industrial development exceeded thresholds of a maximum of about 40-60% of the range impacted by industrial development. Recommend planning at the range level (~8,000km ²) scale.
Stotyn et al. 2007 Spatial partitioning among caribou moose and wolves	<i>Rtc</i>	No	9,000 km ² and 6 years	roads and cutblocks	Observational, n=37 caribou, n=14 wolves, n=26 moose	Habitat selection between caribou and wolves was spatially segregated in all seasons. Caribou and moose used different habitats creating a high level of spatial segregation in all seasons. wolves and moose had low levels of spatial separation.	n/a
Stuart-Smith et al. 1997, Woodland Caribou relative to landscape patterns in northeastern Alberta	<i>Rtt</i>	Yes	20,000 km ² and 4years	n/a	Observational, n=65	Adult survival averaged 0.88, calf survival was 18 calves/100 cows. λ was 0.92. Lower calf survival and smaller home ranges in landscape with less fen patches and a higher proportion of upland.	An "isolation" strategy may reduce the probability of detection by predators, thereby lowering the predation risk for young calves.
Vistnes and Nellemann 2001 avoidance of cabins, roads and power lines by reindeer during calving	<i>Rtt</i>	Yes	213 km ² and 2 years	resorts, power lines and roads	Observational, n= 776 and 678 caribou in each season	Reindeer density was 78% lower within 4km of a tourist resort complex and 73% lower within 4km from high voltage power lines. Forage availability also decreased significantly with increasing distance from human impacts.	Reindeer avoid human disturbance even at low levels of human traffic. Cumulative effects increase fragmentation and may reduce body condition and calf survival.

Vistnes and Nellemann 2008 spatial and temporal scales: a review of reindeer and caribou response to human development	<i>Rtt</i>	Yes	review	human activity	Review	Rangifer tarandus will reduce use of areas within 5 km of infrastructure and human activity by 50-95%.	Mitigation must regulate human impacts in caribou habitat.
Vors et al. 2007, Woodland caribou extirpation and landscape disturbance in Ontario	<i>Rtc</i>	Yes	n/a and 15years	roads, utility corridors, mines, pits and quarries, trails, rail lines	Modeling	Forest cutovers were the best predictor of caribou occupancy with a tolerance threshold of 13 km to nearest cutover and a time lag of 2 decades between disturbance by cutting and caribou extirpation.	Buffers should be incorporated around habitat and range of occupancy should be monitored.
Webster 1997 Response of caribou to human harassment	<i>Rtt</i>	No	n/a	human harassment - foot, ATV, snowmobile, aircraft, mines and exploration	Review	Review of papers on human harassment of caribou.	
Weclaw & Hudson 2004, simulation of conservation and management of woodland caribou	<i>Rtt</i>	Yes	20,000 km ²	roads, infrastructure	Modeling	The most detrimental factor is the loss of habitat due to avoidance of good habitat in proximity of industrial infrastructure.	Wolf control is not a practical solution. Development thresholds to maintain habitat required.
Weir et al. 2007, Effects of mine development on woodland caribou distribution	<i>Rtc</i>	Yes	195 km ² and 6years	gold mine development	Comparative, before, during development, n=~8000	Caribou avoided areas within 4km of the site in most seasons. Group size and number decreases as mine activity progressed in late winter, pre-calving and calving seasons.	Importance of evaluating the year-round impact of human-induced environmental change.
Wittmer et al. 2007 Changes in landscape composition influence the decline of a threatened woodland caribou population	<i>Rtc</i>	Yes	50,000 km ² and 20 years	forestry and human disturbance	Observational, n=338 radio collared over 10 years	adult female caribou survival is lowest in areas with a higher proportion of young and mid-seral forests and that caribou were killed by predators more often in areas with low old forest composition.	We conclude that apparent competition can cause rapid population declines and even extinction where changes in species composition occur following large scale habitat change.

Table 7. Review of scientific literature of human impacts on grizzly bears.

Authors,Year, Title discription	Spp.	Peer Review	Study Area Size, Duration	Human Impact Type	Study design, size & data type	General Results	Management Recommendations
Apps et al. 2004 Estimating grizzly bear distribution and abundance relative to habitat and human influence	<i>Ursus arctos</i>	Yes	11,218 km2 and 3 years	Human Access, Roads, Logging (via forest type)	Modeling, n=120 dna hair trap sampling	bear range has strong association with terrain conditions that would inhibit human access. Bear detection has negative correlation with human-related variables.	DNA hair-trap sampling that combines mark–recapture population estimation with spatial modeling of population distribution may be valuable in the conservation of grizzly bears.
Benn et al. 2005 Grizzly bear mortality and human access in the central rockies ecosystem of Alberta and British Columbia	<i>Ursus arctos</i>	No	21,150 km2 (Alberta) 10,960 km2 (BC) and 31 years	Human caused mortality	Observational, data from grizzly bear mortalities	in AB 229 bears were killed by humans 48% legally harvested, 18% management control, 16% illegal 11% self defense. In BC 397 bears were killed by humans. Legal harvest 81%, management (16%), illegal (3%). most within 500m of roads and 200m of trails.	Decrease human access to roads.
Benn & Herrero 2002 Grizzly bear mortality and human access in Banff and Yoho	<i>Ursus arctos</i>	Yes	8,149km2 and 27 years	Wildlife Control, Linear Features (Roads, Rails, Utilities)	Modeling, n=119 bear mortalities	Human-caused mortalities all within human zones of influence, over half due to garbage/food. Most deaths in berry season (57%), then pre (35%), then post (8%). Majority also during peak tourist season.	better data and coordination in gathering it by park managers. Especially need to know mortality location and human factors involved in mortality. Managing garbage/food waste very important, should have backcountry user regulations.
Chruszcz et al. 2003 Relationships among grizzly bears, highways and habitat in the Banff	<i>Ursus arctos</i>	Yes	11,400 km2 and 12 years	Trans Canada Highway	Obervational, n=74 radio collared (42 females and 32 males)	Grizzly bears used areas close to roads more than expected. Habituated bears were closer to roads than wary bears. Bears were more likely to cross low-volume roads than high- volume roads. TCH was a barrier to movement.	Efforts to prevent loss of habitat connectivity across highways should involve maintenance of high-quality grizzly bear habitat adjacent to roads and should address the effects of traffic volume
Ciarniello 2006 PhD Demography and habitat selection by grizzly bears in BC	<i>Ursus arctos</i>	No - Thesis	18,096 km2 and 6 years	logging, roads, human Caused Mortality	Observational, n=59 radio collared	Bears selected for forestry clearings.Increased human access lead to low density in valley populations. Attractive sinks near forestry use areas.	Restoration through road closures.

Ciarniello et al. 2007 components of grizzly bear habitat selection	<i>Ursus arctos</i>	Yes	18,096 km ² and 5 years	Logging, Roads, Human Caused Mortality	Observational and Modeling, n=54 radio collared	bear density higher in mountains than plateau, suggest that this is due to selection or avoidance of open roads and risk of human caused mortality.	Emphasis on level and type of human road use instead of actual road network. Management plans should reduce active road density. leave debris in blocks and on roads to encourage bear foraging while discouraging human travel.
Ciarniello et al. 2003 Resource Selection Function Model for Plateau Landscape Grizzlies	<i>Ursus arctos</i>	No	n/a and 4 years	Roads, Logging	Observational and Modeling, n=1048 with 54 radio collars	RSF incorporates and distance to nearest road. Selection for closer to roads, likely closed/decommissioned roads instead of active roads/highways, latter leading to increased mortality from proximity to humans	roads and human use relationships need to be factored into future models, as they are possibly biologically relevant to bears and are influencing how they utilize the landscape
Fuhr and Demarchi 1990 A Methodology for Grizzly Bear Habitat Assessment in British Columbia	<i>Ursus arctos</i>	No	Hart Ranges, Nechako Lowlands and n/a	Hunting, Hiking/Camping.	Modeling, n/a	estimated carrying capacities for the two regions based on stuff to the left.	large and small scale habitat maps are both relevant. Habitat changes over time due to succession can be identified. Carrying capacity and habitat should be used in population management/harvest. Mapping can help identify human conflict sites.
Gibeau et al. 1996 Grizzly bear population and habitat status in Banff National Park.	<i>Ursus arctos</i>	No	Banff National Park and 24 years	Roads, Logging, Wildlife Control	Modeling, n=73 bear mortalities from database	over 90% mortality within 500m of roads and human infrastructure. Habitat - ability of landscape to support bears has been significantly reduced. Core Area - loss of core areas since 1950. Linkage Zones - dramatic decrease in potential crossing areas over time.	restore fire to natural regime to give good forage systems. No more development beyond that necessary for highway redevelopment. Kill fewer bears, and kill more males than females.
Gibeau et al. 2002 grizzly bear response to human development in Alberta	<i>Ursus arctos</i>	Yes	11,400 km ² and 4 years	Roads	Observational and Modeling, n=49 radio collared bears	grizzly bears avoided the Trans Canada Highway (TCH). Sub-adult males were found closer to the highway when in the proximity of high quality habitat. Females avoided the highway regardless of habitat quality or time of day.	Management agencies must maintain access to high quality habitat, especially for adult females, and create new opportunities to support the reproductive potential of the population

Graves et al. 2006 Frequency and distribution of highway crossings by Kenai Peninsula brown bears	<i>Ursus arctos</i>	Yes	23,310 km2 and 6 years	Roads (Highway Crossings)	Observational, n=13 radio collared bears	roads may have a stronger barrier effect on bears with cubs. Bears less likely to cross areas with greater road density. Crossings more likely at night. bears move more quickly and perpendicular to highways while crossing, perhaps to minimize time there. likely cross for salmon resources.	maintain or reduce current highway volumes, add more crossing structures in lowlands - lots of details about these structures. Nightly highway closure may help. Make sure to do longterm studies of bear use of crossings (takes 5 years+).
Herrero 2005 Biology, demography, ecology and management of grizzly bears	<i>Ursus arctos</i>	No	Central Rockies Ecosystem (entire) and n/a	Human activities	Review Report of Eastern Slope Grizzly Bear Project	Many studies on grizzly bears near Banff and surrounding area. Lots of work on human access and human caused mortality.	Reduce human encroachment into grizzly habitat
Herrero et al. 2000 The grizzly bears of the central rockies ecosystem	<i>Ursus arctos</i>	No	Central Rockies Ecosystem (entire) and n/a	Human activities	Review Report of PHVA for the Eastern Slope Grizzly Bear Project	Population and Habitat Viability Assessment workshop results	Reduce human encroachment into grizzly habitat
Hood & Parker 2001 impact of human activities on grizzlies	<i>Ursus arctos</i>	Yes	10,878 km2 and 7 months	Trail Usage, Campground Usage, Vehicles/Day, Motorized Boat Use	Observational and Modeling, n=43	Used Electronic trail counters, direct counting, self-counting to compare use in linear, point, and dispersed landscape features. Our results suggested that when human activities increased in areas of high habitat suitability for grizzly bears, habitat effectiveness values decreased.	only develop in areas with low habitat suitability. Reroute trails/roads to provide secure corridors for bear movement.
Jaeger et al. 2005 Predicting when animal populations are at risk from roads: an interactive model of road avoidance behavior	NA	Yes	n/a	Roads	Modeling, n/a	most vulnerable pops have high noise and high road surface avoidance, then high noise avoidance only. Least vulnerable pops have high car avoidance only, then high road surface and car avoidance.	model's predictions about road avoidance behavior can be tested in the field
Johnson et al. 2005 Cumulative Effects of Human Developments on Arctic Wildlife		Yes	190,000 km2 and 5 years	Mines, Roads, Communities, and related infrastructure	Observational, n=81 radio collared	Mineral exploration - moderate negative up to 23km, outfitter camps negative up to 12km. Avoidance most extreme in late summer and autumn, little evidence for spring and early summer.	Regional cumulative effects analyses serve as the coarsest framework for understanding the impacts of human developments on wide- ranging animals.

Linke et al. 2005 Seismic cutlines, changing landscape metrics and grizzly bear landscape use in Alberta	<i>Ursus arctos</i>	Yes	3,040 km2 and 2 years	Roads/Rail, Logging (Recent/Older), Seismic Lines	Obs and Model, n=39 GPS collared	seismic cutlines modify landscape negatively for bears by changing configuration of landscape and increasing inter-patch distances.	nothing substantial - "use our model!" basically.
Mace et al. 1996 Relationships among grizzly bears, roads, and habitat in the Swan Mountains, Montana	<i>Ursus arctos</i>	Yes	1,457 km2 and 5 years	Roads	Observational, n=14-20	female home range doesn't include private lands, with good habitat but illegal hunting and sanitation problems. Ranges had lower road densities. Some good food resources found near roads. Roads also led to more human-caused illegal deaths.	Road density standards and closure programs should take into account seasonal habitat requirements. Avalanche chutes during spring, for example. Standards could then be relaxed in less suitable habitat.
Mace & Waller 1998 Demography and population trend of grizzly bears in the swan mountains, montana	<i>Ursus arctos</i>	Yes	1,457 km2 and 9 years	Hunting, Defense of Life/Property Kills, Illegal Kills	Obs and Model n=50 radio collared	Annual mortality rates for bears utilizing the rural and wilderness zones was 21 and 15 times higher, respectively, than for bears using only multiple-use lands. multiple-use zone is a population source area, wilderness and rural zones are sinks.	provide habitat security by protecting core areas, reduce conflicts on private lands, monitor mortality and habitat effectiveness
Mattson et al. 1992 yellowstone grizzly bear mortality, human habituation and whitebark pine seed crop	<i>Ursus arctos</i>	Yes	20,000 km2 and	habituation and human mortality	Observational, n=n/a radio collared, transects for seed crops	high mortality of adult females and subadult males during small seed crop years was a consequence of their tendency to range closest (of all sex-age cohorts) to human facilities; they also had a higher frequency of human habituation	management strategies for grizzly bears should be based on prior experience and knowledge of food conditions.
McLellan & Shackleton 1988 Grizzly bears and resource-extraction industries	<i>Ursus arctos</i>	Yes	264 km2 and 7 years	Roads and resource extraction industries	Observational, n=27 radio collared	most bears used habitats within 100m of roads less than expected. Created a 8-7% habitat loss. Avoidance was independent of traffic volume.	Limit road access to humans.
McLellan & Hovey 2001 Habitats selected by grizzly bears in a multiple use landscape	<i>Ursus arctos</i>	Yes	2,000 km2 and 17 years	cutblocks, fire	Observational, n=56 radio collared bears	Regenerating cut-blocks and rock outcrops consistently ranked lowest for selection. Riparian and avalanche chutes had relatively high mean use.	We suggest that riparian habitats be kept undisturbed if possible by restricting road construction and reducing timber harvest in productive flood plains.

McLellan et al. 1999 Rates and causes of grizzly bear mortality in the interior mountains of BC, AB, MT, WA, and ID	<i>Ursus arctos</i>	Yes	12 study areas and 22 years	Human caused mortality	Observational, n=388 radio collared bears mortality data from 13 study areas	People killed 77-85% of the 99 bears suspect to have died while radiocollared. Legal harvest accounted for 39-44% of mortality.	Without radiotelemetry, management would be unaware of about half (46-51%) of deaths of radiocollared bears. Reduce human use levels of certain areas.
McLoughlin 2002 Managing risks of decline for hunted populations of grizzly bears given uncertainty in population parameters	<i>Ursus arctos</i>	No	Western North American Griz Habitat and n/a	Hunting	Modeling, PVA of several populations	Errors in estimates of initial population are important in model variance. Depending on habitat, different levels of human kills are acceptable.	Hunting or harvesting in poor habitat may be beyond the kill threshold. Get better population estimates, then reduce non hunting mortality or adjust harvest rates appropriately. Approx 3-5% total annual kill in bears w/medium-good habitat and 100+ individuals.
Merrill et al. 1999 Defining landscapes suitable for restoration of grizzly bears <i>Ursus arctos</i> in Idaho	<i>Ursus arctos</i>	Yes	n/a	Roads, human presence, population centers	Modeling, HSI model for grizzly bears in Idaho	Use many methods to generate a HSI model of grizzly bear habitat in Idaho. estimate that there is 14 800 km2 of suitable habitat in two blocks or 37 100 km2 in one block in central Idaho, respectively.	Future conflicts between humans and bears are most likely to occur on the western and northern margins of suitable habitat in central Idaho, rather than to the east, where opposition to reintroduction of grizzly bears is currently strongest
Mowat et al. 2004 Predicting Grizzly Bear (<i>Ursus arctos</i>) densities in British Columbia using a multiple regression model	<i>Ursus arctos</i>	No	n/a (uses 46 different study areas from numerous studies)	Human caused bear mortality, human and livestock density	Modeling, various bear population density estimates from various authors	food availability ultimately limits bear density. Roads/logging not included, should be in future.	None
Nielsen 2005 Habitat Ecology, Conservation, and Projected Population Viability of Grizzly Bears in West-Central Alberta, Canada	<i>Ursus arctos</i>	No - Thesis	2,677 km2 and 3 years	Logging, human mortality, etc	Observational, n=21 radio collared	Grizzly bears and forestry parts 1 and 2. Ch 4 human-caused bear mortalities Ch 5 grizzly bear habitat segregation from resource competition Ch 6 genetic relatedness and habitat selection Ch 7 habitat based framework in AB Ch 8 a comparison of disturbance-based forestry on population persistence.	Model found that within 30 years all effective territories were within or adjacent to protected mountain parks, suggesting a substantial decline in foothill populations.

Nielsen et al. 2003 Development and testing of phenologically driven grizzly bear habitat models	<i>Ursus arctos</i>	Yes	10,878 km ² and 2 years	n/a	Observational and Modeling, n=1343 field plots, 10 bears	food resources principally related to elevation, hillshade, age of stand, soil drainage, interaction of vegetation and age.	None
Nielsen et al. 2004 grizzly bears and forestry 1: selection of clearcuts	<i>Ursus arctos</i>	Yes	2,677 km ² and 4 years	clearcuts	Observational, n=21 GSP collars	grizzly bears select for clearcuts, but different types of clearcuts in different seasons. Clearcuts provide a variety of food. Areas of human use (roads/trails/terrain) correlate positively with bear mortalities.	increase perimeter to edge ratio, use low impact site prep treatments, limit human access to high qual areas.
Nielsen et al. 2004 grizzly bears and forestry 2: distribution of grizzly bear foods in clearcuts	<i>Ursus arctos</i>	Yes	2,677 km ² and 4 years	clearcuts	Observational, sample plots	Overall, we found that clearcuts provided a diverse array of food resources for grizzly bears, particularly roots and tubers, herbaceous materials, and ants. Although fruit production was similar between clearcuts and forests, the occurrence of other food resources likely explains the seasonal use of clearcuts by grizzly bears.	suggest that forest design and silviculture consider strategies that maximize grizzly bear food abundance, while minimizing human access.
Nielsen et al. 2004 Modelling the spatial distribution of human-caused grizzly bear mortalities in the Central Rockies ecosystem of Canada	<i>Ursus arctos</i>	Yes	29,264 km ² and 31 years	human caused mortality	Modeling, n=297 human caused mortalities	Models describing relative risk of mortality were positively associated with human access, water, and edge features and negatively associated with ruggedness and greenness indices. Relatively little of the landscape was secure from mortality.	Best way to make more of the landscape safer would be to control human access.
Nielsen et al. 2006 A habitat-based framework for grizzly bear conservation in Alberta	<i>Ursus arctos</i>	Yes	9,752 km ² and 3 years	hunting, edge distance, buildings (anthro land cover), logging	Modeling, n=13 radio collared females	sinks evident in foothills where bears used forest edges associated with oil/gas/forestry. Safe sites more common in protected alpine/sub-alpine sites.	selective harvesting of mature stands during winter with immediate removal of roads can improve habitat quality and reduce mortality. When modifying primary or secondary sinks, restore equivalent ones elsewhere (no net loss policy)

Peek et al. 2003 Management of grizzly bears in british columbia: a review by an independent scientific panel	<i>Ursus arctos</i>	No	n/a	Human harvest	Review	Suggestions for dealing with grizzly bear hunting in BC. Must know initial population size.	as harvests approach maximum sustainable yield, more effort needs to be spent on population estimates/trend information. Human related mortality the greatest impact on bear demographics.
Reynolds & Ver Hoef 2000 Effects of harvest on grizzly bear population dynamics in the northcentral alaska range	<i>Ursus arctos</i>	No	n/a	Hunting, Defense of Life/Property Kills, Illegal Kills, Capture-Related deaths	Observational, n=257 radio collared	bear populations subject to external conditions that lead to substantial annual variation in cohort size, cub production, litter size, survival, and period of maternal care.	human caused mortality varies yearly, often related to weather during hunting season or ungulate season openings.
Schwartz et al. 2005 Temporal, Spatial, and Environmental Influences on the demographics of grizzly bears in the greater yellowstone ecosystem	<i>Ursus arctos</i>	Yes	34,500 km ² and 18 years	Human caused bear mortality	Observational and Modeling, n=108 adult females, 104 litters, 49 radio collared females with 65 litters and 137 young, 323 radio collared male bears,	most important factors in survival and reproduction - humans killing bears, changes in food abundance, and density-dependent factors affecting reproduction and survival of dependent young.	Natural foods monitoring and population monitoring are needed. Griz always must be carefully managed. Distinguish between short term (reversible) and long term (irreversible) impacts. Recognize that there will always be statistical uncertainty, so management decisions might always be wrong.
Suring et al. 2006 patterns of landscape use by female brown bears on the Kenai Peninsula	<i>Ursus arctos</i>	Yes	n/a and 5 years	Roads, Trails, Recreation Sites, Buildings	Observational, n=43 radio collared females	relative probability of use by female brown bears on the Kenai Peninsula declined as road densities increased. Density of human development negatively associated with relative probability of female bear occurrence.	planning should include management of human access, development of recreation facilities, and development of housing in a way that minimizes impact on bear landscape use patterns. Bears and people both want proximity to salmon, which creates a problem.
Waller & Servheen 2005 Effects of transportation infrastructure on grizzly bears in Montana	<i>Ursus arctos</i>	Yes	2,730 km ² and 3 years	Roads (Traffic Volume, Type, Railroad Traffic, Monthly, Night v. Day)	Observational and Modeling, n=43 radio collared bears	crossings frequent and successful, but highway had an impact on behavior - crossed when there was less traffic. Threshold traffic volume for any crossings = 100 vehicles/hour. Railroads are a much bigger problem.	as traffic increases on this highway, more management will become necessary. Will reach threshold within 30 years. Planning now saves effort/money later. These methods may help predict when management will be needed in the future.

Wasser et al. 2004 Scat detection dogs in wildlife research and management: application to grizzly and black bears in Yellowhead Ecosystem, Alberta, Canada	<i>Ursus arctos</i>	Yes	5,200 km2 and 8 weeks, 1,500 km2 and 8 weeks	human activity	Observational, n=23 radio collared and scat surveys	Used dogs to search for bear scat, looked at spatial comparisons. In the park, black bear scat found in areas of highest human activity but not grizzly. Outside of the park, both concentrate in the most heavily disturbed/high human-use areas.	n/a
Wielgus & Bunnell 2000 Possible negative effects of adult male mortality on female grizzly bear reproduction	<i>Ursus arctos</i>	Yes	6,300 km2 and 3 years, 5,700 km2 and 5 years	Hunting	Comparative, n=23/27 radio collared	mortality rate higher in hunted pop, more younger males in hunted pop due to immigration, mean litter size greater in unhunted pop, results consistent with decreased reproduction hypothesis - higher mortality of older adult males coincided with increased numbers of younger, potentially infanticidal males and smaller litter sizes for females.	trophy hunting may cause sex and age habitat segregation, which could lead to smaller litter sizes and lower body mass due to worse diet quality. Managers should be especially careful with hunting of small populations on the edge of the species' range
Wielgus 2002 Minimum viable population and reserve sizes for naturally regulated grizzly bears in british columbia	<i>Ursus arctos</i>	Yes	n/a	Hunting	Modeling, Data from 6 different studies	Minimum population sizes - 200-250 for P<0.05 of decreasing to threatened in 20 years. Adult females really important. Minimum reserve sizes - must encompass complete home ranges of all females in order to ensure protection.	Recommend a no hunting buffer zone around the core gbmu.
Wielgus et al. 2001 Estimating effects of adult male mortality on grizzly bear population growth and persistence using matrix models	<i>Ursus arctos</i>	Yes	6 300 km2 and 3 years, 5,700 km2 and 5 years	hunting	Modeling, n=38	Hunted population has shorter mean time to extinction than unhunted population under both environmental and demographic stochasticity. Sexual segregation caused by hunting resident adult males can result in pop decline esp. when pops are small.	Urge caution in managing small populations, empirical evidence for negative effects is sufficient to question the advisability of hunting such populations at least until evidence to the contrary is forthcoming.
Wielgus & Vernier 2003 Grizzly bear selection of managed and unmanaged forests	<i>Ursus arctos</i>	Yes	5,700 km2 and 6 years	clearcuts and roads	Observational, n=22 radio collared	grizzly bears used clearcuts as available (neither selected nor avoided)	We recommend that open forestry roads be restricted to forestry use only.

Wielgus et al. 2002 Grizzly bear use of open, closed, and restricted forestry roads	<i>Ursus arctos</i>	Yes	5,700 km2 and 5 years	Roads	Observational, n=22 radio collared	Most females and males selected against open roads, most females selected against closed roads, and no bears selected against restricted roads.	Exclusive forestry use of roads has no apparent negative impact - restrict to this use only as much as possible. Bears don't select against them, and aren't shot from them.
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Table 8. Review of scientific literature of human impacts on moose.

Authors,Year, Title discription	Spp.	Peer Review	Study Area Size, Duration	Development Type	Sample design, size & data type	General Results	Management Recommendations
Andersen 1991 Habitat changes in moose ranges: effects on migratory behavior, site fidelity and size of summer home-range	<i>Alces alces</i>	Yes	n/a and 6 years	Hydroelectric development	Before after, tracking and radio collars	The habitat alteration has so far caused only minor changes in migratory behavior. Most moose migrate along the same routes, crossing the artificial lake at the same place as they previously crossed the river.	reduced home range overlap indicated that increased disturbance and habitat deterioration had caused a decline in site fidelity
Andersen et al. 1996 Short term behavioural and physiological response of moose to military disturbance in Norway	<i>Alces alces</i>	Yes	1,600 km2 and 3 weeks	Human disturbance from foot approach to F-15 fighters	Before/after, n=4 heart rate monitors and n=12 radio collared	sources of disturbance which can be identified as human in origin trigger flight responses at greater distances, and elevate heart rate for longer periods, than those recognized as mechanical.	military activity of the type studied here is not especially detrimental to moose, and that the effects of their activity should not differ from comparable civilian harassment.
Ball and Dahlgren 2002 Browsing damage on pine by a migrating moose population in winter	<i>Alces alces</i>	Yes	120 km road and	Roads	Observational, counting browsed branches and pellet counts	the road itself might increase browsing on pine by acting as a partial barrier to migration and increasing moose density near the roads.	increasing tree planting density may be one way to increase the number of undamaged pines
Belant 1995 moose collisions with vehicles and trains in northeastern Minnesota	<i>Alces alces</i>	Yes	21,800 km2 and 2 years	Vehicle collisions	Obersvational, data from moose vehicle collisions	Greatest risk of collision in summer, and night. Traffic volume explained 59% of monthy variations.	Increase sign placement and public awareness programs.
Berger 2007 Fear, human shields and the redistribution of prey and predators in protected areas	<i>Alces alces and Ursus arctos</i>	Yes	500 km2 and 9 years	Roads and human activities	Comparative, n=192 radio collared	Moose selected to be closer to human activity as grizzly bear predation increased. Grizzly bears avoided human activity, providing a human-caused refugia from predation.	Effects of human activities on wildlife can be counter-intuitive in the presence of human-caused refugia from predation. Considering indirect effects of trophic interactions to gauge development impacts key.

Collins & Schwartz 1998 Logging in Alaska's boreal forest: creation of grasslands or enhancement of moose habitat	<i>Alces alces</i>	Yes	n/a and 5 years	Logging	Observational, vegetation data from clearcuts	With proper timer harvest, soil scarification and good seedling establishment, carrying capacity for moose based on forage supply can increase 20-45 fold over mature forest. Properly regenerate clearcuts yield high quantities of moose browse for approximately 20 years following logging.	Timer harvest can greatly enhance or severely reduce moose quality habitat depending on management objectives, timing and methods of harvest and post logging site preparation.
Colescott & Gillingham 1998 reaction of moose to snowmobile traffic in WY	<i>Alces alces</i>	Yes	0.04 km ² and 1 month	Snowmobiles	Observational, observations from blinds	Snowmobile traffic did not appear to alter moose activity significantly though it did influence the behavior of moose within 300m of the trail and displaced moose to less favorable habitats	Restrict the timing of snowmobile use to mid day when moose are resting
Courtois et al. 1998 Characteristics of cutovers used by moose in early winter	<i>Alces alces</i>	Yes	500 km ² and	Logging, clearcuts	Observational,	Moose were more selective of sites supporting more abundant deciduous browse and where mean height of regeneration and lateral cover were higher than control sites.	maintain cutovers to have a browse density fo 10,000 to 15,000 stems/ha to keep moose in clear cut areas.
Courtois et al. 2002 habitat selection by moose in clear cuts	<i>Alces alces</i>	Yes	3,200 km ² and 4 years	Logging, clearcuts	Observational, n=65 radio collared, aerial surveys	on a coarse scale clearcuts did not affect home range selection and cutovers were not related to increased mortality. at a fine scale, moose tended to avoid clearcuts during most seasons, and selection was strongest for mixed stands	Our work adds more evidence that moose and forest management can co-exist. However, recent clear-cuts are avoided except in early winter.
Dussault et al. 2006 temporal and spatial deistribution of moose-vehicle accidents in Quebec	<i>Alces alces</i>	Yes	7,861 km ² and 13 years	Vehicle collisions	Observational, data from location/date of moose-vehicle accidents	accidents with large mammals involved 161-310 moose. The risk of accident per vehicle was at least 2-3 times higher at night (when traffic volume was lowest) than during any other time. collision rate increased with moose density, in the presence of at least one brackish pool (by 80%)	Dynamic signage should be used mostly during summer months,where moose density is high and especially in areas with brackish pools or where the surrounding topography is broken with valleys facilitating moose movements across the landscape.

Ericsson 2003 Of moose and man: The past, the present, and the future of human dimensions in moose research	<i>Alces alces</i>	Yes	n/a	Human dimensions	Review	in the past 10 years there has been a decline in research on moose-human interactions. Furthermore, hunting and vehicle collisions studies made up the majority of the literature	more studies needed on how humans effect moose and moose effect humans
Garrett & Conway 1999 Characteristics of moose-vehicle collisions in Anchorage, Alaska	<i>Alces alces</i>	Yes	and 5 years	Vehicle collisions	Observational, data from moose collisions	collision rate increased during the study period from 40 to 52 MVCs per 100,000 registered vehicles in Anchorage. Collisions were 2.6 times more likely to have occurred in the dark	reduce speed limits around greenbelt areas, brighter vehicle headlights, placement of street lights in known moose areas, underpasses for wildlife at known crossings, and snow removal to reduce berm height in areas of high moose concentrations.
Jolicoeur and Crête 1994 Failure to reduce moose-vehicle accidents after a partial drainage of roadside salt pools in Québec	<i>Alces alces</i>	Yes	7,861 km2 and	Vehicle collisions	Observational, data from moose mortality on roads and pool salt info.	A management attempt to drain pools in 1979 failed to reduce moose abundance or moose mortality at salt pools	develop new techniques to keep moose away from roadside pools and use CaCl ₂ instead of NaCl as a road deicer.
Joyce & Mahoney 2001 Spatial and temporal distributions of moose-vehicle collisions in Newfoundland	<i>Alces alces</i>	Yes	106,000 km2 and 6 years	Vehicle collisions	Observational, data from location/date/landscapes of moose-vehicle accidents	Seventy-five percent of all MVCs occurred between dusk and dawn. Seasonally, 70% of MVCs occurred between June and October. Collisions were dependent on moose densities and traffic volume, with greater probability of MVCs in areas of high or low (but not moderate) moose densities and high traffic flow.	We suggest that a long-term driver education program may be the only viable mitigation effort available to reduce number of MVCs.
Kunkel and Pletscher 2000 Habitat factors affecting vulnerability of moose to predation by wolves in BC	<i>Alces alces</i>	Yes	n/a and 11 years	logging and wolf predation	Observational, n=29 radio collared	Moose density was greater and hiding-cover levels were lower at kill sites than at control sites. Forest harvest practices in this study area apparently did not increase the vulnerability of moose to wolf predation.	moose are less likely to be killed by wolves at higher elevations, farther from trails, away from other moose, nearer to or within areas sheltered by large trees, and in areas with higher road density.

Leblanc et al. 2006 Upgrading a 144km section of highway in prime moose habitat	<i>Alces alces</i>	Yes	9,000 km ² and 12 years	Vehicle collisions	Modeling, data from moose vehicle collisions and habitat features	more moose collisions in areas moderate topographic variation, in areas of high moose density and good forage, and when rivers and streams are within 250m of the road. less likely in areas were steep embankments or deep ditches paralleled the roadway.	recommend that road sections with high collision risk be fenced and underpasses provided and combined with all major river crossings during the upgrade project from a two-lane to a four-lane divided highway.
Leblond et al. 2007 Management of roadside salt pools to reduce moose-vehicle collisions	<i>Alces alces</i>	Yes	7,861 km ² and 3 years	Roadside salt pools	Before, after, control, remote video cameras at each of 12 locations	filling roadside pools has the potential to decrease vehicle collisions with moose, though their results did not correlate collision risk with pool use. They found reduced use and frequency of visits to altered pools during the night. Moose were often disturbed by passing vehicles while at roadside salt pools.	Our results indicate that draining roadside salt pools and filling them with rocks may reduce the risk of moose-vehicle collisions where roadside salt pools are common.
Meth et al. 2000 Moose and the proposed Churchill River Power Project: A Literature Review	<i>Alces alces</i>	No	n/a	Hydroelectric development	Review	Although a number of studies have assessed the potential effects of dams and hydroelectric facilities on moose, few have actually documented changes in moose demography and moose habitat use after such development occurred	n/a
Ricard & Doucet 1999 winter use of powerline rights of way by moose	<i>Alces alces</i>	Yes	n/a and 2 years	Powerlines	Observational, track surveys and browse surveys	The presence of rights of way did not affect winter habitat selection or regional moose abundance. Powerlines did not offer very good feeding habitat but neither did the adjacent forest.	Might need to try different methods of vegetation management in powerline rights of way.
Schneider & Wasel 2000 The effects of human settlement on moose density	<i>Alces alces</i>	Yes	376,224 km ² and 2 years	Human settlement	Observational, aerial surveys	at the regional scale the density of moose was positively associated with the density of roads. The regions with the greatest moose densities also had the greatest intensity of licensed hunting.	in our study, high densities of moose were observed in association with a highly fragmented landscape with substantial agricultural clearing, implying that moose requirements for cover may be quite flexible, at least in regions where snow fall is not extreme

Seiler 2005 moose-vehicle collisions in Sweden	<i>Alces alces</i>	Yes	13,569 km ² (model area) 8,576 km ² (test area) and	Vehicle collisions	Observational, data from location/date/landscapes of moose-vehicle accidents	Overall, moose–vehicle collisions were most likely to occur on unfenced roads with intermediate traffic volumes and intermediate speed limits, and in hunting districts that produced large moose harvests.	According to the models, reduced vehicle speed in combination with fencing and increased roadside clearance provides the strongest mitigation
Silverberg 2003 Moose responses to wildlife viewing and traffic stimuli	<i>Alces alces</i>	Yes	0.04 km ² and 3 years	wildlife viewing and vehicles	Observational, moose behavior observed along road at view site	moose were highly tolerant of quite viewers at a viewing stand and fled less than 4% of the time. Moose were most sensitive to cars stopped and trucks passing as well as multiple combinations of several stimuli.	wildlife viewing can be successful when people are properly educated through signs, etc.
Snaith et al. 2002 Preliminary habitat suitability analysis for moose in mainland Nova Scotia	<i>Alces alces</i>	Yes	n/a	Roads	Modeling, HSI model based on literature and expert opinion, pellet data for validation	Model predictions were tested by comparing HSI values to provincial pellet inventory data. Road density was found to be more important than habitat composition in determining moose pellet distribution.	A better model for habitat suitability will incorporate human-induced habitat characteristics, such as road density, into index calculation.
Trimper et al. 1996 Distribution of wintering moose in south central Labrador and northeastern Québec	<i>Alces alces</i>	Yes	14,000 km ² and	Overflights	Observational, aerial surveys	Moose were absent from areas of apparently suitable habitat. No moose activity was observed within the olomane river valley or the petit mecantina river valley. Density was lower than projected.	Extreme snow depth, illegal harvest and wolf predation have probably contributed to low moose activity. We believe that the winter distribution of moose has not been affected by the present low level flying regime
Yost and Wright 2001 Moose, Caribou, and Grizzly Bear distribution in relation to road traffic in denali national park	<i>Alces alces</i> , <i>Ursus arctos</i> , <i>Rtt</i>	yes	130 km road and 2 years	Roads	Observational, observed animals in backcountry and along roads	Moose sightings were lower than expected within 300 m of the road. more moose than expected occurred between 900 and 1200 m from the road. The distribution of moose sightings suggests traffic avoidance, but the spatial pattern of preferred forage may have had more of an influence.	n/a

Table 9. Review of scientific literature of human impacts on mountain sheep.

Key: Oc - *Ovis canadensis*, Odd - *Ovis dalli dalli*

Authors,Year, Title discription	Spp.	Peer Review	Study Area Size, Duration	Development Type	Sample design, size & data type	General Results	Management Recommendations
Armentrout & Boyd 1994 conseunces of habitat fragmentation on wild sheep metapopulation management within USA	Oc	No	n/a	fragmentation	Review and Questionaire	Habitat fragmentation effects many wild sheep populations across the western US. Desert bighorn occupy 75% of historic. Rocky mountain occupy 52% of historic, california bighorn occupy 37%	develop a metapopulation management strategy that incorporates ecosystem based guidelines.
Bleich et al. 1990 responses of mountain sheep to helicopter surveys.	Oc	Yes	n/a and 2 months	helicopters	Observational, radio collared	sheep move 2.5 times further the day following a heli survey than the previous day, some leaving the study area after surveys. Even low intensity heli censusing had a substantial effect on mountain sheep movement/distribution.	Movement by mountain sheep during a helicopter survey may violate fundamental assumptions of several population estimators
Bleich et al. 1994 mountain sheep and helicopter surveys: ramifications for the conservation of large mammals	Oc	Yes	n/a	helicopters	Observational, radio collared	helis and fixed wing aircraft reduce foraging efficiency, alter use of habitat, increase susceptibility to predation, increase nutritional stress.	Need further study.
Dalle-Malle & Van Horn 1991 Observations of vehicle traffic interfearing with migration of Dall's sheep in Denali	Odd	Yes	130km road and 1 year	road	Observational, field ovservations	2 observations of Dall's sheep unsuccessfully attempting to cross the Denali NP road. Sheep occupying ranges further from the road do not habituate and miragtion is disrupted	Animals distant from human activity are less likely to habituate.
Etchberger et al. 1989 Mountain sheep habitat characteristics in the pusch ridge wilderness, AZ	Oc	Yes	78 km2, and 2 years	Human disturbance	Observational, n=11 radio collared	Habitats used by bighorn sheep have less human disturbance, and higher forage biomass.	Fire is important and restoration of fire could enhance sheep habitat. Reducing human activity in the abandoned areas could enhance restoration of this population.
Frid 2000 Fleeing decisions by Dall's sheep exposed to helicopter overflights	Odd	No	n/a and 3 months	Helicopter	Expirmental, n=56 experimental overflights	Sheep groups fled during overflights in 43 of 56 observations (77%). sheep >20 m from rocky slopes always fled, even during indirect approaches, and distance fled increased with distance to rocky slps.	future work should address whether horizontal setback distances for pilots can be relaxed when helicopters are very high above or very far below sheep ranges.

Frid 2000 Behavioral responses by Dall's sheep to overflights by fixed-wing aircraft	<i>Odd</i>	No	n/a and 3 months	Fixed wing aircraft	Experimental, n=42 experimental overflights	When focal sheep were active prior to overflights (N = 51), 37% fled and 63% did not. Sheep ran during 84% of fleeing events	Results support that fixed-wing aircraft are substantially less disturbing to sheep than helicopters.
Frid 2003 Dall's sheep responses to overflights by helicopter and fixed-wing aircraft	<i>Odd</i>	Yes	n/a and 1 year	Helicopter & fixed wing aircraft disturbance	Experimental, n=56 experimental overflights	Aircraft approaches that were more direct (relative to the sheep) were more likely to cause sheep to flee or disrupt resting, and latency to respond was longer. Sheep had a 10% chance of fleeing when aircraft were as close as 750m, and a 10% chance of disrupting rest as far as 1.5km away.	Recommend avoiding known sheep ranges by as much as 1.5 km based on disturbance to resting behavior instead of fleeing behavior – the most costly response.
Hook 1986 Impacts of seismic activity on bighorn movements and habitat use	<i>Oc</i>	No	n/a and 4 years	seismic lines	Observational, n=8 radio collared	the average annual home range size significantly declined (28%) from average following seismic line disturbance.	Oil and gas activities are detrimental to bighorn range.
Jansen et al. 2006 Bighorn sheep selection of landscape features in an active copper mine	<i>Oc</i>	Yes	n/a and 2 years	Mining disturbance	Observational, n=12 radio collared	Minor differences in sheep behavior inside and outside the mining area. Sheep used areas within the mine site. female bighorn sheep foraged less while on the mine than off.	Sheep appeared to habituate to mining activity rapidly. Emphasis placed on restoration, especially in desert or semi-desert environments.
Jansen et al. 2007 Influence of mining on behavior of bighorn sheep	<i>Oc</i>	Yes	58 km2 and 3 years	Mining	Observational, n=12 radio collared	bighorn sheep fed less (6%) while inside the mine perimeter. Other behaviors (e.g., bedding, standing, alert, and interacting) were observed for similar amounts of time while within and outside the mine perimeter.	Bighorn sheep can habituate to mining activity.
Jorgenson 1988 environmental impact of the 1988 winter olympics on bighorn sheep of Mt. Allan	<i>Oc</i>	No	n/a and 4 years	human activity on ridge, snowmaking, helis, heavy blasting	Observational, ground observation and aerial surveys	18% decline in local sheep population, including lower lamb survival, range abandonment, and more lungworm larvae.	Continue to monitor herd health and use mitigation measures to avoid unnecessary harassment.

Keller & Bender 2007 Bighorn sheep response to road-related disturbances in Rocky Mountain National Park, Colorado	Oc	Yes	1,076 km2 and 2 years	Human recreational disturbance, roads	Observational, behavioral observation	The number of sheep groups visiting a key mineral lick adjacent to a road declined as human disturbance increased, and the time and number of attempts required by bighorn to reach Sheep Lakes was positively related to the number of vehicles and people present at Sheep Lakes.	Negative effects of road and human avoidance may affect population dynamics. Recommended seasonal human use restrictions to maintain sheep populations..
Krausman & Hervet 1983 mountain sheep responses to aerial surveys	Oc	Yes	n/a and 2 years	Aircraft overflights	Observational, n=15 radio collared	low-level overflights interrupted activities and sheep moved >100 m 19% of the time. Aircraft below 50m above ground caused the greatest reactions	flights should be > 100 m above ground to minimize disturbance
Krausman et al. 1998 Effects of jet aircraft on mountain sheep	Oc	Yes	3.2 km2 and 2 years	Jet aircraft (F-16 overflights)	Observational, n=22 sheep in enclosure n=5 heart rate monitors and 149 overflights	Heart rate increased above preflight levels in 21 of 149 overflights but returned to preflight levels within 120 sec. when aircraft flew over the noise level created did not alter behavior or use of habitat or increase heart rates to the detriment of the sheep.	heart rate and behavior data suggest sheep habituated to aircraft and the noise they created.
Legg 1998 a review of the potential effects of winter recreation on bighorn sheep	Oc	No	Yellowstone	human recreation	Review	Review of the potential impacts of winter recreation on bighorn sheep in Yellowstone.	Limit the use of winter range by humans, don't allow dogs, and expand protect of current winter ranges.
Loehr et al. 2005 Gender- and age-class-specific reactions to human disturbance in a sexually dimorphic ungulate	Odd	Yes	n/a and 1 year	Human disturbance by hikers	Observational, n=35 sheep observed	Females rested less and foraged more under human disturbance and were more vigilant, but not males.	with the proper precautions and continued monitoring (to assess whether disturbance becomes more frequent or reactions of individuals change), disturbance of this type can be tolerated by ungulates.

MacArthur et al. 1982 Cardiac and Behavioral- Responses of Mountain Sheep to Human Disturbance	Oc	Yes	n/a and 2 years	Human disturbance, hikers and dogs	Observational, n=5 heart rate monitors	Cardiac and behavioral responses were greatest to humans and humans with dogs or approached sheep from over a ridge. Reactions to road traffic were minimal, and no reactions to helicopters or fixed-wing aircraft were observed at distances exceeding 400 m from sheep.	Responses to disturbance were detected using HR telemetry that were not evident from behavioral cues alone.
Oehler et al. 2005 Mountain sheep and mining: Implications for conservation and management	Oc	No	Unk, 3 years	Mining disturbance	Comparative, mine vs. non-mine area, n=19 radio collared	Size of annual HR, composition of diet, and ratios of young to adult females did not differ between sheep inhabiting mined and nonmined areas. Nonmined areas had higher forage biomass than mined sites. In spring sheep near mine had lower forage quality.	Greatest impacts were observed in the summer, recommended either providing alternate water sources away from the mine to mitigate negative impacts or ceasing mining activities during the summer.
Papouchis et al. 2001 Responses of desert bighorn sheep to increased human recreation	Oc	Yes	8,341 km ² , and 2 years	Human disturbance, hiking, vehicles, mt. bike	Observational, n=42 radio collared and direct observation	Hikers caused the most severe responses in desert bighorn sheep (61% fled), followed by vehicles (17%) and mountain bikers (6%). Some sheep avoided roads some habituated to roads	We recommend managers confine hikers to designated trails during spring lambing and the autumn rut in desert bighorn sheep habitat.
Stockwell et al. 1991 Conflicts in national parks: a case study of helicopters and Bighorn Sheep time budgets at the Grand Canyon	Oc	Yes	n/a and 2 year	Helicopter & aircraft disturbance	Observational, observed sheep from a distance	Bighorn were sensitive to disturbance during winter (43% reduction in foraging efficiency) but not during spring (no significant effect). Further analyses indicated a disturbance distance threshold of 250-450 m.	Helicopters alter foraging behavior which is most severe in winter.
Weisenberger et al. 1996 Effects of simulated jet aircraft noise on heart rates and behavior of desert ungulates	Oc	Yes	small pens and 3 months	Simulated noise of jet aircraft	Experimental, simulated noise	bighorn sheep and mule deer (<i>Odocoileus hemionus</i>) were able to habituate rapidly to noise from a simulated jet overflight. They recorded 34 incidents of increased heart rate in bighorns during 112 overflights and heart rate returned to normal within 60-180 seconds.	results suggest that bighorn sheep do not view overflights by jet aircraft as a threat

Table 10. Review of scientific literature of human impacts on mountain mountain goats.

Key: *Oa* - *Oreamnos americanus*

Authors,Year, Title discription	Spp.	Peer Review	Study Area Size, Duration	Human Impact Type	Study design & size	General Results	Management Recommendations
Cote 1996 mountain goat responses to helicopter disturbace	<i>Oa</i>	Yes	21 km2 and 3 months	helicopter (energy exploration)	Observational, n=14 radio collared n=98 marked, observed responses	Goats showed overt responses to 58% of helicopter flights within 2 km. When helicopters flew within 500 m, 85% of flights caused the goats to move >100 m or to be alert for >10 min	recommended avoiding helicopter flights within 2 km of mountain goat habitat
Cote & Festa-Bianchet 1996 Human disturbance and management of mountain goats: lessons from caw ridge	<i>Oa</i>	No	28 km2 and n/a	Helicopters, ATVs, Reseach capture, Resource exploration & development	Observational	reacted 2k from heli use, broke up social/family groups, nanny/kid survival affected by all these forms of disturbance - lower survival rate of kids when separated.	helis stay at least 2km away from goats and also from habitat, don't create seismic lines in habitat, 2km buffer zone around known populations, direct arial traffic away, if unavoidable stay at least 300m above ground and don't land on treeless ridges
Foster and RaHS 1983 Mountain Goat Response to Hydroelectric Exploration in Northwestern British-Columbia	<i>Oa</i>	Yes	n/a	Aircraft and ground disturbance (hydroelectric exploration)	Observational	responded to aircraft and ground disturbance during >80% of events and recorded a "severe flight response" during 33% of observations. Fifty-five percent of severe flight responses were observed when disturbances occurred at distances <100 m.	need formulation of management guidelines to lessen project impacts during future exploration, construction, and operation phases.
Foster and RaHS 1985 A study of canyon-dwelling Mountain Goats in relation to a proposed hydroelectric development in northwest BC	<i>Oa</i>	Yes	n/a and 2 years	Hydroelectric exploration activities	Observational, observed goats and n=56 marked with dye and neck collars	mountain goats shifted their distribution 1 km - 3 km when subjected to drilling disturbances fully visible from escape terrain, but they returned when the disturbance was removed.	recommended a 2km buffer to prevent an overt disturbance response to human activity
Goldstein et al. 2005 Mountain goat response to helicopter overflights in Alaska	<i>Oa</i>	Yes	n/a and 2 years	Helicopters (recreational)	Observational, ground based observations 347 overflights	The probability of a goat group being disturbed was inversely related to distance of the helicopter from the group. Odds of disturbance increased by a factor of 1.25 for every 100-m reduction in approach distance.	An effective management strategy requires developing no-fly zones to surround known mountain goat locations, preferably accomplished through a validated habitat model

Gordon and Wilson 2004 Effects of helicopter logging on mountain goat behavior in coastal British Columbia	Oa	No	and 2 years	Helicopters (logging)	Before, during, after, control, observations of mt. goat behavior	mountain goats increased their use of forest cover or moved away and spent less time bedded when helicopter activity was most intrusive.	recommend that helicopter activity <1.5 km from occupied mountain goat habitat be managed to reduce behavioural disruptions
Joslin 1986 mountain goat population changes in relation to energy exploration along montana's rocky mountain front	Oa	No	823 km2 and 7 years	Energy exploration, Seismic lines	Observational, n=24 radio collared, n=8 neckbanded	significant decline in numbers of adult females, kids, and productivity that coincided with a peak in seismic/exploration activities by energy industry.	Efforts should be made to reduce human activities in the Teton-Dupuyer segment in order to allow goat populations to recover.
Pedevillano and Wright 1987 The influence of visitors on mountain goat activities in Glacier National Park, Montana	Oa	Yes	n/a and 2 years	human disturbance	Observational	park visitors did not disturb goats enough to stop them from using licks but people on overpasses and traffic did scare goats away from crossing highways.	All crossings were eventually successful. Before underpass made goats ran back 44% of the time, after underpass only 24% of the time
Penner 1988 Behavioral response and habituation of mountain goats in relation to petroleum exploration at Pinto Creek, Alberta	Oa	No	n/a and 6 years	Energy exploration noise	Observational, watched goats reactions to noise	Goats were exposed to noise stimuli representative of petroleum exploration. Goats exhibited a tolerance of increased levels of indirect and persistent noise. Goats habituated to predictable, continuous stimuli but were disturbed by sudden, unpredictable stimuli.	Results suggest that goats would tolerate the potentially disturbing noise stimuli that would accompany seismic activity.
Singer 1978 Behavior of mountain goats in relation to U.S. highway 2, Glacier National Park, Montana	Oa	Yes	n/a and 4 months	roads	Observational, n=117 days of observations	A total of 87 successful crossings (692 goats) and 31 unsuccessful attempts (101 goats) were observed in 1975.	Create an underpass so that goats can move to mineral lick without traffic.
Varley 1998 Winter recreation and human disturbance on mountain goats: a review	Oa	No	n/a	Human recreation and disturbance	Review	Conflict between goats and most recreation types are rare because of spatial segregation. Helicopters may pose a threat.	Helicopters should avoid areas within 2-2.5km of areas where goats are known to winter in order to avoid disturbance.

Wilson and Shackleton 2001 Backcountry recreation and mountain goats	Oa	No	n/a	Aircraft disturbance	Review	Helicopters generate the disturbance of greatest concern, while fixed-wing aircraft generate less intense responses. Disturbances associated with foot traffic appear to be minimal and can be easily managed.	Suggest areas of future studies based on holes in the literature.
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